

NATIONAL SECURITY SCIENCE



AMERICA'S NIGHT'S WATCH

Our Forgotten Nuclear Warfighters

In this issue

Nuclear Test Readiness: What is Needed? Why?

Smells Like Alert: A Day in the Life of a Missileer

The Dragon Is Alive: Onboard a B-52 Stratofortress



Welcome to this issue of

NATIONAL SECURITY SCIENCE

Welcome to the December issue of *National Security Science*. This issue provides both surprising answers and some intriguing questions.

For example...

In 1992, the nation made a decision to forgo full-scale underground nuclear weapons testing after conducting more than 1,000 tests since the end of World War II. However, under Presidential Decision Directive 15 (1993) there is a legal requirement to be able to execute a test within 24–36 months if required. In a national emergency, could the United States safely test a nuclear weapon tomorrow? The prevailing attitude seems to be generally yes, but it depends upon the nature of the test.

In “Nuclear Test Readiness: What Is Needed? Why?” (page 8), John C. Hopkins, former head of the Los Alamos Nuclear Test division, who participated in five tests in the Pacific, 170 in Nevada, and witnessed another 35 or so tests, contemplates the challenges of reviving—and possibly relocating—America’s nuclear testing program. The article challenges all of us to be more introspective as we consider our readiness posture, and to ponder further questions such as: “Is Nevada still the obvious place to conduct a nuclear test?” and “Are the non-scientific but equally essential operational and logistic capabilities in place to support such a test?”

What is it like to be a crew member on a nuclear-capable, 55-year-old, B-52 bomber that’s flying toward North Korea on a 24-hour-long nuclear deterrence mission? Air Force Major Brad Haynes knows. He has 13-years of experience, crewed B-52s (and other nuclear-capable bombers), and has some 2,000 hours of flight time. “Winter is coming,” says Maj. Haynes. In “The Dragon Is Alive” (page 26) readers will learn what being on America’s “Night’s Watch” means.

Speaking of the Night’s Watch, what is it like to be an Air Force missileer, on alert for 24 hours at a time, while 60-feet underground inside an intercontinental ballistic-missile launch capsule? Lt. Col. Cynthia Gunderson, who has served in the Air Force for 19 years and pulled 164 alerts as a missileer, provides us with the details in “Smells Like Alert” (page 18).

Will the Japanese be able to find the missing nuclear reactor fuel at their devastated Fukushima power plant? The answer may lie in using the Lab’s unique muon-vision technology, whereby cosmic rays are harnessed to see inside the thick layers of the reactors’ collapsed concrete and steel containers (see “Fixing Fukushima” on page 36).

And finally, what’s it like to work as an explosives scientist at Los Alamos? In “Ask Me Anything” (page 48) the Lab’s explosives experts field questions from the public regarding career choices, working at the Lab, and living in Los Alamos.

Happy holidays and a happy new year to all!

Bob Webster

Principal Associate Director, Weapons Programs

INSIDE THIS ISSUE

About the Cover

Every six months, the Air Force trains approximately 50 people to become new B-52 crew members. “We have 300–400 guys ready to go right now who could put warheads on foreheads,” says B-52 navigator Major Brad Haynes. Read about his deterrence mission to North Korea on page 26.

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**THE HISTORY OF THIS
1,375- SQUARE-MILE PATCH
OF DESERT IS EVEN MORE
DYNAMIC THAN 928 NUCLEAR
TESTS GOING “BOOM!”**

Many Las Vegas showgirls transformed into atomic beauty queens during the 1950s. Among the most famous was showgirl Lee Merlin (pictured), who was Miss Atomic Bomb 1957. Merlin is wearing a cotton mushroom cloud attached to her swimsuit.

(Photo: Las Vegas News Bureau)

NEVADA NATIONAL SECURITY SITE CELEBRATES 65 YEARS

10

THINGS YOU NEVER KNEW ABOUT THE NEVADA NATIONAL SECURITY SITE



1

The Las Vegas Bombing and Gunnery Range, 65 miles northwest of Las Vegas, was selected as the Nevada Test Site (NTS, now the Nevada National Security Site) for its remote location. The site was large enough that unanticipated winds would likely not drop fallout on any nearby town, and the surrounding towns were sparsely populated. South of the range, a government-owned airfield and housing for more than 300 people already existed.

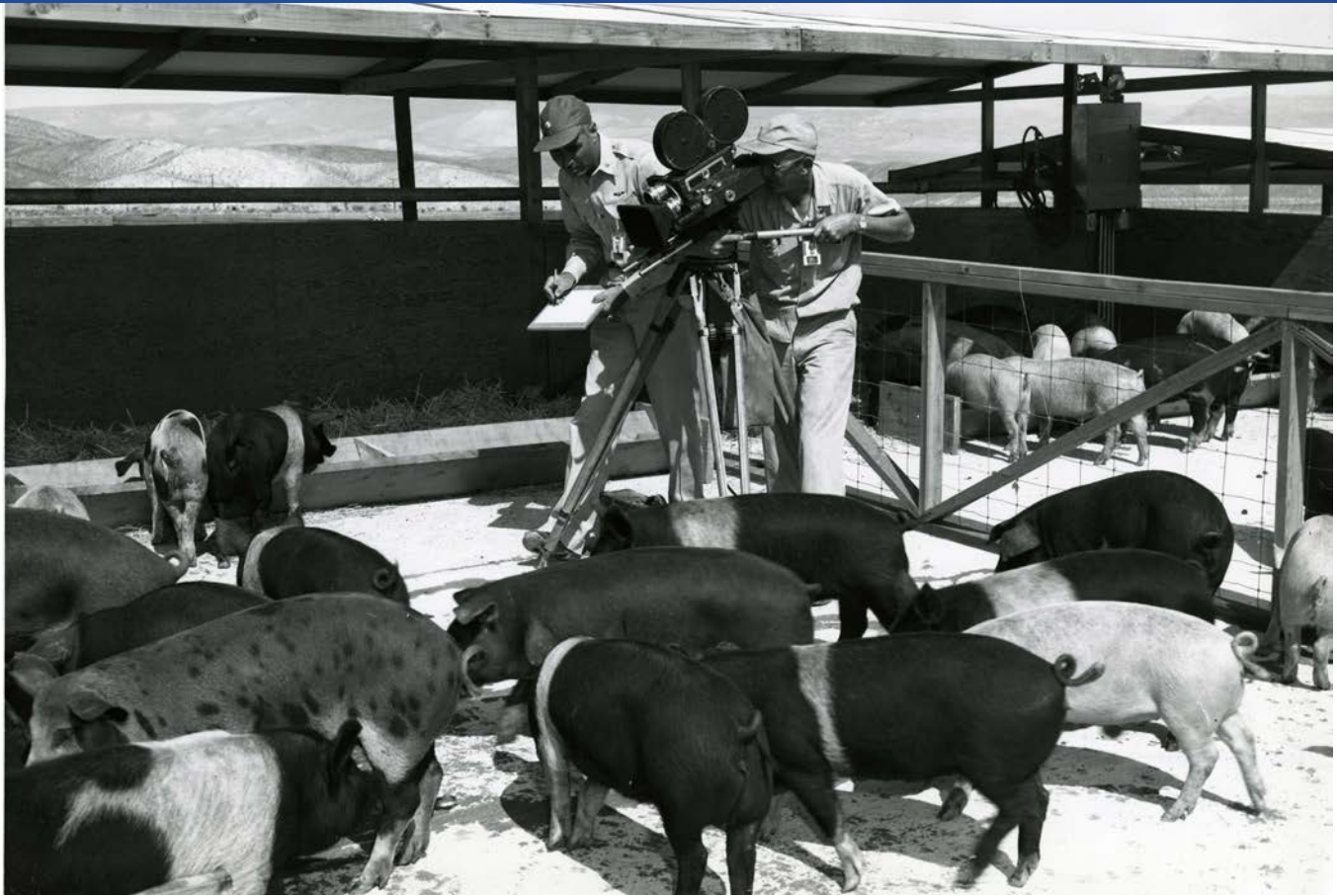
2

The actual nuclear devices being tested at NTS were classified, so scientists assigned each test a nickname that had to be approved by the Office of Military Applications. Early names used the military phonetic alphabet (Able, Baker), but as the number of tests outgrew the alphabet, names included nature terms (Antler, Feather), Native American tribes (Cherokee, Zuni), famous scientists (Galileo, Newton), and New Mexico towns (Bernalillo, Santa Fe).

3

Data collection on nuclear tests went beyond the obvious—yield. One objective for aboveground (atmospheric) nuclear test Annie was to determine what would happen to a typical American home in the event of an atomic blast. A two-story colonial house, located 3,500 feet from the 16-kiloton shot, was more than 90 percent destroyed. Before and after photos of the interior—including clothed mannequins—were printed in the *Las Vegas Review Journal* with the following statement: “These mannequins could have been real people, in fact, they could have been you.”





4

In 1957, the test site was home to 1,200 pigs that lived in several pens collectively called the Pork Sheraton. The sows were used in several tests such as Encore, during which 44 anesthetized pigs were clothed in various fabrics and exposed at varying distances to ground zero. The idea was to see how fabrics, including military uniforms, reacted to heat generated by a nuclear explosion. Prior to the shot, the animals, which had been purchased for \$25 a head as piglets, grew so rapidly that seamstresses from Las Vegas were called in to modify their outfits.

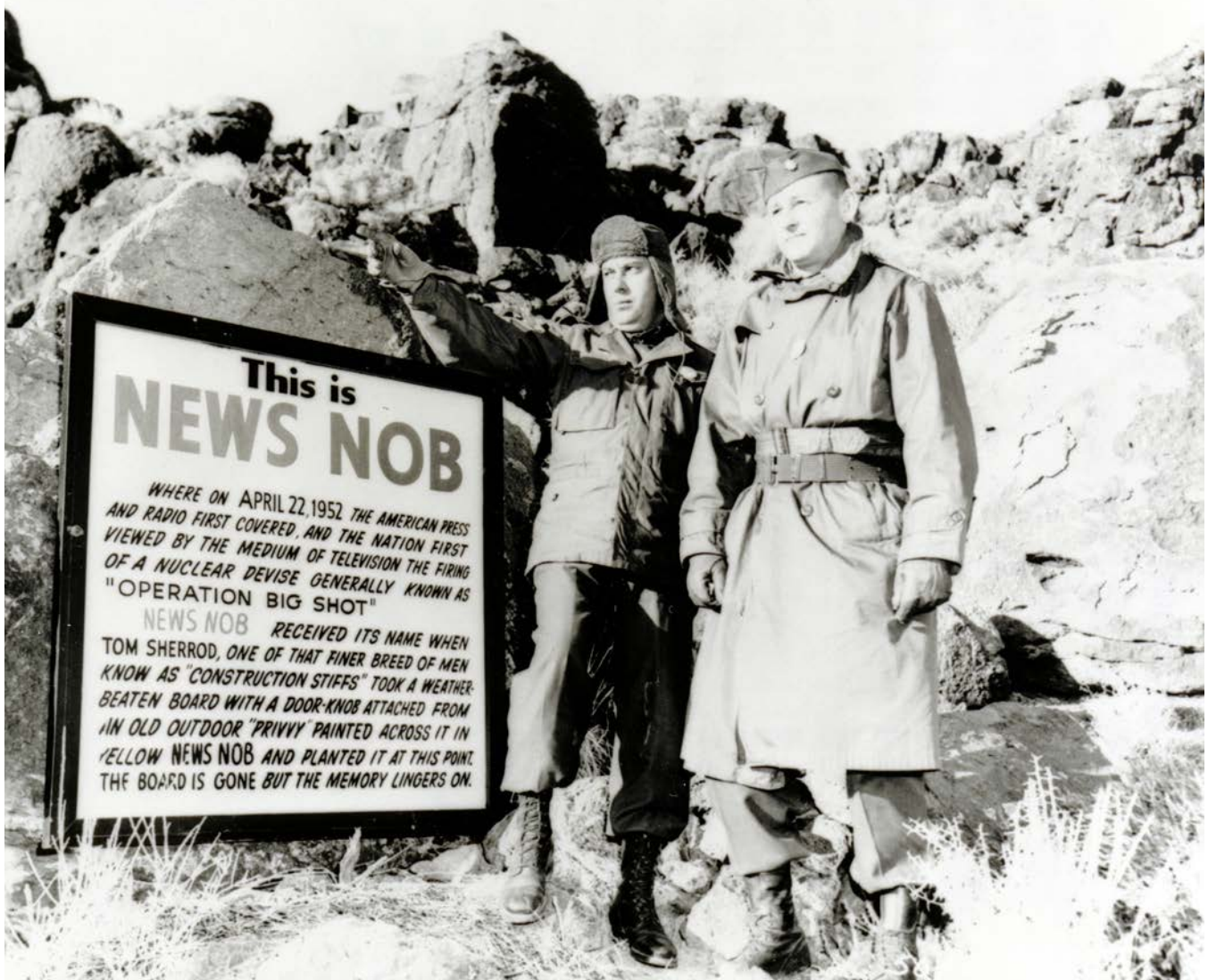


5

The Department of Agriculture and the U.S. Forest Service hoped to study the effects of a nuclear explosion on a forested area—but no forests existed on the NTS. So, in 1953, 145 ponderosa pine trees were brought in from a nearby canyon, stood upright, and cemented into place 6,500 feet away from ground zero of the Encore test. The heat of the explosion caused the model forest to catch fire, and then the blast wave caused the trees to topple.

6

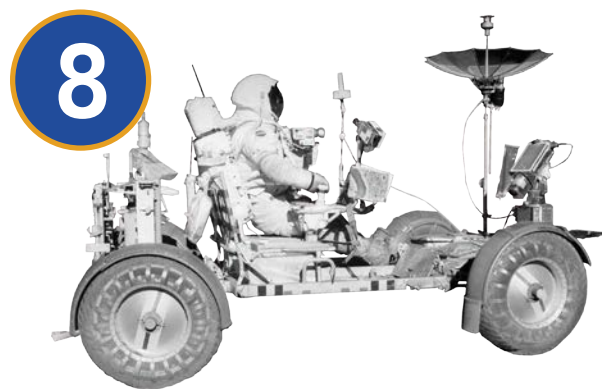
Starting with Operation Big Shot on April 22, 1952, photographers and journalists often observed atmospheric tests from a craggy mound of volcanic tuff on the edge of Yucca Lake. In the 1950s, a construction worker took a weather-beaten board from an old outhouse—with a yellow doorknob attached to it—and painted “This is News Nob” across the wood. The name stuck, and during testing days, News Nob was one of the most photographed and reported-from places in the world.





7

Between 1961 and 1992, 828 underground nuclear tests were conducted at NTS, most of them deep inside specially drilled vertical shafts (see “Nuclear Test Readiness,” page 8). A shaft usually took up to 12 weeks to drill, depending on its location, depth (500–4,000 feet), and diameter (74–120 inches). A nuclear device was lowered into the shaft on a rack and was then buried to prevent radioactive debris and gas from escaping to the surface. Drilling a “big hole” cost an average of \$1.5 million in the 1980s.



NTS’s lunar-like landscape was an ideal location for astronauts to train. Schooner Crater, in the extreme northwest portion of the test site, was visited by Apollo 14, 16, and 17 astronauts. Schooner was formed by a 30-kiloton underground shot that was part of the Plowshare tests in December 1968. At 200 feet deep and 725 feet wide, Schooner is the second-largest crater at NTS.



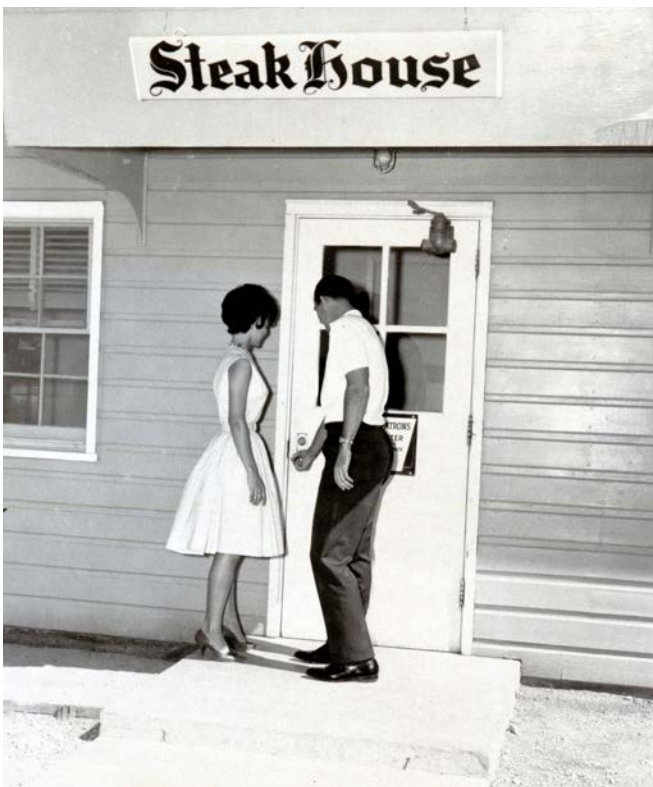
9

From 1964–1981, the Environmental Protection Agency (EPA) managed a 36-acre farm on the test site. Plant and soil studies evaluated the uptake of pollutants in farm-grown vegetables and from the forage eaten by 100 Hereford beef cattle. Researchers found no disease or tissue damage to the cattle resulting from radiation exposure (here, an EPA employee takes a food sample from a fistulated steer). Nuclear testing was sometimes delayed so that the 30 Holstein dairy cows could be milked on schedule.



10

The town of Mercury, 65 miles northwest of Las Vegas, was the social hub of the testing site and included amenities such as an eight-lane bowling alley, an Olympic-size swimming pool, a library, and a movie theater. The Steak House was the best restaurant on site, according to many.



“When there was time to relax, test crew members did so with the same exuberance they demonstrated on the job,” remembers Los Alamos Test Director Ron Cosimi. “I think all who spent time at the Site will remember the raucous poker games in the dorms, the wild softball games, the exploring of the nearby canyons and mountains, the beer drinking at the bowling alley, the long nights at the Mercury Steak House, and the innumerable pranks. You could say we were a family.” ✦

~Whitney J. Spivey



All photos courtesy of the Department of Energy.



In the 1970 Baneberry Test, a 10-kiloton device was detonated approximately 900 feet underground. Despite a careful geological analysis of the test site and appropriate backfilling of the test shaft, undiscovered geological features allowed the blast to breach the surface. The resulting radioactive dust plume is shown here. (Photo: Los Alamos)

NUCLEAR TEST READINESS

What is needed? Why?

In a national emergency, could the United States safely test a nuclear weapon tomorrow? Is Nevada still the obvious place to conduct a nuclear test? John C. Hopkins, former head of the Los Alamos Nuclear Test division, contemplates the challenges of reviving—and possibly relocating—America’s nuclear testing program.

I am one of the dwindling number of people left who participated in U.S. nuclear weapons tests. I participated in five tests in the Pacific in 1962 and some 170 tests in Nevada in the 1960s through the 1980s. I witnessed another 35 or so nuclear tests.

Because I know something about the skills, equipment, facilities, and infrastructure necessary to field a full-scale nuclear test, I have grown increasingly concerned at the steady degradation of U.S. nuclear test readiness—that is, the capability of the United States to test its nuclear weapons should the need to do so arise.

In fact, my review of assessments made by the Department of Energy (DOE) of U.S. nuclear test readiness leads me to question whether the DOE has, after almost 25 years of being out of the testing business, any realistic appreciation for what nuclear testing involves or how to stay prepared to do it again within 24–36 months, as legally required by Presidential Decision Directive 15 (1993).

Starting up or starting over?

Nuclear testing as we did it at the Nevada Test Site (NTS, now called the Nevada National Security Site, or NNSS) was a profoundly large and complex endeavor. The 1,375-square-mile site sits about 65 miles northwest of Las Vegas and was used from 1951–1992 for 928 atmospheric and underground nuclear tests. Back then, the U.S. nuclear enterprise was not just a program; it was a nationwide industry that required more than 100,000 highly trained, experienced people. During the Cold War—peak testing years—we averaged about one test a week, and NTS employed more than 7,000 people onsite. (See “Nevada National Security Site Turns 65,” page 2.)

According to the National Nuclear Security Administration (NNSA)—the organization within the DOE obligated to maintain U.S. test readiness—much, if not most, of the equipment and technology required for nuclear testing in the past has not been adequately maintained, is obsolete, or has been sold or salvaged. More importantly, the knowledge needed to conduct a nuclear test, which comes only from testing experience, is all but gone too. Currently, no

federal funding directly supports maintaining test readiness (although the government does fund subcritical tests; see “Do Subcritical Experiments Help?” page 16).

In sum, there is essentially no test readiness. The whole testing process—whether to conduct one test or many—would in essence have to be *reinvented*, not simply resumed.

If the United States decided tomorrow that it wanted to test a weapon in the nuclear triad (see “Why the Nuclear Triad,” page 17), the path to actually do so (safely) would be long and complicated, and it would look something like this:

Where could we conduct a nuclear test?

This answer largely depends on how soon the president, who orders the test, wants the test to happen.

At first look, the NNSS is the obvious place to resume testing. But in reality, this is far from certain.

In an emergency—such as the need to evaluate the safety, security, and performance of an existing but questionable nuclear weapon design—I assume that we would test underground and not abrogate the 1963 Limited Test Ban Treaty that bans tests in the atmosphere, oceans, and outer space. I also assume we would adhere to the 1974 Threshold Test Ban Treaty, which limits tests to a maximum yield of 150 kilotons of TNT. (Nuclear yield is the amount of energy released, expressed as a TNT equivalent. A kiloton is 1,000 tons, so the treaty limits yield equivalents to no more than 150,000 tons of TNT.)

At first look, the NNSS is the obvious place to resume testing. But in reality, this is far from certain. More than 800 of the nuclear tests there were conducted underground in deep shafts (or sometimes tunnels). More than a dozen shafts still exist that *might* be serviceable.

However, since the last underground test in 1992, nearby Las Vegas has exploded in population. In 2015, the city had

630,000 residents—360,000 more residents than in 1990. (In 1951, the year testing began, the population of Las Vegas was about 25,000.) In 2015, the greater Las Vegas metropolitan area had a population of more than 2.1 million—1.4 million more people than in 1990.

In 2015, the greater Las Vegas metropolitan area had a population of more than 2.1 million, 1.4 million more people than in 1990.

More people equals more buildings. Today, Las Vegas has more than 50 buildings over 328 feet tall (25 stories high), including the 1,150-foot Stratosphere Tower, the tallest observation tower in the United States.

What is the maximum yield that could be fired at the test site without causing seismic damage to Las Vegas infrastructure and its surrounding communities? Will recent construction be resistant to seismic energy following a 150-kiloton blast? Will future maximum test yields have to decrease as the local population increases?

How big of a test could be conducted in Nevada?

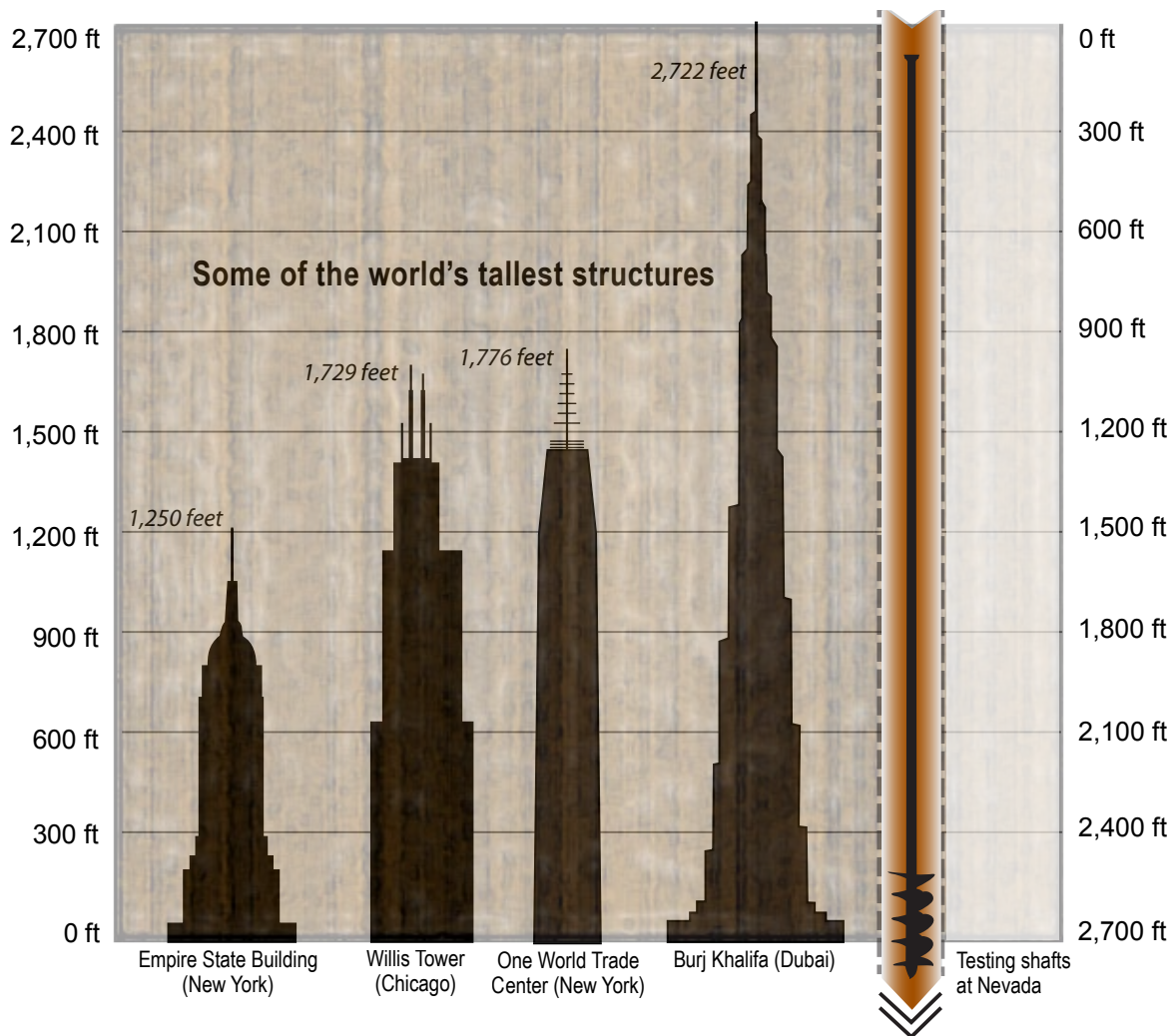
The answer to this critical question lies in accurately predicting the seismic effects of a nuclear test’s yield at NNSS on Las Vegas and the surrounding communities.

Detailed geologic and safety analyses of the current Las Vegas area would be required to develop a prudent estimate of the upper limit of the yield. Ultimately, scientific judgment would play a key role in this estimate, but that judgment would rely on recommendations coming from relatively young scientists and engineers who have no experience in nuclear testing.

Previously, the Atomic Energy Commission (the predecessor to today’s DOE) hired an engineering contractor to analyze the structural integrity of buildings in Las Vegas and their vulnerability to ground motion due to nuclear explosions. Test readiness means that buildings—especially skyscrapers—

Left: A mushroom cloud is visible from downtown Las Vegas. This scene was typical from 1951 to 1962 as the government conducted 100 atmospheric tests at the NTS. Right: Downtown Las Vegas in 2010. (Photos: DOE, Open Source)





During the period of underground testing at the NTS, 13 shots were fired at a depth of 3,000 feet or more; six of those were fired at least 4,000 feet below the surface.

and the greater metropolitan infrastructure would have to be carefully evaluated. Reconstituting this program would require a major effort.

Throughout the testing period, Las Vegas construction workers were notified when an upcoming shot might cause significant ground motion. The reasoning was that such shaking could be unsafe for workers in exposed locations, particularly at high-rise construction sites. Mines in the region were also notified of ground motion that could conceivably cause damage and injury. A new plan to communicate a testing schedule to the civilian workforce would have to be developed.

How can seismic effects be mitigated?

“Decoupling” an explosion can mitigate seismic energy. Decoupling involves testing the nuclear device in an underground cavity large enough to absorb—and thus reduce—the force of the blast. Higher yield explosions

require larger cavities. Larger cavities require significantly more time, effort, and cost to excavate. The National Academy of Sciences estimates that, depending on geology, a cavity 121 feet in radius requiring the removal of nearly 7.5 million cubic feet of material, would be needed to decouple a 3-kiloton test.

How can a nuclear test be contained?

The risk of venting—the leaking of radioactive materials from the ground into the atmosphere—must be minimized. An underground test was designed to prevent venting. In the past, preventing venting was a major challenge for the geologists, engineers, and construction crews at the test site.

Previously, we selected a location and designed the emplacement shaft to contain a yield that was usually about 10 percent larger than the expected yield. Successful containment depended on studying the geology at each test



Gas-blocked cables are shown here laid out in an s-shape prior to an underground nuclear test. The cables were lowered down-hole along with a giant steel rack that contained the test device and multiple diagnostic sensors used to gather data. The cables relayed the data up to trailers (shown here in the foreground and parked at a safe distance from the detonation) containing the data recording equipment. In the background is a 10-story tower assembled around the giant rack and directly over the test hole. The tower was disassembled and removed in sections after lowering the rack but before the detonation. The tower was then reassembled over the next test hole. (Photo: DOE)

location—no two test locations had the same geology—to see if the shaft could contain the test after successfully stemming (backfilling) the shaft.

Stemming was both a science and an art, and few experts with stemming experience can still be found.

To be effective, stemming required an experienced expert to layer a special brew of adhesive epoxies (which are no longer available) and various types and sizes of gravel. This mixture would then be packed around specially designed gas-blocked cables that were used to transmit command-signals down-hole and send scientific data up to the surface. (The cables were gas-blocked to prevent any venting up through the cables, and I doubt whether these special cables are still available. If not, they would have to be redesigned, tested, and manufactured anew.)

Each test's stemming was unique, varying with the test's predicted maximum yield and a thorough study of the geology surrounding the shaft. Stemming was both a science and an

art, and few experts with stemming experience can still be found.

All of the geophysical tools that were, over many years, designed, built, tested, calibrated, and fielded at the NTS specifically to collect samples and characterize the geology no longer exist. The designers and operators are long gone, too. The Laboratory analysts who had the skills and experience to evaluate the samples for grain density and for compressive and shear strength are likewise long gone.

Today, the kind of detailed geologic and safety analyses and yield predictions needed to successfully contain a nuclear test would depend upon people who have no nuclear testing experience.

Amchitka is part of the Alaska Maritime National Wildlife Refuge, and going back there to test would be concerning to environmentalists and Native Alaskans.

Even with stemming, the risk of venting could never be reduced to zero. Dangerous surprises (for example, unknown

cracks, caves, or moisture) might be lurking right next to the area of geologic sampling. One dramatic failure was the huge venting from the 1970 Baneberry shot, which was caused by undiscovered geological problems at the test site.

To be prudent, we always assumed that massive venting might occur. So, we were in touch with all of the potential downwind residents and had helicopters ready and evacuation plans for every rancher out mending fences and every sheepherder tending to his flock—anyone who might be at risk the day of a test.

What would it take to plan and implement emergency evacuations close to the NNSS today?

What about sticking to lower-yield tests?

The NTS was originally chosen for nuclear testing largely because of its remote location at that time. Once testing went underground, we soon discovered that, fortuitously, the geology is nearly ideal for reducing venting and seismic impact—thus limiting negative impacts to the environment caused by higher-yield (more than 10 kiloton) tests.

How to revive these critical, complex, and costly skills for a future nuclear test must be addressed.

The water table at the NTS is deep: 1,300 feet at Yucca Flats, where low-yield shots were traditionally fired, and 2,000 feet at Pahute Mesa, which was used mostly for high-yield shots. The overlying layers of weak, porous tuff and alluvium provide dry pore space to trap radioactive gases. The site's easily crushable porous tuff would also significantly absorb the seismic waves of our higher-yield tests.

But surprisingly, and perhaps counterintuitively, low-yield nuclear tests are harder to contain at the site. In part, this is because the crushable tuff doesn't crush as well from lower-yield tests, meaning that the risks of venting increase. So, risks to the environment actually loom larger. Successfully stemming a lower-yield test is actually more difficult.

These risks can be addressed by burying a low-yield test as if it were higher-yield test, but this approach requires the commensurate level of time, effort, and expense of conducting a higher-yield test. Therefore, the better approach is to design an effective containment plan at the nominal depth required for the lower yield, assuming that the expertise necessary to do this is available.

Clearly, the assumption that focusing on lower-yield tests gets us any closer to nuclear test readiness needs a closer look.

If not in Nevada, then where?

If challenges preclude using NNSS, an alternative testing site would be required. Amchitka Island in the Alaskan Aleutians Islands would probably be the next best candidate site. Three tests were fired there: Longshot (1965) and Milrow (1969) by Los Alamos and Cannikin (1971) by Lawrence Livermore.

However, not much infrastructure is left on the island other than an airstrip and perhaps two holes that were, at one time, meant for future nuclear tests. All the buildings are gone. The lack of infrastructure, great distance, and remote location make Amchitka vastly more expensive and inconvenient than working in Nevada. The island also has a wretched climate with dense fog and rain. In addition, Amchitka is now part of the Alaska Maritime National Wildlife Refuge, and going back there to test would certainly be concerning to environmentalists and Native Alaskans.

Do other locations exist? Studies of alternative sites have been made in the past, but like at Amchitka, political, cultural, and natural environments have changed since those studies were undertaken. New, costly, and time-consuming assessments would need to be done. Should the nation be actively searching?

Critical skills and assets

As might be imagined, many unique and critical assets—facilities, materials, and equipment, much of which is not commercially available—must be available to successfully execute an underground nuclear test.



Amchitka has been part of the United States since the Alaska Purchase of 1867. During World War II, the volcanic island was home to a U.S. airfield; during the Cold War, Amchitka was the site for three underground nuclear tests. The last test, the 5-megaton Cannikin Test (1971), is the largest underground test ever conducted by the United States.

Tests fired in shafts, for example, had the nuclear device and the experimental equipment installed inside a tall, steel structure called a rack, which was lowered down-hole. The racks, which were designed and fabricated specifically for each shot, could be almost 10 feet in diameter and more than 100 feet tall. The assembly of all the experimental equipment required that the rack be surrounded by a tower, built of prefabricated units, that was large enough for the scientific and engineering staff to work onsite at all levels of the rack.

Seemingly mundane perhaps, but vital, are requirements for housekeeping and security.

The Los Alamos racks were fabricated at Los Alamos and shipped to Nevada to install the scientific equipment. The nuclear test device was installed as the last step before the rack was carefully lowered down-hole on cable harnesses, which were also fabricated at Los Alamos. Livermore's racks were fabricated by a contractor in Las Vegas and were lowered using drill pipe, a completely different technique. Pros and cons exist for each option.

How to revive these critical, complex, and costly skills for a future nuclear test must be addressed.

The stakeholders

After two decades without testing, who would be the current stakeholders, and what would their roles and responsibilities be? What are the challenges to negotiating new and complex chains of command and responsibility?

The White House, DOE, NNSA, Department of Defense, and the state of Nevada would be among the key stakeholders, along with more than a dozen other government organizations such as the Defense Nuclear Facilities Safety Board, the Defense Threat Reduction Agency, the Environmental Protection Agency, the U.S. Public Health Service, the National Oceanic and Atmospheric Administration, the State Department, and Congress.

Because the United Kingdom's nuclear strategy is closely allied to ours, I presume the U.K. would participate where its national security interests are involved. Imagine the difficulties of getting all these gears to smoothly mesh together.



Subsidence craters—depressions on the surface that occur when the roof of the blast cavity collapses into the void left by the explosion—still mark the surface of Yucca Flat, where many underground nuclear tests were conducted at the NTS. The size of subsidence craters depends on the yield of the device, the depth of the test, and the geological characteristics of the surrounding soil. (Photo: DOE)

Although Los Alamos, Livermore, and Sandia national laboratories would supply much—if not most—of the technical staff, the majority of the testing personnel would come from a wide range of outside organizations. Contractors for the NNSA would do almost all construction, related logistics, and other support work.

These contracts might include providing test diagnostic support (once supplied by EG&G, which no longer exists) and the architect/engineering support (once supplied by Holmes & Narver Inc., which is still in business).

The now-defunct Reynolds Electrical & Engineering Company provided the heavy construction services, including operating cranes and drilling shafts, some of which were more than 4,000 feet deep. The technology and expertise to drill new, large-diameter, deep, and straight testing shafts would almost certainly have to be recreated. Significant economical and technological challenges would arise if the pre-moratorium-drilled shafts need to be cleaned of debris or pumped dry of water.

Seemingly mundane perhaps, but vital, are requirements for housekeeping and security. Currently, a few of these requirements are being met at the site (to accommodate staff conducting subcritical experiments, for example), but these requirements would have to be expanded to accommodate a much larger operation. Other services—for example, recreational programs and facilities—would have to be completely reinvented.

The labs

I would strongly urge the three nuclear weapons labs to form one unified test program, with each lab having well-defined responsibilities and clear accountability. (Previously, each lab had its own testing programs.)

I would recommend pulling together a steering committee of the labs' key staff, including weapons designers and engineers, diagnostic scientists (such as physicists and radiochemists), geologists, engineers (civil, mechanical, and electrical), and logistics and travel personnel. (A scaled-down

version of this type of organization probably exists today as a result of the subcritical tests currently conducted in Nevada but probably lacks all the expertise needed to execute a full-scale nuclear test.)

The time delay following the decision to resume testing would, in my opinion, be dangerously long.

I would suggest that the labs' test program leaders put a high priority on selecting an archivist. Perhaps not obvious, the rationale for the archivist is this: In developing the testing organization and structure, there will be many questions about what, how, and why things were done in the past. Laboratory archivists could make answering those questions much easier, assuming that the old testing files are stored somewhere in the labs and can be found.

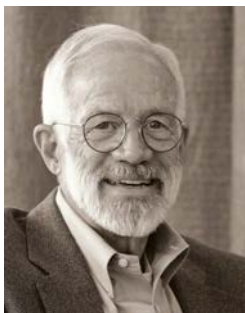
Making nuclear test readiness a priority

With every day that passes, the United States grows more out of practice and out of resources—including the most important resource: people with experience—that are critical to nuclear testing. The testing process, whether for one test or for many, would in many respects have to be *reinvented*, not simply restarted, which would take longer than 36 months. Past practices will help identify *what* to do but not necessarily *how* to do it—primarily because science, technology, politics, and culture have changed so dramatically since 1992.

A resumption of nuclear testing would involve a large, expensive, and complex program. Because the United States has little left from its previous test program, and essentially no test-readiness program, the time delay following the decision to resume testing—because of a loss of confidence in the stockpile or to a geopolitical crisis—would, in my opinion, be dangerously long.

Let's not wait to find out how long. ✦

~John C. Hopkins



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I alone take responsibility for the opinions expressed in this article.

NUCLEAR TEST READINESS

Do Subcritical Experiments Help?

Although the United States halted full-scale nuclear weapons tests almost 25 years ago, the nation does conduct small-scale subcritical nuclear experiments using plutonium and high explosives.

These subcrits, as they're called, are underground experiments at NNSS that are typically conducted safely inside steel confinement vessels. Subcrits are intended to help scientists study—without a full-scale nuclear weapon test—what, for example, are the negative effects aging plutonium pits have on the performance (yield) of weapons in the U.S. nuclear stockpile. (Rocky Flats, where plutonium pits were manufactured, closed in 1989.)

In a typical subcritical experiment, a small shell of plutonium is imploded using high explosives, increasing the plutonium's density until...there isn't a nuclear explosion. And that's the point. Unlike a full-scale nuclear weapons test, a successful subcrit ends without a nuclear bang—not even a whimper. The pit assembly doesn't have enough plutonium or high explosives to reach a critical mass.

A critical mass is the minimum amount of nuclear material (typically plutonium or uranium) needed to initiate the self-sustaining chain reaction that releases huge amounts of nuclear energy—aka a nuclear explosion. In a subcrit, the mass of plutonium used to make the pit remains subcritical. A self-sustaining nuclear chain reaction isn't possible; there is no nuclear yield, no nuclear explosion. The experiment is in line with the nuclear testing moratorium while allowing

scientists to study, for example, how aging plutonium pits perform right up to just before going critically nuclear.

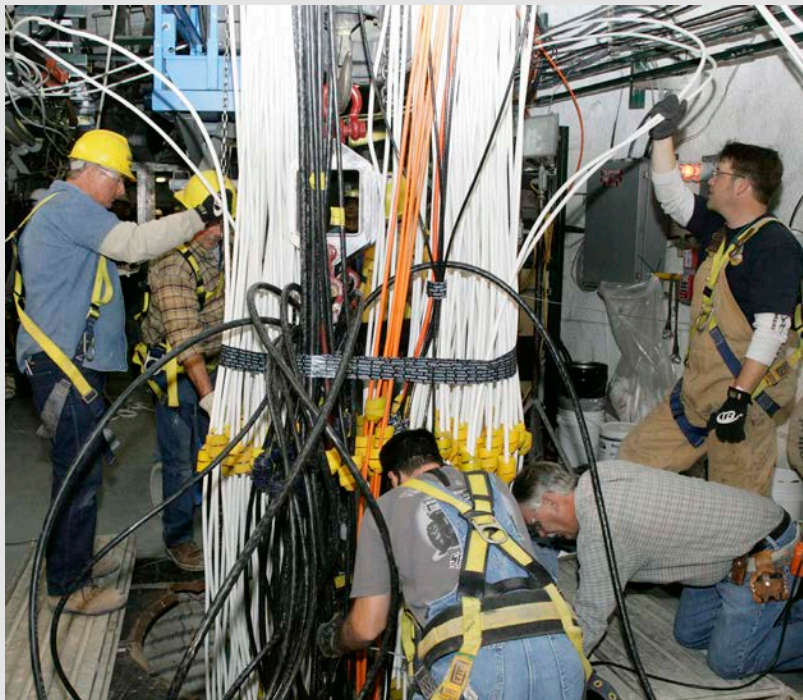
So, do subcritical experiments help maintain U.S. test readiness?

Yes, in the sense that all subcrits are relevant to maintaining test readiness because they exercise *some* of the aspects and skill sets used in full-scale testing, such as firing shots, employing specialized diagnostic equipment, and gathering data.

However, subcrits are small scale. A full-scale nuclear test, which reveals how well the entire device works from start to finish, is quantitatively and qualitatively different in many key ways. For example, safely containing a full-scale test requires the skills and equipment for carefully studying and geologically characterizing a test site, drilling an appropriately deep shaft, emplacing the test device and all of its diagnostic-related equipment deep underground, and then properly containing (stemming) the shaft so the massive detonation doesn't breach the surface.

These—and other critical skills—are not currently exercised by doing subcritical experiments.

In short, though valuable, subcrits don't address all of the issues required to maintain test readiness within a 24- to 36-month timeframe. ✦



The Nevada National Security Site is the only place where subcritical experiments using plutonium and high explosives can be conducted. The U1a laboratory at the site, constructed nearly 1,000 feet underground, is where these experiments are typically conducted. Here, workers prepare to conduct an experiment in the U1a laboratory. (Photo: Los Alamos)



Planes such as the B-2 Spirit (pictured) and the B-52 Stratofortress compose the U.S. strategic bomber force and can carry warheads deep into enemy air space without support aircraft. The stealthy B-2 is made of graphite composite (instead of aluminum) to avoid radar detection. (Photo: Open Source)

Why the Nuclear Triad?

A diverse combination of weapons systems ensures the security of America and its allies.

Just as expert economists recommend a diversified portfolio of stocks, bonds, and other investments to ensure economic security, defense experts recommend that the nation's nuclear deterrent be diversified to ensure U.S. national security—and the security of America's allies.

During the Cold War, America's strategic nuclear defense evolved into a diversified “nuclear triad,” or three separate and distinct methods of delivering warheads to designated targets:

Air: bombs and air-launched cruise missiles deployed from strategic bombers

Land: intercontinental ballistic missiles (ICBMs) dispersed in underground silos across five states

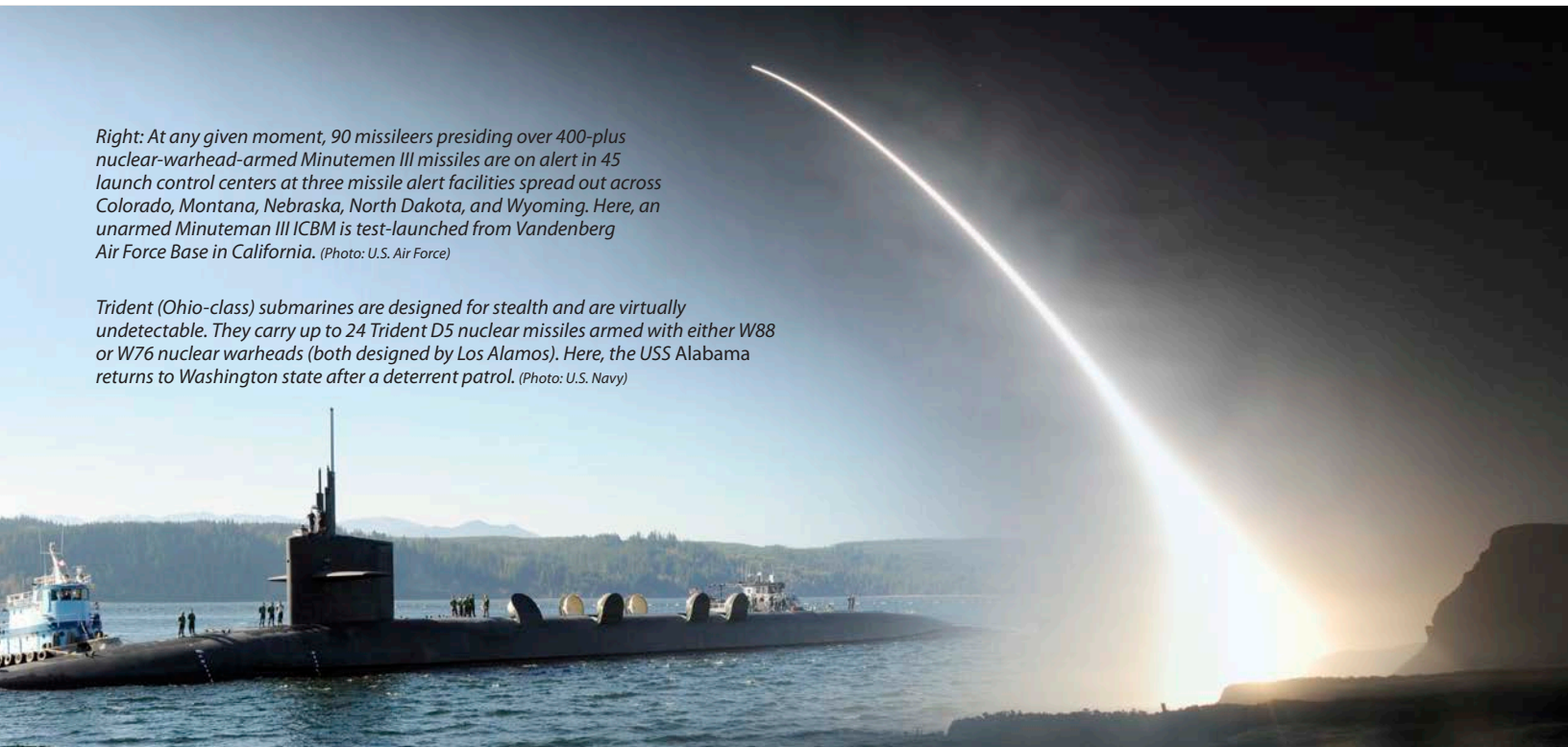
Sea: submarine-launched ballistic missiles (SLBMs) deployed from Trident nuclear submarines

Each method has advantages and disadvantages, and having three unique, widely dispersed nuclear weapons systems eliminates the risk that an enemy could destroy the entire U.S. deterrent in a first strike. (See “Smells Like Alert,” page 18.)

The U.S. nuclear triad also guarantees to the nation, its allies, and its adversaries that the United States will always have the capability to retaliate and destroy any attacking nation—thus deterring any nation from attacking America or its allies. ✦

Right: At any given moment, 90 missileers presiding over 400-plus nuclear-warhead-armed Minutemen III missiles are on alert in 45 launch control centers at three missile alert facilities spread out across Colorado, Montana, Nebraska, North Dakota, and Wyoming. Here, an unarmed Minuteman III ICBM is test-launched from Vandenberg Air Force Base in California. (Photo: U.S. Air Force)

Trident (Ohio-class) submarines are designed for stealth and are virtually undetectable. They carry up to 24 Trident D5 nuclear missiles armed with either W88 or W76 nuclear warheads (both designed by Los Alamos). Here, the USS Alabama returns to Washington state after a deterrent patrol. (Photo: U.S. Navy)





Left: An unarmed Minuteman III ICBM is successfully launched from Vandenberg Air Force Base in California on August 19, 2015. The 45-year-old missile was launched to test its performance and reliability. (Photo: U.S. Air Force)

Below: On March 22, 2016, all the missile crews on alert at all three U.S. ICBM bases consisted solely of women—a first for the Air Force. To commemorate the occasion, the women wore special patches with the likeness of Rosie the Riveter. (Photo: U.S. Air Force)

SMELLS LIKE ALERT



Missileers are highly trained members of the United States Air Force who must be ready, willing, and able to launch nuclear-warhead-armed intercontinental ballistic missiles (ICBMs) at a moment's notice. No pressure.

Oscar-01 Missile Alert Facility, Malmstrom Air Force Base, Great Falls, Montana

I take a deep breath and pick up the pen, not anticipating the swell of emotion in my stomach. The magnitude of my actions—or inactions—suddenly becomes very real, and I sign my name to the paper. I am officially on my first 24-hour alert as a Deputy Missile Combat Crew Commander—a missileer. I am 23 years old.

My signature ensures that I will care for and, if ordered by the president, launch any or all of the 10 nuclear ICBMs now in my custody. I know that from this moment forward, I have to follow ICBM launch protocol to a T. The public, my family, my peers, base leadership, the commander of U.S. Strategic Command, and ultimately the President of the United States depend on me to launch these weapons, should I ever be ordered to do so.

Launching a weapon means I'm not only destroying a military target but also the lives of thousands, possibly tens of thousands, of people. Launching a weapon means world events have gone so far south that it's only a matter of time—minutes, probably—before the enemy's missiles kill me in a similar attack. As a missileer about to go on alert, I'm supporting my daily deterrence mission—but by pledging to defend my country, I'm also effectively signing my name to a suicide mission. And I've accepted that.

I exhale.

One hour earlier

I arrived here, at the Oscar-01 Missile Alert Facility (MAF) in central Montana. Traveling 55 mph in a government-issued van, the drive took nearly three hours. The MAF is 139 miles from my main post at Malmstrom Air Force Base, 147 miles from the closest Starbucks, and I don't even know how far from the nearest Chipotle. In other words, this California girl is in the middle of nowhere. And there's snow on the ground—in April.



The eight-ton steel-and-concrete door of an LCC is hand-painted like a Domino's Pizza box. The "next one" referred to here is a Minuteman ICBM. (Photo: Open Source)

After a topside (aboveground) greeting from the facility manager and members of the security force, I walk into a scissor-gated elevator alongside another, more experienced, missileer named Tom, who will join me on this alert. We descend approximately 60 feet below ground to the Launch Control Center (LCC). A giant American flag mural, painted by other Air Force members, stretches down the length of the elevator shaft—a timely reminder of my duty to our country and the importance of my job.

“World-wide delivery in 30 minutes or less—or your next one is free.”

We step out of the elevator and open a massive eight-ton concrete-and-steel blast door that’s hand-painted with a Domino’s Pizza logo, the silhouette of a Minuteman missile,



and the words “World-wide delivery in 30 minutes or less—or your next one is free.”

On the other side of the door, which is more than six feet high and two feet thick, is the LCC—and its off-going two-person crew. After a 45-minute changeover, during which we discuss the status of weapons, procedures, and other classified information, Tom and I sign for our 24-hour alert. We’re officially on the clock.

The capsule: womb? . . .

The LCC, our home for the next day, is a 10-by-22-foot steel capsule that’s suspended within a larger vessel shaped like a giant aspirin bottle lying on its side. This suspension system allows for the capsule to sway in the event of a nuclear attack, supposedly increasing the survivability of the equipment and people inside. I feel the capsule waver, ever so slightly, as I move around the space. I thank my lucky stars that I am not susceptible to motion sickness or claustrophobia.

The walls of the capsule are lined with mint-green-colored racks that house circuit breakers, communication equipment, air conditioning, and air-regeneration equipment—all of which contribute to a constant humming sound and a briny, stale, electrical odor.

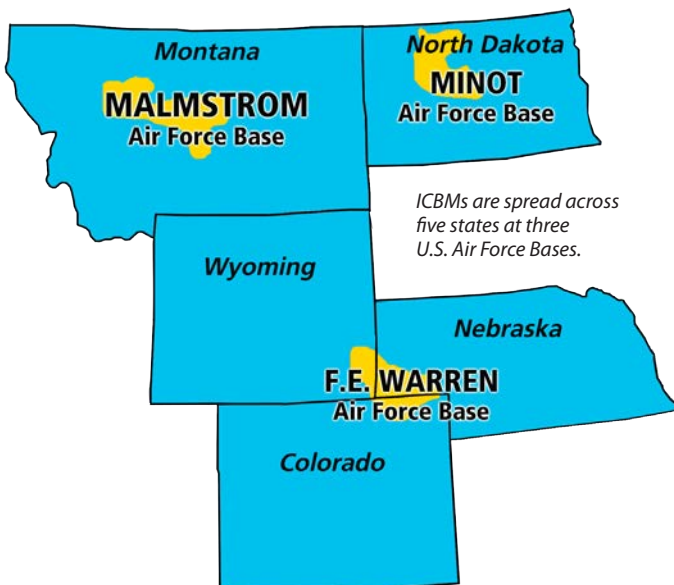
“Smells like alert,” says Tom as he settles into one of two red chairs. “Back in the day, we didn’t have shredders in here, so we had to burn certain classified documents. Some say that’s where the smell comes from. Well, that, and the ancient electrical equipment. And the constant, confined human occupation.”

I’ve heard from others that “the alert smell” will permeate my clothes and hair before my shift is up. Knowing that the scent will never really wash out of my uniform, I’ve already designated the T-shirt and sweatpants I’m wearing as my “alert outfit.” Although I don’t plan on doing any vigorous physical activity while I’m down here, I’ve packed some wet wipes and face wash to freshen up.

A cramped bathroom, smaller than one you might use in an airplane, is built into one corner of the capsule. A “sink” sits atop the tank of a prison-style stainless steel metal toilet and drains directly into the toilet bowl. Somehow, some missileers wash their hair in the tiny sink—but I think I’d rather just endure a bad hair day.

At my fingertips are 10 of America’s Minuteman III missiles.

The capsule floor is covered with well-worn, commercial-grade, earth-toned carpet squares that can be quickly removed to gain access to the emergency batteries and motor generator below. Carpet also covers the ceiling, which helps absorb the electrical and ventilation noise and insulates the usually 68-degree space. I try not to think about all the dead skin cells and food crumbs that this carpet has collected over time.



Missile maintenance crew members work on a Minuteman III ICBM in its silo. (Photo: U.S. Air Force)

A bed frame, with a sagging mattress and a heavy hospital-style curtain hung around it, sits along the short wall opposite the door. That’s where I’ll try to take a nap for a few hours during this alert.

About three feet from the bed is the focal point of the capsule: a cream-colored console, which is the main computer and communications work area. At my fingertips are 10 of America’s Minuteman III missiles, housed in silos below ground, approximately five miles from the MAF. If launched, each 60-foot-long, 80,000-pound weapon can carry up to three nuclear warheads more than 6,000 miles in any direction to a predetermined target in about 30 minutes—the same amount of time it takes to have a pizza delivered.

If directed by the president (who, by the way, is the *only* person who can command a missile launch), a missileer such as myself can directly influence world events by delivering widespread devastation to anywhere on the planet. We do not take this responsibility lightly.

... or tomb?

But our mission isn’t just about launching missiles in retaliation. In the event of a nuclear war, the missileers on alert would expect to be hit with incoming enemy missiles. You see, the enemy must destroy all of America’s 400-plus dispersed missiles or risk being attacked by those missiles in retaliation.

In other words, missileers are “the sponge”—the buffer between the enemy and American civilians. Every warhead that’s aimed at us is one that isn’t aimed at someone else. Take away the ICBM bases, and hundreds of the enemy’s missiles would certainly find new targets.

The hardest part about being the sponge in such an attack would be never seeing my family again. Even if I were to survive a missile attack, the likelihood of actually getting out of the capsule alive is slim to none.

There’s an escape plan, sure, but if it were implemented, the resulting scenario would probably play out like this:

The two missileers climb out of the capsule and, using a built-in ladder, climb on top of it. One of them opens a heavy steel hatch in the ceiling of the surrounding vessel. This hatch, which covers an escape shaft, not only weighs more than a person but also holds up a column of sand that’s two feet in diameter and more than 60 feet high. The hatch will most likely smash into and kill whoever opens it. So, not only is one missileer dead at this point but also buried by the ton of sand that falls down the shaft into the vessel.

The surviving missileer now climbs over this burial mound and up a ladder into the shaft. Using a small shovel, this person removes what remains of the shaft’s decades-old, compacted sand. Should the missileer succeed in making it to the top, he or she must then knock away the railroad-tie-size wooden beams

near the surface. And if that works, well, best of luck to this person actually getting out: Years ago, the Air Force laid down new asphalt parking lots at some of the MAFs—including one right on top of our escape shaft.

It’s a suicide mission in more ways than one.

But we missileers accept that risk.

Nuclear nanny—or not

At any given moment, 90 missileers are on alert at 45 MAFs spread across Colorado, Montana, Nebraska, North Dakota, and Wyoming.

I don’t know whether the average American has heard of a missileer, knows what we do, or appreciates the risks associated with our job. I don’t think most people realize that missileers are constantly on alert, every day of the year.

Being a missileer can be a monotonous, thankless job, and we perform it with pride.

Being a missileer is not sexy or well-publicized. In fact, I became aware of the job only once I joined the Air Force. Intrigued by the position, I pursued a career as a missileer



Two missile combat crew commanders run through the morning hand-over briefing. The LCC bed is behind the red curtain. (Photo by Jay Olivier/PBS News Hour)

and began highly specialized training that involves everything from reading classified launch-protocol manuals to performing hands-on launch simulations.

Many of my fellow missileers, however, didn't choose this career path. They were assigned to become missileers by the Air Force, and they do it because that's how the military works. Being a missileer can be a monotonous, thankless job, and we perform it with pride.

Outside the Air Force, however, some people think that the relevance of the missileer mission has declined since the end of the Cold War and that present-day missileers are simply sitting in underground bunkers babysitting nuclear weapons.

Babysitting. Ouch. I turn to Tom. "Do you ever feel like the red-headed stepchild of the Air Force?" I ask. "Like nobody really understands what we do?"

"Sure," he says. "Especially because it seems like the only press we get is bad press."

I grit my teeth and struggle to think of recent positive media coverage we've received. Nothing comes to mind.

Tom gives me a sideways glance. "What's the big deal?" he says. "If you wanted prestige, you should have become a fighter pilot."

I sit quietly for a moment before I return to my task at hand, which involves completing our daily LCC and communications equipment inspections. Tom cracks open a textbook. He's halfway through a master's program, and downtime during an alert is ideal for studying. Later we'll perform several more hours of necessary tasks, such as targeting, monitoring for missile and LCC anomalies, and reviewing operational procedures.

Some people think that the relevance of the missileer mission has declined since the end of the Cold War.

Eating is also on the to-do list, and that happens when the MAF cook delivers food to the LCC. I've ordered a grilled chicken salad for lunch, even though I know Tom's burger and fries will make my mouth water. The food, although not exactly gourmet, is welcome—I am hungry. I close my eyes and dream about which restaurant I'm going to treat myself to once I'm back in civilization.

Not that I will be home for that long. A day and a half will be just enough time to catch up with my family, Air Force training, and on sleep—before I'm back on alert again.

I wonder whether I'll miss my daughter's upcoming school play or her gymnastics recital because of this crazy schedule. As if he can read my mind, Tom says, "So I was able to go to my high school reunion last weekend."

"Oh yeah?" I grin. "Did everyone dress like they'd 'made it?'"

Tom rolls his eyes. "I wore my dress uniform," he says. "And when I told my classmates that I have been entrusted to defend them with nuclear weapons—well, no one else's career seemed quite as cool."

I smile and nod in agreement. "No kidding," I say. "I wouldn't trade this job for the world." ✨

~Whitney J. Spivey

A Missileer in New Mexico

This article was written largely from the perspective of Air Force Lt. Col. Cynthia Gunderson, who has served in the Air Force for 19 years and pulled 164 alerts as a missileer.

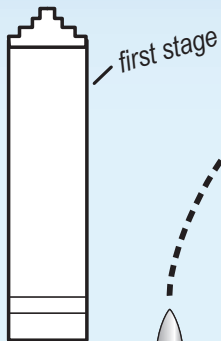
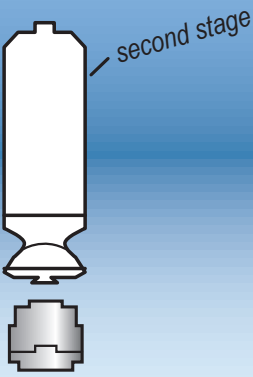
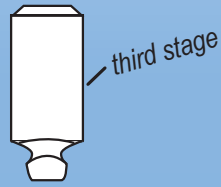
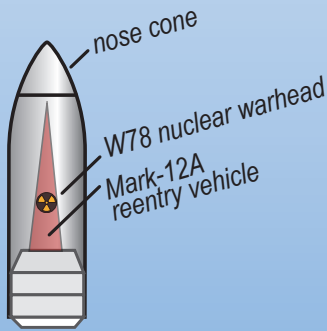
Lt. Col. Gunderson came to Los Alamos National Laboratory in July 2015 on a one-year Air Force Fellowship, which is considered part of her professional military education. "My goal while here is to learn as much as I can about nuclear weapons, Lab capabilities, and the Department of Energy's nuclear weapons complex," she says. "This will allow me to be a better steward for the nuclear enterprise—both military and civilian sides."



"I absolutely love it here," Lt. Col. Gunderson says of living and working in Los Alamos. "The technology and science here are awesome, and the people are amazing."

SMELLS LIKE ALERT

The Minuteman Takes Flight

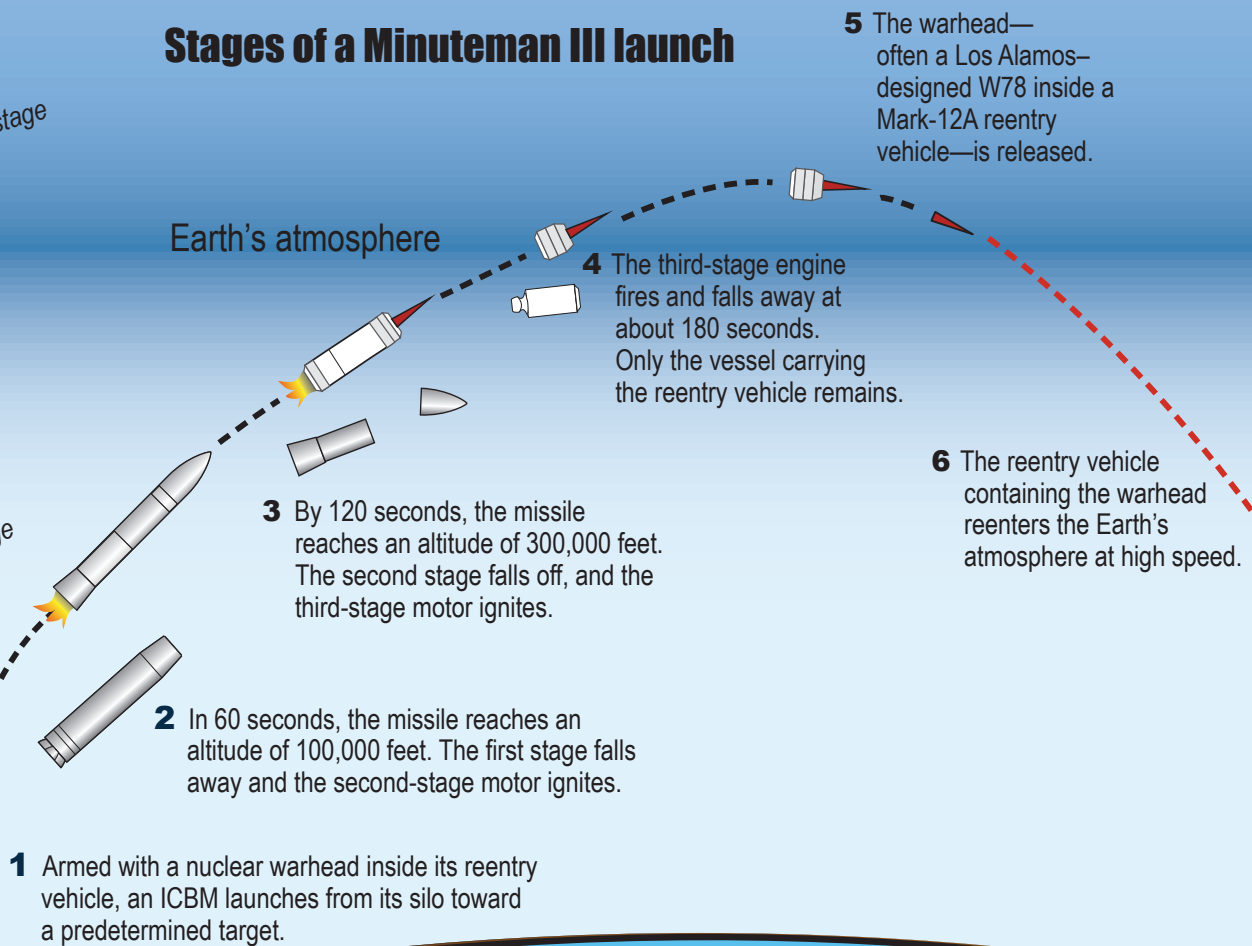


Should the president ever order a launch, it will come in the form of an Emergency Action Message and appear on the computer screen in the LCC. After both missileers ensure the message is legitimate, together they will turn separate keys to launch an ICBM.

The LCC is connected electronically to the vertical silos in which the ICBMs are stored. Buried 80 feet into the ground, each silo is covered with a massive 100-ton concrete-and-steel blast door that is blown violently open amidst a cloud of smoke and fire as the missile takes flight.

Once airborne, the 80,000-pound missile enters stages during which parts are dropped to shed excess weight and to accelerate to high velocities 700 miles above the Earth's surface. Traveling at 15,000 miles per hour, the weapon can reach a target on the other side of the world in about half an hour. ✦

Stages of a Minuteman III launch





Beyond an eight-ton blast door is a suspended walkway and then the LCC, where missileers pull 24-hour alerts. (Photo: Dan Sagalyn/PBS News Hour)

ICBM flight testing builds confidence

Minuteman III missiles are periodically launched (without their nuclear warheads, of course) from Vandenberg Air Force Base on the southern coast of California. These launches test missile capabilities and boost the confidence of U.S. allies—and the missileers.

Testing is increasingly necessary as Minutemen III age. Currently in their 40s, these missiles will be 60 years old by the time they are scheduled to be replaced in 2030. Components deteriorate every year, and since 2007, the Pentagon has spent more than \$7 billion to keep them up to date. Aging guidance systems have been replaced, solid-propellant rocket motors have been remanufactured, standby power systems have been swapped out, launch facilities have been repaired, and updated communications equipment has been installed. Test launches are a good way to demonstrate that all the new and updated parts work.

“While ICBM launches from Vandenberg Air Force Base almost seem routine, each one requires a tremendous amount of effort and absolute attention to detail in order to ensure a safe and successful launch,” says Col. J. Christopher Moss, who was the launch decision authority on five missiles that were tested in February 2016. “The data from these launches allows us to maintain a high readiness capability and ensures operational effectiveness of the most powerful weapons in the nation’s arsenal.”

Test launches from Vandenberg typically reenter—come back to Earth—off the coast of Kwajalein Atoll in the Pacific Ocean. In almost a blink of an eye, a glowing orange streak on its ballistic path hits the water and disintegrates. ✦



7 The nuclear weapon hits its target.

The W78 Lives On

Joint Test Assembly flight tests evaluate the Minuteman III’s aging warhead.

The W78 warhead, which was designed by Los Alamos and is one of the two types used to arm Minuteman III ICBMs, will turn 40 in 2019.

One way to evaluate the health of the aging W78 is by Joint Test Assembly (JTA) flight tests. These joint Department of Energy-Department of Defense tests gather key data from the sophisticated sensors inside the missile, the reentry vehicle (RV), and the W78 warhead tucked inside the RV. These data provide weapons scientists and engineers a way to assess the warhead’s ability to survive and function while traveling through multiple severe environments: the extreme violence of launching; accelerating within seconds to Mach 23 (about 18,000 miles per hour); entering the frigid vacuum of space; then reentering the atmosphere at speeds that threaten to break up or burn up the reentry vehicle and its warhead.

The key to a JTA, however, is that it uses a mock nuclear warhead: surrogate materials have replaced all of the nuclear materials inside. For example, the W78’s plutonium pit is replaced with a pit of non-nuclear material, making this mock-warhead incapable of generating any nuclear yield. The mock warhead is otherwise all but identical to a real warhead.

All types of nuclear warheads are flight-tested using JTAs. Because Los Alamos designed the W78 (and the W88, W76, and B61 warheads), it provides the mock warheads for those JTA flight-tests.

Although the mock warhead is technically a “dud,” JTAs are still one of the best ways to provide confidence that the W78 remains safe, secure, and reliable. ✦





Known officially as the Stratofortress, the mighty B-52 is sometimes referred to as a dragon for its size, dominance, and relentlessness. The B-52 is also affectionately called a BUFF (Big Ugly Fat Fellow—or **[REDACTED]**, depending on the company you keep) for its ungainly appearance. The B-52 model H (B-52H) is the only model of the plane that is capable of carrying nuclear weapons.

DECLASSIFIED

THE DRAGON IS ALIVE

The five-person crew of a B-52 Stratofortress is responsible for flying a 55-year-old dragon for 24 hours at a time at 650 miles per hour above some of the world's most dangerous countries—without navigation displays, modern computers, or a flushing toilet. And they like it.

*Prep time
Andersen Air Force Base, Guam, South Pacific
February **[REDACTED]***

I run my finger down the schedule until I reach my name and assignment: *Major Brad Haynes, Korean Peninsula*. In 35 hours, I will board a 1961 B-52H Stratofortress—the backbone of the U.S. strategic bomber force—as part of a standard 24-hour Air Force strategic deterrence mission in response to a nuclear test in North Hamgyong Province. It's time to show North Korea who's the boss.

But first, my crew—call sign Havoc 92—has to understand every detail of our assignment, which will cover 9,600 nautical miles, cost millions of dollars, and involve multiple countries. Although the purpose of this mission is to be seen and heard by North Koreans—not to actually attack them—our first step is still to select a target. In this case, the target is to fly to the southern border of the Korean Demilitarized Zone (DMZ), the 2.5-mile-wide buffer between North and South Korea, to make our presence known to our adversary—and to our allies (Japan, Taiwan, and South Korea).

We gather in the windowless, vault-like mission planning room, the five of us wearing flight suits and seated around a conference table. Our average age is 26. Jane, the pilot, is our aircraft commander. Paul is the copilot, and George is the radar navigator. Richard is the electronic warfare officer—also called the EWO or the “defender” because he electronically jams and scrambles the locating and targeting capabilities of the enemy's missiles and fighter jets. Then there's me. I am the other navigator, also called the “offender” because I offend the enemy when dropping precision-guided bombs on them.

Together we work backward from our target, discussing mission support assets, obtaining diplomatic clearances, air traffic, and weather. The pilot team breaks off to learn more about our aircraft, fuel, and takeoff data. George and I, as the navigation team, start planning routes, weapons needed, scheduling, and food menus. Richard looks at potential enemy threats, such as surface-to-air missiles and fighter aircraft. He also considers how to use allied aircraft to help with jamming the enemy's radar and targeting capabilities.



A B-52 refuels from a KC-135; aerial refueling gives the B-52 a distance range limited only by the endurance of its crew. (Photo: U.S. Air Force)

Chair Force

Two hours later, we come back together to share everything we've learned. We call this "chair flying" the mission. We run through the whole assignment, beginning with waking up in the morning and ending with going to sleep 24 hours later.

I am the navigator, also called the "offender" because I offend the enemy when dropping precision-guided bombs on them.

In ad-nauseam detail we discuss every possible action, reaction, situation, and emergency procedure that might occur during our mission. We speak all voice commands to make sure we understand how they sound. We scrawl notes and equations on wall-sized white boards. We pick apart every flight checklist, manipulating them until they're correct for the mission at hand.

I use latitude and longitude coordinates to hand-draw navigation air charts of our route, which leaves Andersen Air Force Base and travels northwest above the Pacific to the Japan Identification Zone, over the Sea of Japan, west into

Korea, and then back to Guam. I distribute the charts to each crew member.

These charts—and my job as the navigator—are essential because a B-52 doesn't have any type of navigation display. The computers inside the plane have significantly less processing power than an Apple iPhone 7 and show only numerical coordinates, not moving map displays. (However, the B-52's computers seem state-of-the-art compared with its lack of other amenities; this plane doesn't even have a microwave oven.)

During the chair fly, I also distribute hand-drawn weapons cards that depict the characteristics—air speeds, types, loads, etc.—of the weapons chosen for a bomb run on our selected target. Even though we're not dropping bombs on this particular mission, we still go through a no-weapons version of this scenario. Enforcing correct checklist procedures is an important part of a deterrence mission.

Our chair fly lasts nearly three hours and ends when the entire crew understands the entire mission backward and forward.

I head to the mess hall for dinner. I am not tempted by the Thai offerings or spicy Mexican burritos, both of which might haunt me during our imminent mission. I opt for the most bland item on the menu: pasta. I add a buttered roll and a



A view into the cockpit of a B-52 shows three of the plane's five crew members—the pilots and the EWO. The navigators sit downstairs. (Photo: U.S. Air Force)

side of steamed vegetables. I chug several glasses of water in an effort to get hydrated.

It's easy to confuse yellow Gatorade with an empty Gatorade bottle that's been filled up with a certain bodily fluid. No one wants to swig from the wrong bottle.

I also fill up a couple-gallon water jug to take on the plane the next morning and grab several blue Gatorades. As much as I like the lemon-ice flavor, 18 hours into a mission, it's easy to confuse yellow Gatorade with an empty Gatorade bottle that's been filled up with a certain bodily fluid. No one wants to swig from the wrong bottle.

Go time: o'dark-thirty

The crew meets at the chow hall at 4:15 a.m. before gathering in the office for a weather briefing three hours before takeoff. At the Life Support building, officers go through each crew member's personal equipment, which includes a helmet, oxygen mask, survival vest, life preserver, and jackets.

For the next 24 hours, we'll be wearing our fire-retardant flight suits, which are *not* individually temperature controlled. Right now the air on the ground at base is 85 degrees, but in a few hours, we'll be shivering inside a below-freezing cockpit. I make sure to pack a down jacket.

Before leaving the Life Support building, I use the bathroom—it's my last opportunity to use a toilet that actually flushes. On the B-52, we use the "honey bucket"—a four-inch yellow jerrican that sits on the floor, just inches from the navigator's seat. Defecation is not an option. I swallow a couple antidiarrheals.

The crew boards a Bluebird bus with no airconditioning. We throw our equipment in the first several rows, put down the windows, and take a seat for the 15-minute drive to our plane. As we move slowly—15 mph—down the taxiway, we pass by dozens of sleeping B-52s: The Memphis Belle, Destination Unknown, The Last Laugh, and others. Finally, we reach ours: The Devil's Own. I feel my heart beat faster. This is happening.

I step off the bus. Our dragon's hulking black form looms above me. Her wings, which hold more than 300,000 pounds of fuel, droop toward the ground. In her shadow, I find comfort in her decades of steadfast reliability.

The crew chief—the plane’s caretaker, whose name is stenciled on her side—informs us that the No. 5 engine is “slow to start,” the No. 2 main tank fuel gauge is “stuck,” the left multi-functional display is “not working”—but nevertheless, The Devil’s Own is the best plane in the line to fly!

If we were flying an armed mission, I would verify that all 70,000 pounds of weapons were attached correctly.

The crew breaks, and I walk around the airplane, which is as wide as a football field. I feel her presence, am inspired by her years of service, and begin going through my checklist: bomb bay (internal weapons storage) doors attached and pinned; hundreds of circuit breakers in their correct positions; wires connected; and then the most important part: checking the weapons areas.

I grab a ladder from the crew chief and climb ten feet to see where the B-52’s weapons would ordinarily be secured below her wings and in her belly. If we were flying an armed mission, I would verify that all 70,000 pounds of weapons were attached correctly and that all fusing wires were routed correctly and showing green.

But because we are on an unarmed deterrence mission, instead I check to see that the wings and bomb bay are appropriately bare and that the equipment that would ordinarily secure weapons is in its correct place.

After 30 minutes of preflight and weapons checks, I climb into the cockpit through a hatch at the bottom of the plane and am hit by a wave of stifling 120-degree air. This painted-black metal plane has been baking in the sun for hours on the concrete. The two windows near the pilots’ seats do little to ventilate the stuffy interior.

The dragon comes to life

After all five of us are situated in the two-level cockpit—three upstairs and two down—we begin the process of getting air and power into the plane. Thousands of switches, circuit breakers, levers, and pulleys must be set in their correct positions to accept a 400-hertz jolt from a generator brought up to the plane on a cart.

When the jet and the generator are connected, the fully fueled 500,000-pound plane comes alive. Dials twitch, screens flicker, fans hum, and circuits are energized. Eight turbofan jet engines sputter to life. A race against time to get the jet airborne has started, and the entire crew works toward an on-time takeoff. Checklists are yelled, switches hit, buttons mashed, and levers pulled. This is a ballet of sorts: Think of starting eight 1962 Ford Thunderbirds, 64 steam gauges, and three computers from 1983 in 40 minutes and making sure they’re in sync with one another—and five overheated aviators.

The dragon eats about 4,000 pounds of fuel just sitting and waiting to go airborne while the crew does final checks on gauges, electronics, and navigation systems. Finally,

The B-52H can carry up to 70,000 pounds of conventional and nuclear weapons, including air-launched cruise missiles armed with W80 nuclear warheads and the B61 nuclear bomb. Both the B61 and the W80 were designed by Los Alamos. (Photo: U.S. Air Force)



a message pops up in a bright green font on one of the navigator's 1960s-era 10-inch displays: GO.

Crew, we are ready to taxi.

A B-52 doesn't actually take off from the ground—it scares the ground away from it.

Slowly—at the speed of a brisk walk—we begin to move. As we roll onto the runway, the crew performs one last check: switches, circuit breakers, fuels, electronics, navigation, final buddy check. I nod to George, who is seated next to me in the lower cockpit. Like the three men upstairs, we are both buckled in and wearing fire-retardant flight suits, oxygen masks, and helmets with the visors pulled down. I am sweating profusely.

“Havoc 92,” air traffic control says into our headsets. “You are cleared for takeoff!”

We begin the manual takeoff procedure. Timing is initiated on a stopwatch to check thrust against a known standard, 64 steam gauges are evaluated, and the decision to go airborne is made.

I like to think that a B-52 doesn't actually take off from the ground—it scares the ground away from it. At a certain speed, the wings—even though they are so heavy with fuel—begin to fly. Then the fuselage unsticks, and suddenly the plane is in the air. The smooth transition of a slight nose down, tail-high climb is taking over, and the bounds of Earth are pushed away at 180 knots. The dragon is alive!

As we rise above 10,000 feet, we remove our oxygen masks because the cabin is now pressurized. The point of no return is long gone; we will be in the air until we burn enough fuel to come back down. We can't dump fuel like other jets, and we can't land if The Devil's Own weighs more than 290,000 pounds (because our brakes and parachutes can't bring that much weight to a stop). We are airborne for the next 24 hours. The fun is just starting.

We level off at 35,000 feet, all systems in the green, with checks ongoing. Now is the time to relax a bit—which is easier said than done now that everything we're wearing has been soaked through with sweat, the outside temperature has dropped to minus-50 degrees, and we are freezing inside the plane.

“Give me a shot of heat,” I yell into my headset, and the pilots let in a blast of scorching exhaust off the engines, which is the only way to “regulate” the plane's internal temperature.

Somewhere over the Pacific

The B-52 is loud—like a 1976 AC/DC concert front-row-by-the-speakers loud. Normal cruise noise is about 140 decibels, so we wear earplugs and silencers with a helmet or headset



This custom uniform patch was designed by Instructor Radar Navigator Kerry Baker (93d Bomb Squadron at Barksdale Air Force Base) and depicts Miller Time—the point in a B-52 mission when the crew is headed home. (Photo: bomberpatches.com)

at all times to be able to communicate. Five crew members, three radios, and air traffic control are talking nonstop.

“System check,” the copilot yells at the top of the hour. We take a quick inventory of the plane's systems. Defense says they are good. Offense has a problem.

“Pilot, this is the navigator, we have a situation,” I say. “There are 39 bombs on this jet.”

The crew is silent.

Then I hear, “No s—, navigator, we are a bomber!” crackle through my earpiece, and the jokes start to fly.

I am in an ancient plane, hurtling in the heavens with less than an eighth-inch-thick sheet of aluminum between myself and certain demise.

The dragon is now moving at 400 mph into the wind. The B-52's ancient computer cannot calculate distances from one geographic latitude and longitude point to another, so I perform distance and time calculations every couple minutes using a 1953 E-6B flight computer (essentially a slide rule).

Using my brain like this—trying to be “in front” of the jet at all times—is what I like best about this job. I'm a frontiersman, in a sense. I can make my way without modern equipment. Sure, the B-52 could be updated with fancy new computers, but if the old system ain't broke, why fix it? Plus, it



A B-52 Stratofortress leads a formation of aircraft during a refueling exercise. The tanker's boom is extended toward the B-52. (Photo: U.S. Air Force)

costs an arm and a leg to nuclear-certify new technology, and nobody in Washington wants to pay for that.

But then again, every large bump, weird noise, and bad smell are reminders that I am in an ancient plane, hurtling in the heavens with less than an eighth-inch-thick sheet of aluminum between myself and certain demise. I think of a paper clip bending back and forth, only so many times before...

Snap!

Back to reality. I am hungry! I yell at the EWO to start the toaster oven, a tiny hotbox with one temperature: about a billion degrees. We throw in frozen pizza bites that come out completely charred but are still popsicles on the inside. My favorite!

To refuel a B-52, another plane joins us at a predetermined rendezvous point in the air.

As the mission continues, so do problems and emergencies: Pilot, the No. 5 engine oil pressure is low; we need to shut it down to save the engine. Navigator, one of the internal

navigation systems is running away and is now 20 miles off location. EWO, your cooling system is down, and your ectoplasmic *Ghostbusters* goo is leaking on my boots.

Emergency checklists start to make the flight interesting. What are go or no-go criteria to finish the mission? In this case, go is six engines, two good navigation systems, and five electronic detectors. We continue on.

Water, land, and more water continually pass below the dragon as she lumbers through the air. About 10 hours into the flight, we hear: "Havoc 92, this is Gasser 11. We are on time and ready to give you some fuel."

To refuel a B-52, another plane—in this case, a 1959 KC-135 tanker from Okinawa, Japan—must join us at a predetermined rendezvous point in the air. We slow down to our refueling speed of 450 mph. No computers control this meeting: eyes, ears, and hands move these two planes to within 12 feet of each other. Above us, the tanker's boom (rigid hose) is extended, and the dance starts.

The dragon is guzzling 22,000 pounds of gas an hour; we need to receive 120,000 pounds from this tanker to make our next refueling point. After making contact via a receptacle in the top of our plane, we receive gas at 5,000 pounds a minute.

DECLASSIFIED

Fewer than 25 minutes later, we hear “Havoc 92, you have received 121,000 pounds of gas!”

“Have a great day,” continues the KC-135 pilot. “Gasser 11 out.”

Approaching the target

Every country has an air identification zone that begins 12 nautical miles off its landmass. Planes entering an ID zone are interrogated so that the country knows who is in its airspace. As we approach South Korea, we hear: “Havoc 92, this is Korean Defense Identification Zone. Turn right heading 350 [degrees] until you intercept your friends.”

These friends are allied F-16 fighter jets that have taken off from South Korea and will fly beside us as we approach North Korea.

B-52s are the watchdogs. Every day, we are in the air, defending our country.

“Roger, Havoc 92 is searching for friendlies,” Jane says.

“Pilot, I have something off our nose at 12 miles,” the EWO says. “I have visual on a flight of four F-16s forming on us, two off each wing.”

“Falcon 31, it is good to see you,” Jane says to one F-16 crew.

“Roger Havoc, we picked you up 50 miles ago by your contrails,” says the F-16 pilot, referencing the B-52’s four distinct white contrails streaking across the sky.

Flying in formation with the fighters is easy. They fly off our wings as we head north to the DMZ. It’s time to cast a shadow on our Northern “friends.”

Knocking on North Korea’s door

Although we are unarmed, as far as North Korea is concerned, we have a plane full of nuclear weapons. As we approach the 38th parallel, [REDACTED]

[REDACTED]
[REDACTED] the dragon, [REDACTED]
[REDACTED] North Koreans
[REDACTED]

Night’s Watch

The eight-hour flight back to Guam—or Miller Time, as we call it—is lower stress, but nothing compares with unstrapping from the jet and stepping onto the tarmac.

We have two days before leaving on our next mission. The first day is spent catching up on paperwork, computer training, and performance reports. The second day, we’re back in the office, mission planning and chair flying again.

If I have the energy, I will stay up late to call my parents in Florida (I’m deployed to Guam for six months, so visiting them is out of the question). The 14-hour time difference can make staying in touch difficult, but I am always thankful to hear their voices.

My [REDACTED]-year-old mother would never sleep if she knew that I fly a plane her same age to North Korea twice a week. I’m glad her understanding of the B-52 deterrence mission is vague.

But what gets under my skin is our government’s lack of understanding. People think “Air Force,” and they think of shiny fighter planes and Memorial Day air shows. B-52s are old and uninteresting in comparison. But B-52s are the watchdogs. Everyday, we are in the air, defending our country against enemies who want to destroy us. We are the faceless defenders of a mission that nobody in Washington wants to talk about because “nuclear” is considered a four-letter word.

We’re like the Night’s Watch in the *Game of Thrones* series—we are holding the enemy “behind the wall” through our deterrence missions. We are always present but rarely appreciated.

Winter is coming, and we are a necessity. ✦

~Whitney J. Spivey

* Classification markings/redactions are fictitious.

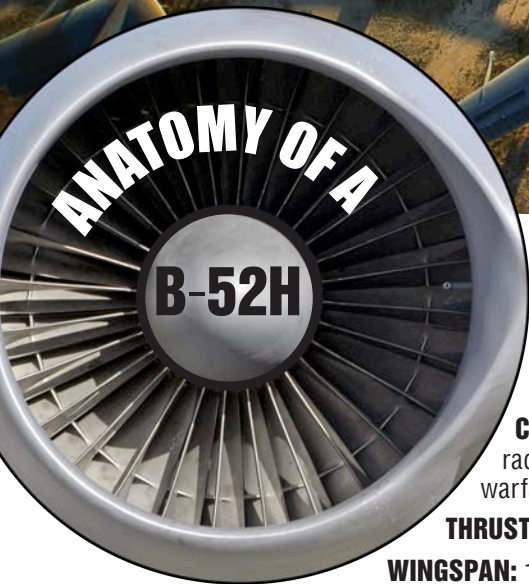
Navigating Los Alamos

This article was written largely from the perspective of Major Brad Haynes, who has served in the Air Force for 13 years and has 2,000 hours of flight time. Maj. Haynes came to Los Alamos National Laboratory in July 2015 on a one-year Air Force Fellowship, which is considered part of his professional military education. “Understanding that there are literally tens of thousands of people behind me when I set foot on that jet,” is Maj. Haynes’s biggest takeaway from his time at the Lab. “There are scientists, engineers, and machinists who are stewarding nuclear weapons for me to use with 100 percent confidence.”



THE DRAGON IS ALIVE

Stratofortress Statistics



Old military aircraft, such as these B-52 bombers, are stationed indefinitely at the "graveyard" at Davis-Monthan Air Force Base near Tucson, Arizona. (Photo: Getty Images)

CONTRACTOR: Boeing Military Airplane Company

DEPLOYED: 1962

CREW: Five (aircraft commander, pilot, radar navigator, navigator, and electronic warfare officer)

THRUST: up to 17,000 pounds per engine

WINGSPAN: 185 feet

HEIGHT: 40 feet, 8 inches **LENGTH:** 159 feet, 4 inches

CEILING: 50,000 feet **RANGE:** 8,800 miles **SPEED:** 650 mph (Mach 0.84)

EMPTY WEIGHT: approximately 185,000 pounds

ARMAMENT: approximately 70,000 pounds mixed ordnance: bombs, mines, and missiles, including nuclear-armed cruise missiles

INVENTORY: active force, 58; reserve, 18

Introduced in 1954, the B-52 Stratofortress is the backbone of the U.S. strategic bomber force. With proper maintenance and upgrades, the B-52 is expected to remain in service until 2040. No other U.S. bomber has been called on to remain operational for more than 70 years.

The B-52 is a long-range heavy bomber that flies at subsonic speeds at altitudes up to 50,000 feet or as low as 50 feet. Fully fueled, the plane has a range of 8,800 miles; with aerial refueling, the B-52's range is limited only by the endurance of its crew.

The B-52 can strike any target on Earth with air-launched cruise missiles armed with Los Alamos-designed W80 nuclear warheads. During a non-nuclear mission, the B-52 carries a large number and wide array of conventional weapons. No other U.S. weapon system offers the flexibility and versatility of the B-52. ✨

THE DRAGON IS ALIVE

B61 Life Extension Program Advances

More than a half-century after its creation, the nation's oldest nuclear warhead is one step closer to a new life.

One of the many weapons that can be carried by the B-52—and some fighter jets—is the nuclear-armed B61 gravity bomb, which can be dropped at high speeds from as low as 50 feet. The warhead can be dropped free-fall or deployed (and slowed down) with a parachute. The B61 can be detonated in the air or on the ground.

Los Alamos designed and engineered the B61 in 1963. Most B61s were produced in the 1970s, and production ended about 20 years later. The B61, which initially had a life expectancy of 10 years, is the oldest type of nuclear weapon in the stockpile. Over the years it has been modified many times to meet changing military requirements.

Currently, the B61 is undergoing a life extension program (LEP) at Los Alamos (in partnership with other organizations in the weapons complex) to convert four earlier versions of the warhead (models B61-3, -4, -7, and -10) into a single modification: the B61-12. The LEP will ensure that the weapon remains safe, secure, and reliable by refurbishing key components through a combination of reuse, redesign, and remanufacturing. The LEP will also add a tail kit that will improve the B61's accuracy.

On August 1, the National Nuclear Security Administration (NNSA) announced that it authorized the production-engineering phase of the B61-12 LEP. This achievement—marking the final phase before production—comes after four years of work in the development-engineering phase of the program. The first production unit of the B61-12 is planned for 2020, followed by full-scale production.

“Reaching this next phase of the B61-12 LEP is a major achievement for NNSA and the exceptionally talented scientists and engineers whose work underpins this vital national security mission,” says NNSA Administrator Lt. Gen. Frank G. Klotz. “Currently, the B61 contains the oldest components in the U.S. arsenal. This LEP will add at least an additional 20 years to the life of the system.”

Which means that the B61-12 will remain a crucial part of the stockpile until 2040—and likely far beyond.

“These are major milestones for the program,” says Patti Buntain, B61 Life Extension Program Manager at Los Alamos, “and I would like to thank the Laboratory's B61 team for making it a success. We have been working for the last four years to ensure that we deliver a safe, reliable product to the U.S. Air Force.” ✦



The B61 LEP refurbishes both nuclear and non-nuclear components to extend the bomb's service life while ensuring it remains safe, secure, and reliable.
(Photo: Sandia National Laboratories)



Sailors aboard the USS Ronald Reagan scrub the aircraft carrier's flight deck to remove potential radiation contamination from the Fukushima Daiichi nuclear power plant meltdown. The Ronald Reagan provided humanitarian assistance to Japan following the March 2011 earthquake and tsunami. (Photo: U.S. Navy)

FIXING FUKUSHIMA

Los Alamos's muon vision to the rescue.

On the afternoon of March 11, 2011, a 9.0-magnitude earthquake occurred off Japan's northeast coast. About 50 minutes after the quake, a 45-foot-high tsunami slammed into the Japanese coastline. More than 18,000 people were killed, 300,000 were evacuated, and entire communities were destroyed.

And as if two natural disasters in less than an hour weren't devastating enough, the quake initiated the meltdown of three reactors at the Fukushima Daiichi nuclear power plant. A plan for locating and removing the melted fuel is just now coming to fruition—thanks to a technology developed by Los Alamos scientists.



Japan's Fukushima Daiichi nuclear power plant before the March 2011 earthquake and tsunami. (Photo: TEPCO)



These photos showing the extensive damage at Fukushima were taken less than a week after the tsunami of March 11, 2011. Left: Conditions around Reactors 5 and 6. Right: The Reactor 3 building after an explosion blew off its upper floors. The explosion was triggered by the ignition of hydrogen gas created by reactor fuel overheating. Reactor buildings 1 and 4 suffered similar explosions in the days immediately following the tsunami. (Photos: TEPCO)

The quake initiated Fukushima's automatic reactor shutdown. It also cut off the reactor complex from the electric power grid. However, the tsunami that followed overwhelmed the 30-foot-high seawall that Japanese experts believed would protect Fukushima, swamped the lower floors of the reactor buildings with 15 feet of water, and permanently knocked out the reactors' emergency electric generators—and with them, their cooling-water circulation pumps. The reactors' cores containing hot nuclear fuel lost critical cooling and some (perhaps all) of the fuel became so hot it melted. Life-threatening radiation was released.

Now, more than five years later, radiation levels inside the buildings that contained the melted fuel are still lethal. The deadly fuel must be removed, but key questions still need definitive answers. Before the process of fuel removal can begin, the exact status of the fuel must be known. How much has melted? Where is it? The Japanese government, nuclear engineers, and plant operators will not have the answers until they can see inside the reactors. Yet without technology that allows them to proceed safely, the Japanese cannot begin the process.

Before the process of fuel removal can begin, the exact status of the fuel must be known.

Muon vision

That's where Los Alamos National Laboratory comes in. Los Alamos scientists have created a new type of penetrating "vision" that can detect nuclear materials, such as uranium and plutonium, hidden inside very thick layers of concrete and steel. This so-called muon vision (see "What is Muon Vision?" page 39) uses cosmic ray muons, which are always present and which, unlike x-rays, are harmless to humans.

Muon vision has already been commercialized. Los Alamos and California-based Decision Sciences International Corporation (DSIC) have worked together to create a unique
(continued on page 40)

100 muons
per second per square yard
rain down from the cosmos.

Fe
Iron

Pb
Lead

U
Uranium

Muons hit heavy metals,

scattering at angles specific to those metals.

Detector #1

Cargo passes
between
a pair of muon detectors.

Detector #2

16 million
cargo containers
cross U.S. borders every year.

Is nuclear contraband
hidden in this truck?

?

What Is Muon Vision?

Muons are subatomic particles created when very high-energy cosmic-ray particles from outer space collide with atomic nuclei in the upper layers of the Earth's atmosphere. Once created, muons travel at nearly the speed of light and rain down on the Earth's surface from random locations and in random directions; every second, 100 muons hit each square yard of the Earth's surface. Their tremendous energy enables them to penetrate most objects and even travel hundreds of feet into the Earth's crust. Yet, muons compose fewer than 10 percent of all background radiation and are harmless to people.

Muons continuously scatter as they move through material; they scatter more in very heavy materials than in lighter materials. Uranium and plutonium, which are heavy, cause the largest scattering angles, albeit no more than a few degrees. Lighter elements, such as iron, cause smaller angles, and even-lighter elements, such as oxygen, cause little or no scattering. So, measuring the scattering angle reveals the identity of the material that caused the scattering. Just as important, the angle also reveals the location of the material. In that way, muons can be used to "see" materials deep inside closed containers . . . or inside damaged reactors.

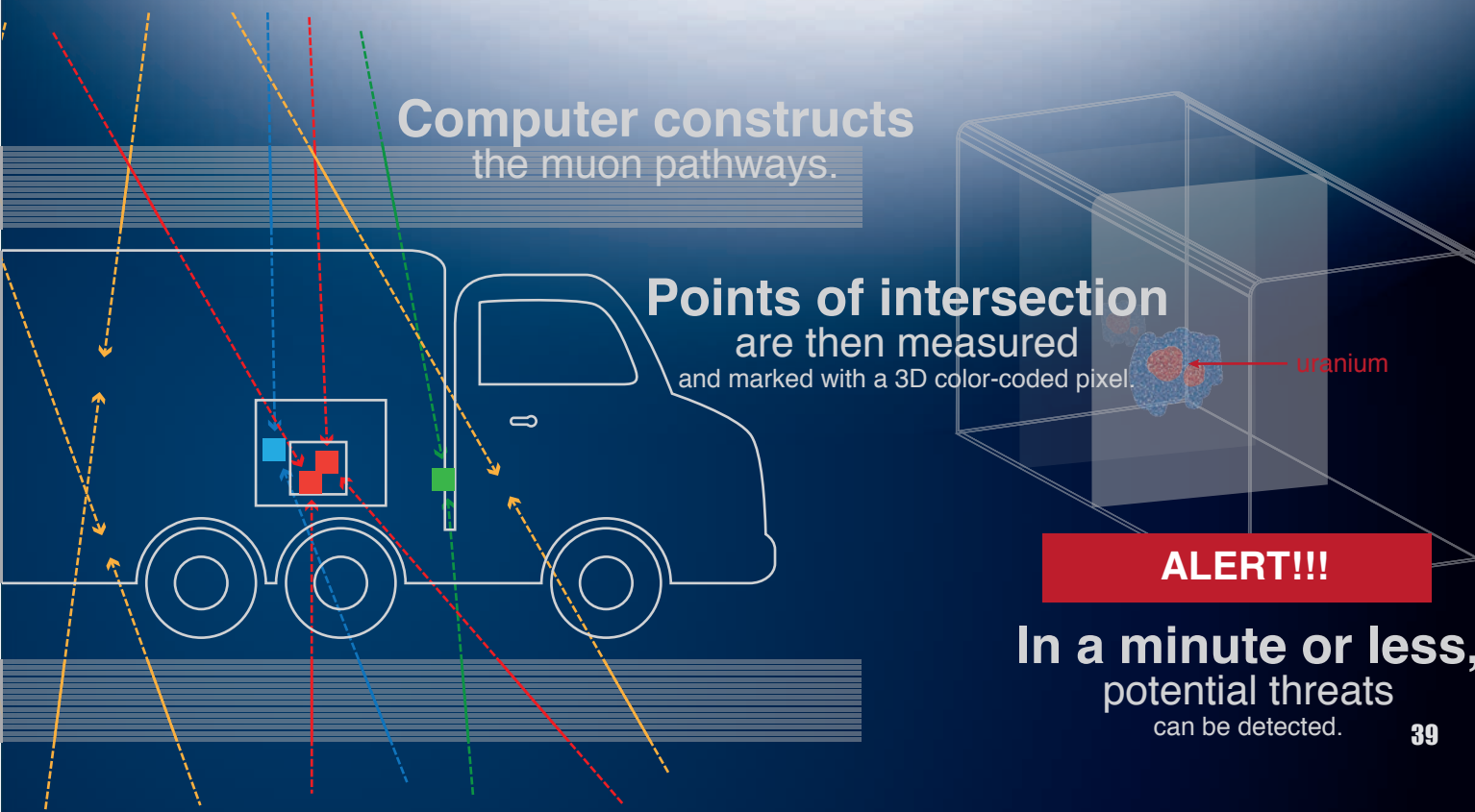
Los Alamos's unique muon vision measures muon scattering and "sees" materials otherwise hidden from

view. To interrogate the inside of a shipping container, Decision Sciences International Corporation (DSIC) has commercialized muon vision. DSIC uses two specially designed detectors placed above and below the container. The system records a muon's path through the top detector (before it enters the container) and then measures its path through the bottom detector (after it exits the container).

Highly sophisticated software then traces the entry and exit paths back to where they meet inside the container—the point of intersection is the location of a material. If the lines meet at a very slight angle, the muon struck a lighter element. If the lines meet at a larger angle, the muon struck a heavy material.

By detecting enough scattered muons, the computer software can also identify the shape of the heavy material—a particularly important feature if a material has melted. The software can even translate the data into a real-time, 3D digital image, color-coded to indicate different heavy materials. As shown in the infographic below, a lead box can be differentiated from smuggled uranium within it and from the sacks of cement that surround it inside a shipping container. ✦

~Necia Grant Cooper

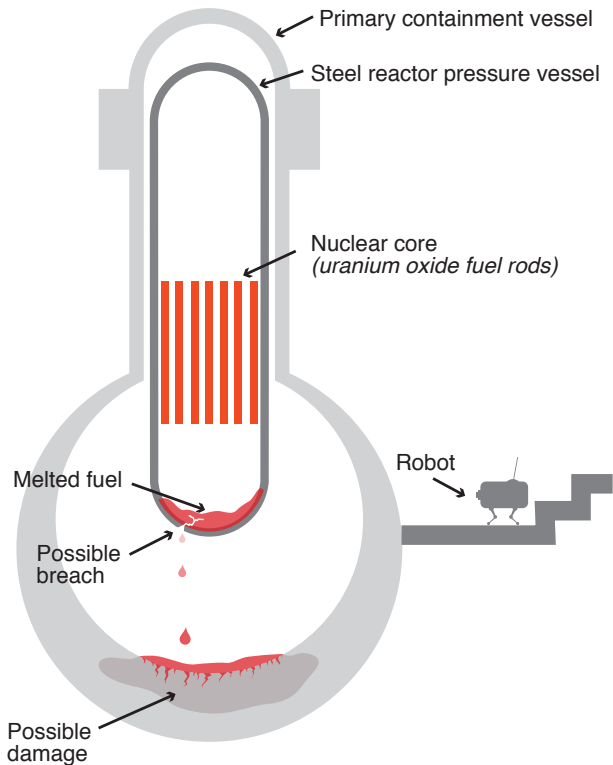


Computer constructs the muon pathways.

Points of intersection are then measured and marked with a 3D color-coded pixel.

ALERT!!!

In a minute or less,
potential threats
can be detected.

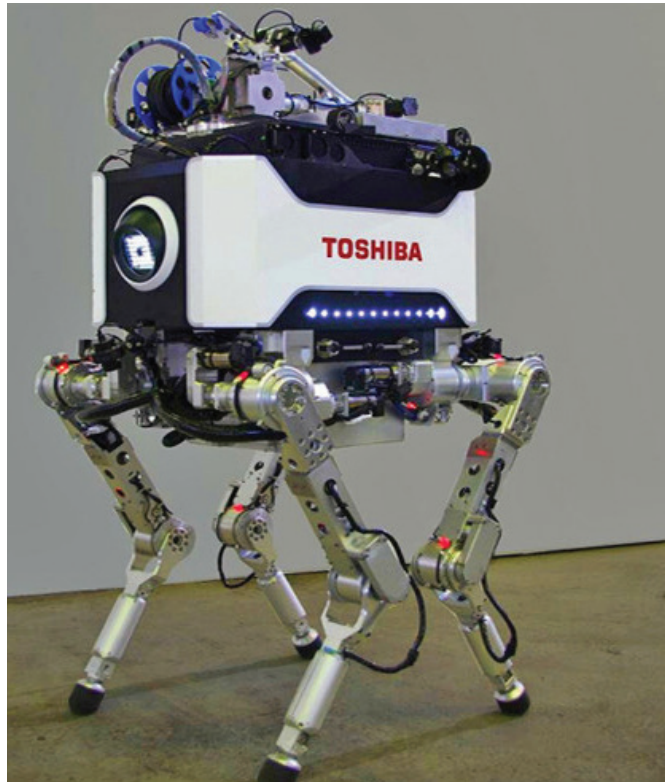


After melting—partially or completely—did nuclear fuel (red) sink to the bottom of the steel pressure vessel and cool? Or did it melt through the steel pressure vessel onto the floor of the reactor’s primary containment vessel (PCV)? Or possibly even eat into the PCV’s very thick concrete base? Once muon vision locates the fuel, robots could enter to assess the cleanup challenges ahead.

muon vision system to scan cargo containers and trucks at ports and border crossings for concealed uranium and plutonium (see “Muon Vision for U.S. National Security,” page 46). Now Los Alamos and DSIC are partnering with Tokyo-based Toshiba Power Systems Company to use muon vision to safely investigate the Fukushima reactors. If the technology works on this large-scale application—and muon vision inventor Chris Morris, a physicist at the Los Alamos Neutron Science Center, believes it will—muon vision could reduce the time it takes the Japanese to clean up the site by 10 years.

The core of the problem

The cleanup efforts are daunting. Tokyo Electric Power Company (TEPCO), which operates the plant, expects the work to take 30 to 40 years without using muon vision and cost at least \$8 billion. (In comparison, cleanup of the much smaller accident at Pennsylvania’s Three Mile Island in 1979 cost \$1 billion and lasted 14 years.) If the exact locations of the fuel can be learned, not only a decade but possibly billions of dollars might be saved. But first, specific questions must be answered: What fraction of the fuel rods is still intact



Toshiba has developed a unique tetrapod robot able to carry out investigative and recovery work inside the damaged reactor buildings at Fukushima—locations too dangerous for people to enter. The remote-controlled robot integrates cameras and a dosimeter (radiation monitor) to investigate the conditions inside the reactors. The multiple joints of its legs enable the robot to walk on uneven surfaces, avoid obstacles, and climb stairs to access areas that wheeled or tracked robots cannot. (Photo: Toshiba)

in the pressure vessels? Has any fuel melted to the bottom of a pressure vessel? Has a pressure vessel been breached, and has fuel reached the bottom of the surrounding containment vessel?

The fuel in Reactor 1 likely melted through the pressure vessel to the bottom of the containment vessel.

Currently, experts suspect that all the fuel in Reactor 1 melted, burned its way through the pressure vessel, and now sits at the bottom of the containment vessel, possibly eating into the concrete base. (See illustration.) The fuel in Reactors 2 and 3 might be distributed between their cores and the pressure and containment vessels.

But the trouble is that the location of the fuel is not really known. Each possible scenario would require a different cleanup strategy. Fuel rods that are intact might be pulled out and removed using one strategy. If fuel rods have melted but are still inside the pressure vessel, another strategy might be to remove the entire vessel. Fuel that has melted

through the pressure vessel will require some other removal strategy. A breached containment vessel will require still another strategy. None of these cleanup scenarios are easy or inexpensive because each is a unique engineering project of monumental proportions. Because of all the wreckage and the radiation danger, the Japanese must design, test, and build specialized tools, equipment, and even robots to do the cleanup work.

But before they can develop safe, cost-effective, realistic cleanup plans with definite goals and produce the tools they will need to do the work, they need to see inside the reactors so they can pinpoint exactly where the fuel is.

Because of all the wreckage and radiation, robots will be designed and built to do the cleanup work.

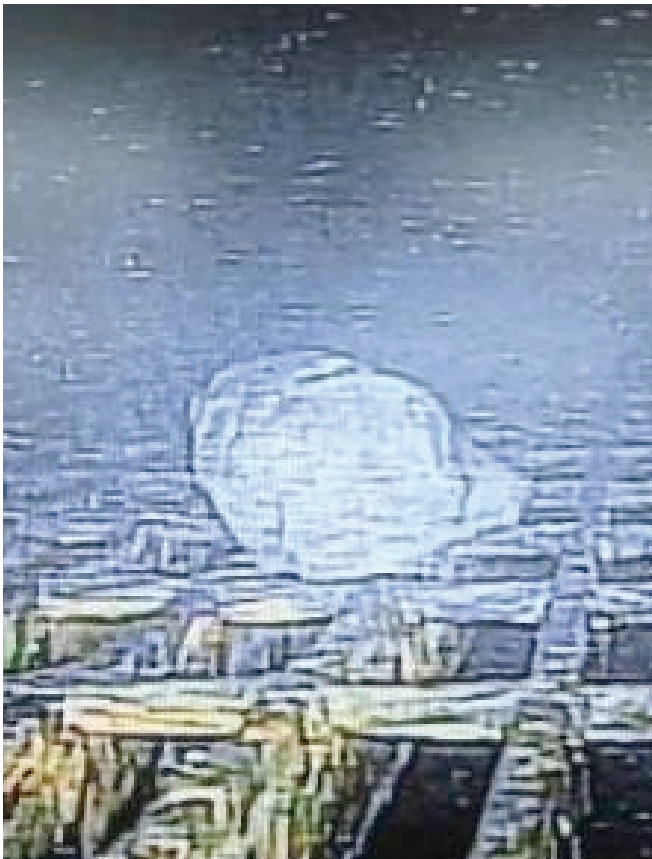
Toshiba and the International Research Institute for Nuclear Decommissioning announced in June 2015 that they had developed a small motorized robot to investigate the primary containment vessel in Reactor 2. The robot will look

along access routes for debris and fallen objects that might interfere with investigating the area. But the robot won't explore the reactor's core because Morris feels confident that the Laboratory's technology can provide that clear interior view. "Muon vision should allow experts to see, in three dimensions, how much of the nuclear material lies in what part of the reactors," Morris says. "Muon vision ought to give them the answers they so desperately need."

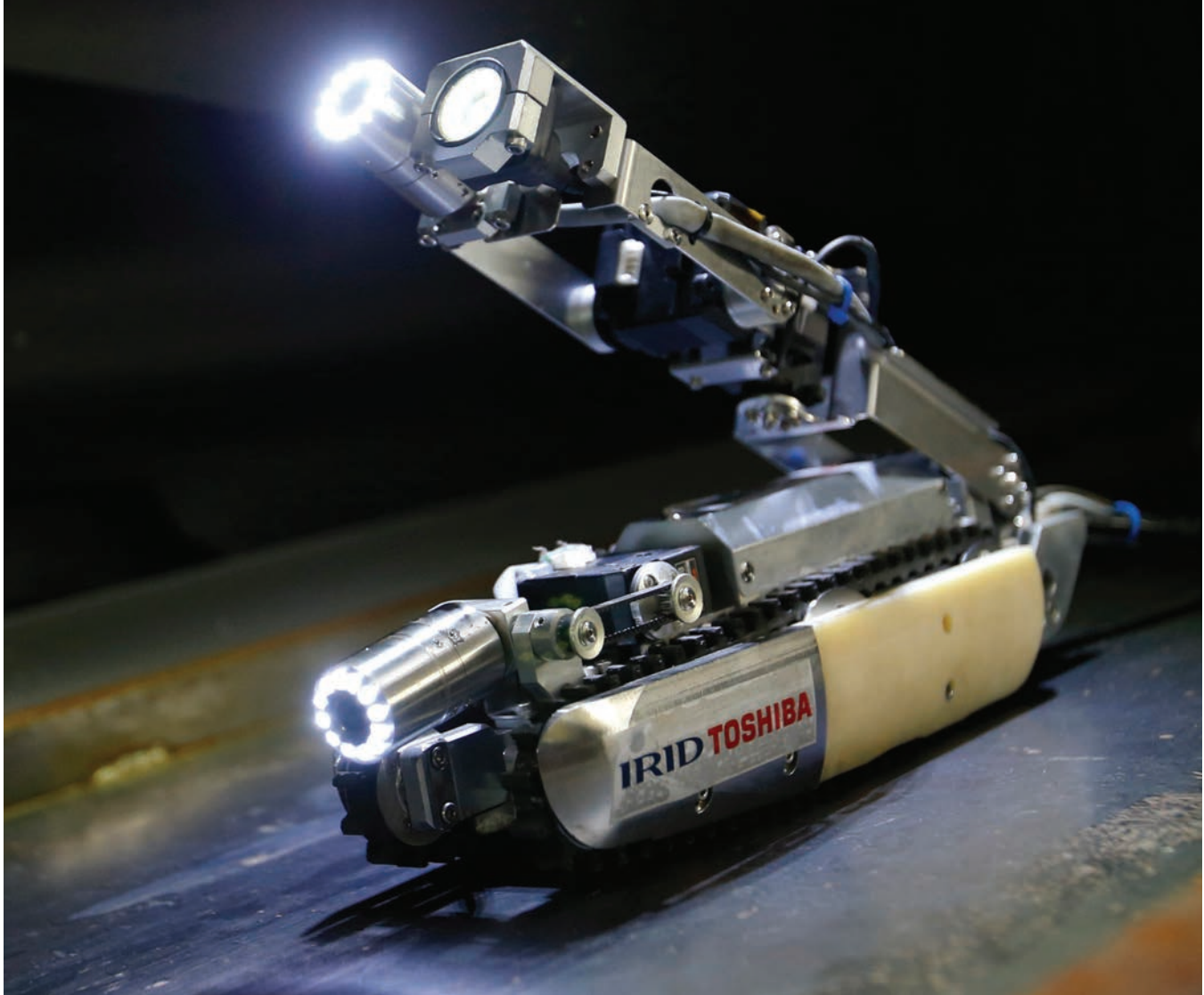
Seeing is believing

In the first days after the disaster, Morris and his team began considering muon vision's utility for Fukushima. Their rough computer simulations suggested that some muons were penetrating the hundreds of tons of concrete, steel, and nuclear fuel inside the crippled Fukushima reactors, but could those simulations be trusted?

To locate, identify, and determine the shape of nuclear materials, such as melted uranium fuel, inside a destroyed reactor, theoretically one has only to design a muon detection system large enough to see inside a reactor. Scaling up to reactor size, however, puts new requirements on the muon vision system. For instance, for a cargo container, the presence of nuclear materials can be ruled out in less than a



In April 2015, a small robot filmed the first images inside the PCV of Fukushima Reactor 1. Shown here are some of the debris it encountered inside the vessel. TEPCO reports that the robot recorded radiation levels of between 5 and 10 sieverts per hour (a tenth of what was expected) in some areas but levels as high as 25 sieverts per hour in others. A person receiving four sieverts in about one hour is at risk for death. (Photo: TEPCO)



Toshiba has developed the “scorpion” robot that raises its tail like a scorpion and collects data inside the primary containment vessel. The machine will help confirm whether robots can successfully navigate around debris. The robot, which is 21 inches long when extended, has two cameras, LED lighting, and a dosimeter. (AP Photo/Shizuo Kambayashi)

minute if there isn't significant scattering. If the scan reveals something heavy (such as uranium), a longer scan—enough to record many more muons—is needed to reveal the identity, location, and shape of the material.

The experiment proved that muon vision should work at Fukushima.

Morris and the team predicted that finding the fuel inside the Fukushima reactors would require the muon vision detectors to be in place for weeks or even months, recording as many muons as possible for a precise-enough reading to reveal the location and shape of the fuel. In theory, that approach should work, but Morris needed experimental confirmation. So his muon vision team constructed a simplified mock-up of a Fukushima-like reactor, substituting lead bricks for the uranium fuel. They offset the lead inside the reactor mock-up to represent the fuel having melted and moved, leaving an empty space.

The team realized, however, that the detectors could not be positioned as they normally are for interrogating cargo: above and below a container or truck to take advantage of the vertical path taken by most muons. (Trucks are simply driven through a structure whose floor and roof are muon detectors.) Such an arrangement would be impossible at Fukushima because a detector cannot be placed below a reactor. So the team arranged the detectors on either side of the reactor mock-up to record muons that were coming through it horizontally. Because fewer muons move horizontally—one-tenth the number that move vertically—the team ran the experiment nonstop for three weeks to get enough data, recording 100,000 muon tracks by the experiment's end.

Sure enough, the experiment produced a color 3D image of the lead and revealed the empty space left by the offset lead bricks. The experiment proved that muon vision should work at Fukushima.

Some engineers worried that there would not be enough horizontally scattered muons traveling through the reactors

to make an image. They thought that the site's extremely high level of gamma-ray radiation (a result of the accident) would also be recorded by the detectors and overwhelm the detectors' ability to record the muons.

It would be a full hands-on, “no-smoke-and-mirrors” demonstration.

The Los Alamos team went to Fukushima to find out whether a scaled-down muon detector would distinguish muons from the massive amounts of gamma-ray radiation. It did.

“The detector wasn’t swamped by the gamma radiation at the site,” Morris recalls. “It could still detect individual muons, in spite of being in that environment.”

A big surprise

Toshiba became interested in pursuing Los Alamos’s proposal. The Los Alamos team was invited to conduct a real-life test using real nuclear fuel on a real reactor—Toshiba’s own research reactor. It would be a full hands-on, “no-smoke-and-mirrors” demonstration.

The Los Alamos team helped Toshiba arrange the muon vision system’s two detectors on either side of the Toshiba reactor to record horizontally moving muons. Then, unbeknownst to the team, Toshiba’s engineers installed two extra fuel assemblies. They also added blocks of steel and concrete outside the main fuel assembly’s surrounding water vessel.

Toshiba wanted to blindly test muon vision’s ability to see the reactor’s fuel where it was not expected to be as well as through intervening walls and debris. Why? Because, if used at the devastated Fukushima site, the detectors could not be placed inside any of the reactor buildings. They would have to be outside but still be able to locate the fuel wherever it was on the inside.

“That’s when we got the really big surprise: The extra fuel assemblies popped up in our images.” ~Chris Morris

Trusting that the test was set up properly, the Los Alamos team returned to the United States and left Toshiba’s engineers to run the experiment. The Japanese collected data for a month before sending the results to Los Alamos for analysis. Los Alamos software constructed the muon tracks from the data, found the locations of scattered tracks, measured the scattering angles, and plotted the images.

“And that’s when we got the really big surprise: The extra fuel assemblies and blocks of steel and concrete blocks popped up in our images,” Morris says. “We sent the images to Japan

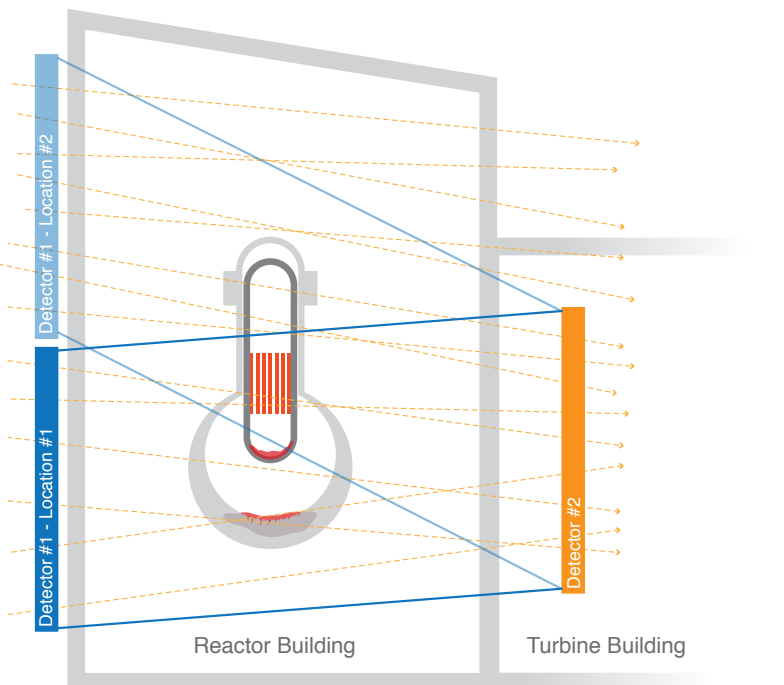
for review, and the once-doubtful Toshiba engineers were suitably impressed. Their extra components, meant to test our technique, were clearly visible in all the right places.”

Muon vision in progress at Fukushima

A Japanese national project started in 2014 aimed at developing two muon detection systems that can be installed at Fukushima. Toshiba developed electronics that enabled operation of the muon detectors in the high-radiation environment and bought detector components from DSIC, and the Los Alamos team developed the algorithms needed to image the reactor. The designs of the electronics and firmware, and all the imaging work, will result from the collaboration between Los Alamos and Toshiba. The partners are working to design and build the two giant (24-foot-by-24-foot) muon detectors destined to scan Fukushima’s Reactor 2.

“The Japanese are not going to let anything fall through the cracks.” ~Chris Morris

When the detectors are ready, Morris’s team will go to Fukushima to help install them, debug the electronics, and test the signals. Los Alamos and DSIC will also provide software, system testing, and data analysis. The Japanese team



Muon vision will locate nuclear fuel using two giant muon detectors placed on opposite sides of the reactor buildings: one outside (blue) and the other inside the adjoining reactor’s turbine building (orange). By changing the outside detector’s position, researchers can determine how much fuel is in the lower portions of the pressure vessel and the containment vessel and how much of the reactor core might still be intact.



These 24-feet-by-24-feet muon detectors (one above and one behind the man addressing the crowd) will be used at the Fukushima Daiichi nuclear power plant to locate nuclear-fuel debris inside the plant's destroyed nuclear reactors. Los Alamos developed muon vision technology. (Photo: Kyodo via AP Images)

will execute the actual measurements at Reactor 2. To get the best-possible image, data will be collected for at least six months.

A vice president of Toshiba Corporation Energy Systems & Solutions Company speaks highly of the project. "All of us at Toshiba are pleased to have worked with [Los Alamos] on development of this technology," he says. "We are confident that it will prove to be a useful tool for analyzing the interior of the [reactor pressure vessel]."

Morris agrees. "The Japanese are not going to let anything fall through the cracks," he says. "We have met with them every week since last summer, testing, refining, and perfecting to make sure this works."

Using muon vision, they hope to locate the fuel in Reactor 2 before 2018. The appropriate robots and other equipment needed for the cleanup should be ready by 2020.

How important is the cleanup?

The plan is to recover as much radioactive material as possible and reclaim the land. At stake are Japan's reputation, its public health, and the health of its environment.

Also at risk is the future of Japan's nuclear industry. Before the Fukushima disaster, nuclear energy provided 30 percent of Japan's electricity, making nuclear energy a mainstay of the country's economy. After the accident, public concern about nuclear-power safety in a country prone to earthquakes led to the shutdown of the country's 48 remaining nuclear reactors.

Since the disaster, electric energy shortages have brought hardships and slowed Japan's economic output. In addition, the cost of producing electricity has increased by 20 percent. The Japanese government estimates that its power companies paid \$29.6 billion more in fuel costs in 2013 than in 2010,

the year before the Fukushima disaster. The main reason for the increase is Japan's greater need for imported fossil fuels to generate electric power. Japan was already importing 84 percent of its energy before the disaster.

The country's greater reliance on imported fuel has increased Japan's concerns about its energy security and its national security, so the Japanese are considering restarting some of the 48 nuclear power plants they closed. The government, TEPCO, and the Japanese nuclear industry hope the full cleanup of Fukushima will help rebuild public acceptance of nuclear power.

“The arc of Los Alamos’s history with Japan is truly awesome.” ~Chris Morris

“The work required for this cleanup project is complex and dangerous, and muon vision may be important to its success,” Morris says. “We’ll be helping to solve one of the biggest environmental cleanup problems in the world.”

“And you know what else is amazing?” he continues. “It was Los Alamos that ushered in the nuclear age. Since then, the Japanese have embraced nuclear technology as being fundamental to their energy and national security. That security is threatened by the Fukushima disaster, and now the Laboratory is going to help them dig out from under it. The arc of Los Alamos’s history with Japan is truly awesome.” ✦

~Necia Grant Cooper



The Los Alamos Muon Radiography team visited the damaged Fukushima Daiichi reactor complex to evaluate whether Los Alamos's scattering method for cosmic-ray radiography could be used to image the location of nuclear materials within the reactor buildings. (Photo: Los Alamos)

Muon Vision for U.S. National Security



Muon vision could help ensure that shipping containers do not contain dangerous radioactive materials or other contraband. (Photo: DSIC)

Every year, more than 16 million vehicles and shipping containers enter the United States through its ports of entry. Suppose a nuclear bomb, a dirty bomb, or enough radioactive material to make a bomb is hidden in one them—how do we prevent nuclear terrorism?

Scientists at Los Alamos have responded to what President Barack Obama calls “the single biggest threat to national security” by proposing a new technology—muon vision—that is specifically designed to detect nuclear materials hidden inside vehicles and containers (see “What is Muon Vision?” page 39). In 2006, Los Alamos partnered with Decision Sciences International Corporation (DSIC) and granted DSIC an exclusive contract to develop and commercialize the Lab’s muon vision system.

Currently, passive radiation monitors, much like giant Geiger counters, are the main screening tools looking for nuclear contraband. These monitors detect the gamma-ray and neutron radiation given off by uranium, plutonium, or other nuclear materials.

However, not all ports have these monitors, and those that do can experience false positives from unexpected sources. For example, crates of bananas or sacks of water-softening

chemicals can set off these monitors because both contain trace amounts of potassium-40, a radioactive isotope of potassium. The glazes of certain ceramics contain radioactive uranium isotopes that also set off the monitors. Tracking down those false positives wastes valuable time and resources.

Furthermore, these radiation monitors are not capable of finding radioactive materials that are shielded—for example, hidden inside lead containers. The walls of a thick lead box, for instance, will stop (absorb) uranium’s gamma rays before they escape, thereby removing the telltale radiation signal that the current radiation monitors need for effective detection. A 50-pound “cube of terror” (about the size of a half-loaf of bread) of highly enriched uranium, which is enough to make a nuclear weapon, can pass through a port without detection.

One defense is to use a very powerful x-ray machine, which would definitely “see” the lead box but could not look inside or identify the contents as nuclear material. In addition, powerful x-ray machines are massive and need lots of electrical power, which means they are very expensive to build and operate. The high voltage and lethal x-rays these machines produce also make them dangerous for

port-of-entry security staff to operate. And what if an interrogated truck is smuggling human cargo?

Muon vision offers a different approach that is potentially less expensive to build and operate and uses no dangerous radiation. DSIC's Multi-Mode Passive Detection System (MMPDS), which has been operating in Freeport, Bahamas, since 2012, safely scans cargo containers, often in about a minute or less.

In April 2015, the Department of Homeland Security's Domestic Nuclear Detection Office successfully completed the final testing phase of its five-part system characterization of the MMPDS at Freeport, bringing muon vision much closer to possible widespread deployment in U.S. border security.

Treaty verification

Muon vision has great potential for solving other challenges to U.S. national security. For example, the State and Defense Departments are partnering with Los Alamos to develop a variation of muon vision that could be a game changer in solving challenges in nuclear weapons treaty verification.

The New Strategic Arms Reduction Treaty limits the number of nuclear warheads deployed on intercontinental ballistic missiles and on submarine-launched ballistic missiles. Inspections are needed to verify compliance, but the treaty proscribes current detection and monitoring methods.

So, how can inspectors see under a missile's nose cone to verify the number of warheads inside? In some cases, a missile might even be loaded with decoy warheads to fool ballistic-missile-defense systems. Verification of the number of warheads would require taking the nose cone off the missile and opening the warheads. The major problem is that militaries refuse to show one another what the insides of their nuclear missiles look like. But even if they did, imagine the labor, cost, and risk involved in removing nuclear missiles from submarine launch tubes or missile silos, disassembling the nose cones and warheads, verifying the number of warheads, reassembling everything, and then returning the missiles to their launch tubes or silos.

But muon vision could solve these challenges. Setting up muon detectors

A truck passes through a pair of muon vision detectors—one in the ceiling and one in the floor—of the MMPDS muon scanner at Freeport, Bahamas. (Photo: DSIC)

on either side of a submarine, for example, could, in principle, safely, quickly, and inexpensively verify the number of warheads and potentially do so without revealing military secrets.

Interrogating nuclear fuel storage containers

The National Nuclear Security Administration's Office of Global Material Security is investing in muon vision as a potential tool for the International Atomic Energy Agency's nuclear inspectors to monitor spent nuclear fuel inside storage containers. The Laboratory's muon team is currently testing the feasibility of this capability at Idaho National Laboratory.

Beyond nuclear screening

Recently, DSIC demonstrated that its MMPDS can combine muon vision with an electron detection technology that is more sensitive to "seeing" less-dense materials. When used together, these technologies might identify items such as conventional explosives, precursor chemicals to make explosives, narcotics, tobacco, and alcohol. So security staff can not only "see" heavily shielded radiological threats, but they can also locate less-dense contraband being smuggled into the country—a step in the right direction for improving national security. ✦

~Necia Grant Cooper



Ask Me Anything

Explosive scientists answer questions on Reddit



On March 21, eight Los Alamos scientists took to the interwebs to participate in a Reddit “Ask Me Anything.” For more than two hours, these explosives experts fielded questions from the public about their careers, the Lab, and living in Los Alamos. Here’s just a snippet of the conversation.

How does one get into the explosives science field?

Virginia Manner: There are a few universities in the United States that have master’s and PhD programs in explosives, but many of us came to Los Alamos with advanced degrees in chemistry and physics and moved to the explosives division later on. As long as you get a degree in the hard sciences, with a little persistence, at Los Alamos you have the option to move from one field to another.

Would you recommend a national laboratory or academia for a postdoc position?

Shawn McGrane: I would recommend a postdoc at a national lab. The benefit of a national lab is that there is typically a group of experts working on any given topic. You can always find someone who can help you make progress. Also, work in explosives or other global security fields can have a positive societal impact, whereas university research might be more academic.

Do you have any ethical qualms about your work?

Virginia Manner: Much of our explosives research is based on explosives detection and defeat, or finding ways to make explosives safer to handle. These are the projects that I am most proud of working on.

How often do you blow things up outside?

Dana Dattelbaum: We typically fire large shots outdoors at the Laboratory or at one of our partner labs or sites. Some of our scientists fire shots outdoors every week, several times a week. I mostly work on smaller shots performed in vessels or in indoor chambers and only fire outdoors maybe once a year.

Have you ever experienced an explosives accident in the lab?

Dan Hooks: No. The work is highly controlled, and most times I feel very safe. However, you can never, ever forget that you are working with explosives. You have to remember that you don’t know everything.

What’s the best part of the job?

Dana Dattelbaum: Learning something new about explosives that has never been known before. It is exciting to apply cutting-edge experimental tools to make in situ, time-resolved measurements on complex explosives assemblies. Our teams are well-trained, creative, and have diverse backgrounds to bring to a single problem.

What’s the gender distribution of explosives scientists at Los Alamos?

Margo Greenfield: As a woman in this field, I am always pleased at how many female scientists I see here at Los Alamos, as well as at external conferences. In the areas where I work (explosive chemistry and explosive shock physics) the distribution is typically one-third to one-half women.

Want even more on high explosives?

In 60 seconds, Virginia Manner explains the science behind homemade bombs at

www.lanl.gov/newsroom/video/playlist-science-in-60.php.

And be sure to revisit the April 2016 issue of NSS to learn how Los Alamos leads explosives-science research:

www.lanl.gov/science/NSS.





Have you run into problems boarding a commercial flight?

Bryce Tappan: I've had positive responses for trace explosives in the airport, which just resulted in extra screening and questioning.

How do you feel about working in Northern New Mexico?

Margo Greenfield: Los Alamos is an amazingly beautiful area, and we are very lucky to have the Lab located here (thanks, Oppenheimer!). We have an abundance of outdoor activities (hiking, climbing, skiing, biking, fishing, the list goes on). I work in a pretty secluded area and often see wildlife (elk, deer, bobcats, coyotes, and sometimes bears) on the drive into work as well as from my office.



Hans Bethe

Do any of you ski at Pajarito Mountain?

Dan Hooks: Many of us love skiing here. In the lodge, there are copies of the original documents that founded the ski area. The first petition was signed by none other than George Kistiakowsky, the Harvard chemist who led the explosives program during the Manhattan Project. Dues were paid and meetings attended by many other familiar names: Hans Bethe,

Victor Weisskopf, Nicholas Metropolis, Seth Neddermeyer, Robert Oppenheimer, even Louis Slotin and Klaus Fuchs!

On July Fourth, I bet you get to play with some big fireworks, don't you?

Dana Dattelbaum: Several of our explosives chemists have created fireworks for the entertainment industry. Just different chemicals and burn rates!



Secret City app now available

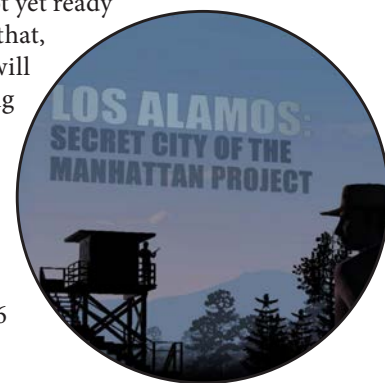
Experience the Laboratory that produced the atomic bomb

Transport yourself back in time to the Manhattan Project via the Secret City app developed by the Laboratory's Visible Team and the Bradbury Science Museum.

The free app allows users of both Apple and Android devices "to view Los Alamos from anywhere in the world, almost like a computer game," explains Laboratory historian Ellen McGehee. "You get off the train at Lamy, New Mexico; you meet Los Alamos's 'gatekeeper' Dorothy McKibbin at 109 East Palace Avenue in Santa Fe; you go up 'the Hill' to the Laboratory; as you go through town, sites in the wartime technical areas are unlocked."

Users of the app will see many of the Laboratory's original buildings that are in the new Manhattan Project National Historical Park (MPNHP) but not yet ready for public admission. The idea is that, even without full access, people will come away with an understanding of the history and legacy of this part of the Manhattan Project.

To learn more about Lab properties in MPNHP, check out "Manhattan Project National Historical Park" in the April 2016 issue of NSS.



Quoted

"We don't know how to disarm a terrorist weapon—we've never seen one." —Barry Charles, Program Director for Nuclear Counterproliferation at Los Alamos, during his TEDxLANL talk titled "Creativity Under Pressure, or Why Disarming a Terrorist Nuke is Like Defending Against Aliens in Space." Visit the Lab's YouTube channel to watch the entire talk.

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Many Las Vegas showgirls doubled as atomic beauty queens in the 1950s. Here, American soprano, entertainer, and philanthropist Marguerite Piazza poses as "Miss Radiation" at the Sands Hotel and Casino in Las Vegas, Nevada, in 1955. She wears a tiara in the shape of a mushroom cloud, reportedly made by the servicemen surrounding her.

(Photo: Las Vegas News Bureau).

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