Battlefield of the Cold War

The Nevada Test Site

Volume I

Atmospheric Nuclear Weapons Testing

1951 - 1963

United States Department of Energy

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Atmospheric Nuclear Weapons Testing

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Terrence R. Fehner & F. G. Gosling
Office of History and Heritage Resources
Executive Secretariat
Office of Management
Department of Energy

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Battlefield of the Cold War
The Nevada Test Site

Volume I
Atmospheric Nuclear Weapons Testing
1951-1963

Volume II
Underground Nuclear Weapons Testing
1957-1992
(projected)

These volumes are a joint project of the Office of History and Heritage Resources and the National Nuclear Security Administration.

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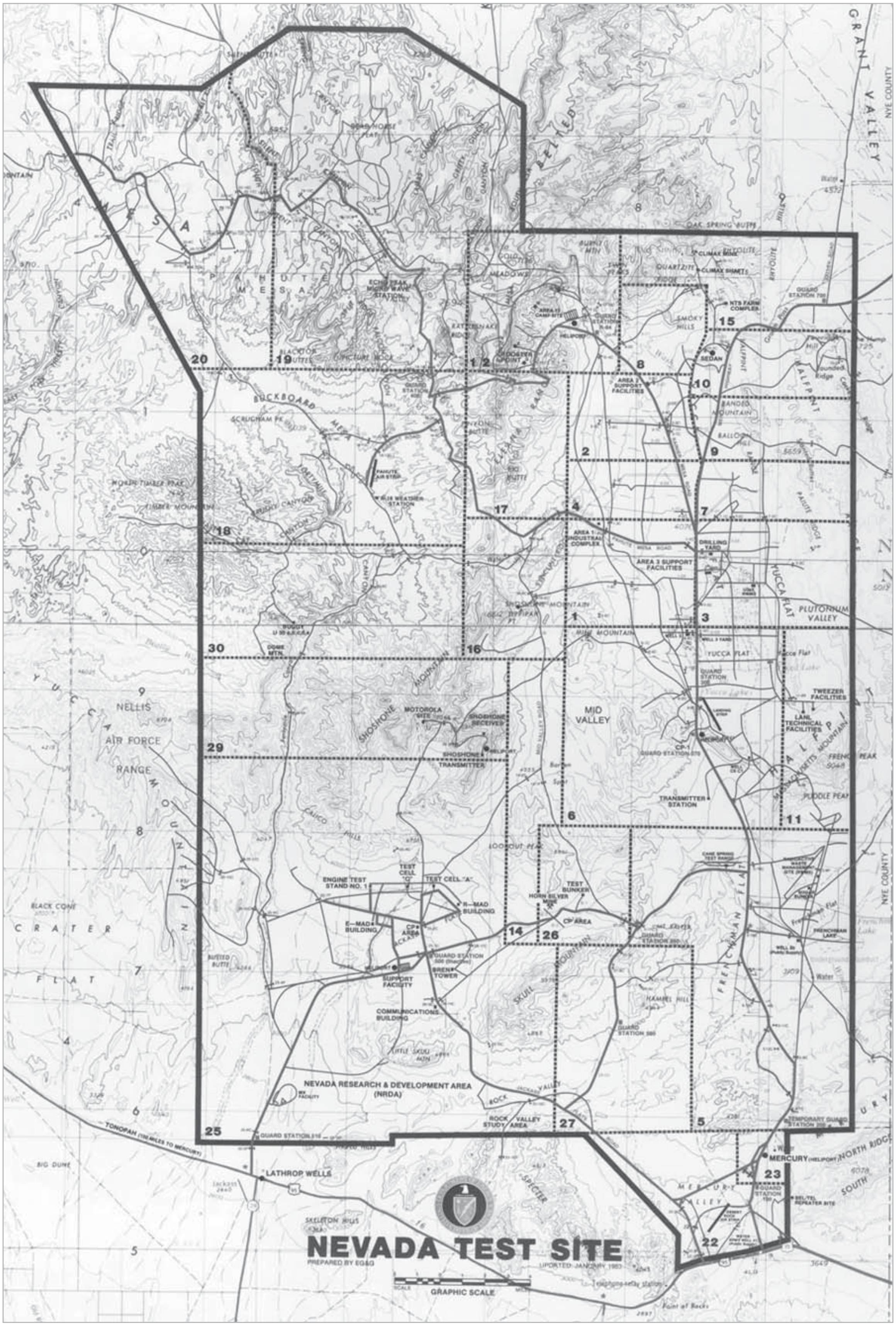
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Introduction

Operation Big Shot, April 22, 1952

Charlie promised to be a "Big Shot," as the press dubbed the nation's twenty-fifth nuclear weapons test. With a projected explosive yield equivalent to thirty-three kilotons of TNT, Charlie would be the largest test conducted to date at the Nevada Proving Ground, formerly—and again to be—the Nevada Test Site. Charlie also was big in the sense that for the first time a nuclear weapons test would be held as an "open" shot that allowed a significant degree of public access. For the first time, as well, ground and airborne troops would conduct military maneuvers on a simulated nuclear battlefield following the shot.

By 9:00 a.m. on April 22, 1952, at H-hour minus thirty minutes,* all was ready and in place for Charlie. Hundreds of observers, dignitaries, and reporters, previously banned from the site, had gathered on a small hill newly christened "News Nob," about nine miles south of ground zero, to await the blast. Some were given high-density goggles to view the burst, while others were told to turn away and shield their eyes. At the top of the Nob stood one of four television cameras prepared to broadcast the test to an anticipated audience of millions of viewers nationwide. Special arrangements made by Klaus Landsberg of KTLA, a Los Angeles television station (relatively close-by Las Vegas as yet having none), to provide pictures direct from the site using still primitive technology were, one reporter noted, "almost heroic." To the north of News Nob, some 1,700 soldiers were positioned in five-foot-deep trenches 7,000 yards from ground zero, the closest by nearly half that any observer had ever been to a nuclear test. A thousand yards out, rockets, whose smoke trails would measure blast pressures, stood ready to be launched remotely only seconds before the blast. The B-50 bomber that would deliver the nuclear device, meanwhile, circled in a clockwise orbit at an altitude 30,000 feet above the Yucca Flat target area.[1]

Surrounding ground zero stood an array of experiments for measuring Charlie's blast, thermal, and radiation effects on a variety of inanimate and animate objects. Trucks and tanks, some 35 parked aircraft, and numerous other pieces of military equipment and ordnance were placed at varying distances out from the detonation point to ascertain how well they would survive a nuclear attack. Effects on a minefield, 15 meters wide and extending out from ground zero to 1,830 meters, would determine the practicality of using nuclear weapons to clear mines. Measurements of motion and strain would be taken on four 50-foot tall coniferous trees anchored in concrete. Pigs, sheep, and mice served as surrogates for humans in various experiments. Anesthetized pigs would be used to measure thermal effects and skin burns. Mice would assist in determining radiation effects. Sheared sheep manned foxholes and trenches, with additional sheep tethered in the open. In one experiment, wood models of dogs were set up to measure blast effects on animals. Real humans, nine miles from ground zero, participated in a "flash

* In the military, the term "H-hour" is used for the hour on which a combat attack or operation is to be initiated. Minus thirty minutes indicates the time preceding the event. Source: U.S. Army Center of Military History, at http://www.army.mil/cmh-pg/faq/ddaydef.htm.

KTLA Broadcasting - Charlie Shot

A military helicopter, top, delivers an eight-foot microwave dish strapped to its side to a mountain top in the Nevada desert so that the signal can be relayed from the test site to the KTLA television studio in Los Angeles. Long-lens camera, middle, focuses on ground zero. Charlie shot, bottom, as seen on television. Source: "KTLA 40th Anniversary Special," KTLA, through Broadcasting 101.

Two soldiers crouch in their foxhole awaiting the blast. Source: DOE, NNSA-Nevada Site Office.

blindness" experiment. Volunteers would look briefly directly at the flash, while others in a control group looked away, and then both groups would be required to read lighted instruments.[2]

At H-hour minus ten minutes, troops moved into their trenches and, at minus two minutes, knelt, covering their faces with their hands and leaning against the forward trench wall. At minus one minute on News Nob, a voice over a loudspeaker instructed observers to "put on goggles or face away from the target area." "Minus thirty seconds . . . " continued the announcer, "Bombs away!" As the device fell, one newsman reported how the observers "breathed quickly in charged air" as they "stared transfixed toward ground zero" and "braced themselves for violence, anticipating the unexpected." The countdown continued as the "voice of doom" in charge of the loudspeaker droned on, "five, four, three, two, one . . . ," and then as the device detonated 3,447 feet above the target area a "blinding flash of light that turned the desert a chalky white," as a *Newsweek* reporter described it, and, when the observers yanked their goggles off three seconds later, feeling the heat in their faces, the flash became "a whirling ball of fire, kaleidoscoping into purples, yellows, and reds." At the same time, the observers witnessed the shock wave striking at ground zero "destroying, you know, the planes and trucks parked there, if they haven't already been vaporized in the heat." From News Nob, they see "a wall of dust, rising slowly into the air and streaking sideways along the desert ground as the shock wave travels," eventually rolling over the trenches and obscuring the troops from view. The voice in the loud speaker, meanwhile, warns, "The shock wave will arrive in 30 seconds." When it hits News Nob, the "shock is nothing but a sound . . . like a revolver fired at close range, then a lower and louder rumble lasting for seconds, and it's gone." The fireball, in the interim, has become "a white cloud, edged yellow in the morning sun, trailed by a stalk which reached down toward the gray dust cloud blotting out ground zero."[3]

An estimated 35 million television viewers were not as fortunate in what they saw. In Los Angeles, the blast pictures were "more than satisfactory," but in other areas of the country many of "those who watched never at any time had a plausible image of whatever it was that the camera was aimed at." Instead, they received "an ever-changing series of geometrical designs, alternating with something that looked like showers of confetti." The first "public" detonation of an atomic weapon, the New York *Herald Tribune* noted, had produced an "odd result: a revolutionary method of mass communication had blurred, rather than clarified, the impression of a revolutionary weapon of warfare."[4]

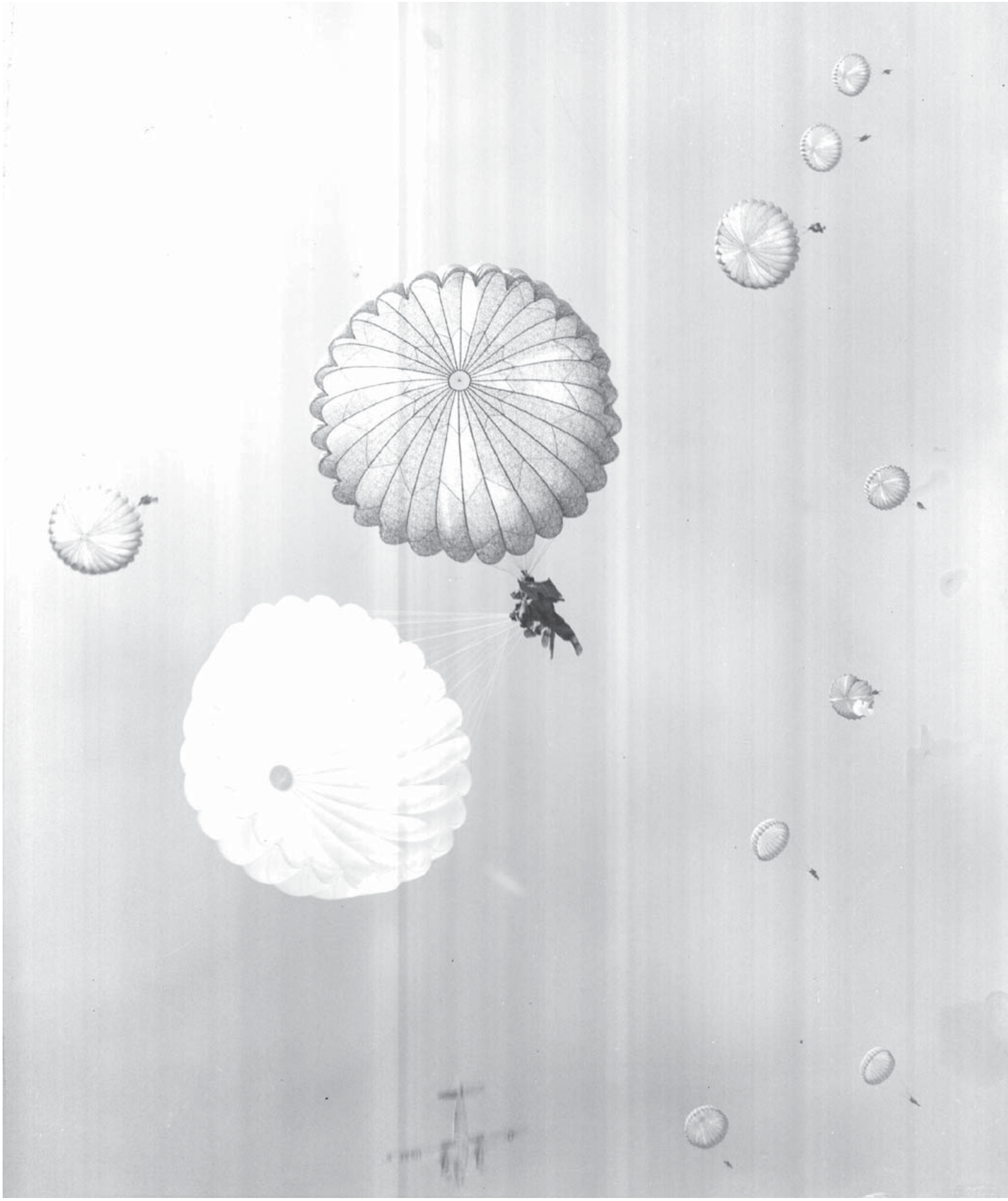
In the trenches, the troops had yet another view. Crouched down, heads lowered and eyes covered, the soldiers experienced a "very bright" flash "just like when you look straight into an arc-welding flare," one corporal noted, followed by a

Mushroom cloud rises over Yucca Flat as dust cloud begins to form below. Vapor trail of the U.S. Air Force B-50 drop plane is seen in the upper left. Above and behind the drop plane are vapor trails of four instrument-bearing aircraft that record scientific data on the atomic detonation. Source: DOE, NNSA-Nevada Site Office.

Soldiers and observers watch Charlie's mushroom cloud form. Source: DOE, NNSA-Nevada Site Office.

heat wave "like you get when you open the door of a blast furnace." Ordered out of the trenches, the troops took in the "strong odor of charred mesquite" and awaited the shock wave. Twenty-one seconds after detonation, the shock wave, observed a lieutenant colonel, "hit us . . . like a rolling surf—r-r-r-r-rumpf." One veteran test observer described it as "comparable to being hit in the face with a feather pillow." The accompanying sound, another noted, was loud enough to "hurt my ears" and the dust from the blast "blotted out everything beyond a yard for a minute or so." The ordeal over, the "young men were laughing and cracking jokes," according to one of three generals who witnessed the shot close in. "The worst thing most of us got was a mouthful of dirt." Waiting for an hour while radiological monitors checked out the burst area, the troops then were transported by bus to a point about two miles southwest of the target area where they viewed the effects of the blast on a variety of military equipment and began a simulated assault, coming within 160 meters of ground zero, against enemy fortifications supposedly taken out by the detonation. They were met on the north side of the blast area by 120 paratroopers who had been air dropped by C-46 aircraft. Thirty paratroopers failed to show up when they jumped early, landing as far as 13 kilometers from the designated drop zone.[5]

Effects from the blast varied, depending on the distance from ground zero. The flash blinded sheep tethered above ground at 900 and 2,000 yards away. Heat from the blast started vegetation fires out to 2,300 yards, leaving numerous yucca plants and Joshua trees smoldering, and gave lethal burns to sheared sheep tethered above ground at 900 yards. In foxholes, sheep at 900 yards received third degree burns and at 2,000 yards, in the open, first degree burns. Some "trinitite," sand turned to green glass first encountered at the Trinity test, formed at ground zero. Radiation was lethal to sheep in the open at 900 yards. Military equipment



After the Charlie shot, members of the 82nd Airborne Division parachute into the area near ground zero. Source: DOE, NNSA-Nevada Site Office.

had wood, paint, and cloth burned at 900 yards. Trucks and jeeps at 2,000 yards suffered bent sheet metal and burned tires and cloth, with windshields broken out, but, one observer noted, "might have been usable." At ground zero, a three-fourths ton truck was "bent all out of shape and burnt." A light tank at ground zero had burns and bent and broken sheet metal but "apparently had no crippling damage." Greater damage to the equipment might have been caused had not a fire truck, in the aftermath, put out many of the fires.[6]

Operation Big Shot was a smashing success. As Atomic Energy Commission Chairman Gordon Dean observed as he watched Charlie's multi-colored mushroom cloud rising overhead, "it was a pretty sizeable bang for this country." More sobering was Federal Civil Defense Administrator Millard Caldwell's assessment of Charlie, a relatively small device compared to the megaton weapons that would follow. "A bomb of this kilo-ton force," he noted, "would have claimed one-half million casualties in New York from blast, fire and radiation effects." Nonetheless, weapon scientists, military officials, and the media, even with some mixed feelings as to the uses that might be made of the "spectacular display," all emerged well-satisfied with the results. Despite the faulty television reception, the American people also had gained a clearer notion of the significance of the events that were taking place at the test site. And significant they were. From 1951 through 1958, the United States conducted 120 tests at the Nevada Test Site. These tests directly contributed to the creation and manufacture of bigger, smaller, better, and safer nuclear weapons that greatly enhanced

Truck between 400 and 500 yards from ground zero. Source: DOE, NNSA-Nevada Site Office.

the capabilities of the nation's security forces and helped deter an all-out hot war. Warheads from a few kilotons to multi-megaton yields, warheads for bombs, guided missiles, ballistic missiles, depth charges, and hand-held bazookas were developed, refined, and stockpiled. On the downside, nuclear weapons testing also produced airborne radioactivity that fell outside the test site and, as the decade progressed, a worldwide uproar and clamoring for a ban on all tests. This combination of off-site radioactivity and an increasingly wary public ultimately would prove to be the undoing of atmospheric testing.[7]

Part I

Origins of the Nevada Test Site

The Nevada Test Site: What and Where

The Nevada Test Site's primary mission has been the testing of nuclear weapons. From 1951 to 1992, when a worldwide moratorium on nuclear testing went into effect, the U.S. Department of Energy and its predecessor agencies conducted a total of 928 tests at the Nevada Test Site. The tests served a variety of national security purposes. These included design testing for the verification of new weapons concepts, proof-testing of existing weapons, effects testing to determine the impact of nuclear weapons on man-made objects and structures, plants and animals, and the physical environment, and experimental testing in the search for possible peaceful uses. The Nevada Test Site played a vital and central role in the development and maintenance of the Cold War nuclear arsenal. Although the site no longer plays host to nuclear weapons tests, the Department of Energy's National Nuclear Security Administration maintains the capability to resume testing should the necessity arise and continues to use the site for a variety of national security and other needs.[1]

The Nevada Test Site consists of approximately 1,375 square miles of remote desert and mountain terrain owned and controlled by the Department of Energy and located in the southern part of the Great Basin northwest of Las Vegas. Elevations range from 3,280 feet at Frenchman Flat in the southeast corner of the site and at Jackass Flats in the southwest corner of the site to 7,675 feet on top of Rainier Mesa toward the northern border. The mountain ranges found on the site are generally lower in the south and higher in the north. Water—or the lack thereof—is the dominating climatic characteristic. The lower elevations have hot, dry summers and mild winters and average six inches or less of annual precipitation. Higher elevations receive somewhat increased precipitation and have lower temperatures. Temperature extremes on the site range from below zero to 110 degrees Fahrenheit.

Despite the harsh climate, the Nevada Test Site is home to a surprising array of plants and animals. The site is in a transitional zone between the Great Basin and Mojave deserts. Species from both deserts, including those native to one but not the other, are found in the area. Kit fox and the sidewinder rattlesnake, common only in the Mojave

Although not native, wild horses roam the higher elevations of the test site. Source: DOE, NNSA-Nevada Site Office.

Desert, live in the southern reaches of the site, and mule deer and the striped whipsnake, favoring a Great Basin desert environment, reside in the northern parts. Other animals found on site include coyotes, golden eagles, wild horses, mountain lions, and an occasional bighorn sheep and antelope. The range in elevation also helps provide for diversity in flora and fauna. Mojave Desert plants such as the creosote bush dominate the lower elevations. Plants of the Great Basin Desert prevail above 5,000 feet, with open piñon–juniper and sagebrush woodland appearing at the 6,000–foot level. Between the two elevation extremes, sagebrush is the most common plant. Springs, the only perennial water sources on the site, sustain the wildlife population and are widely, if not abundantly, scattered across the area.

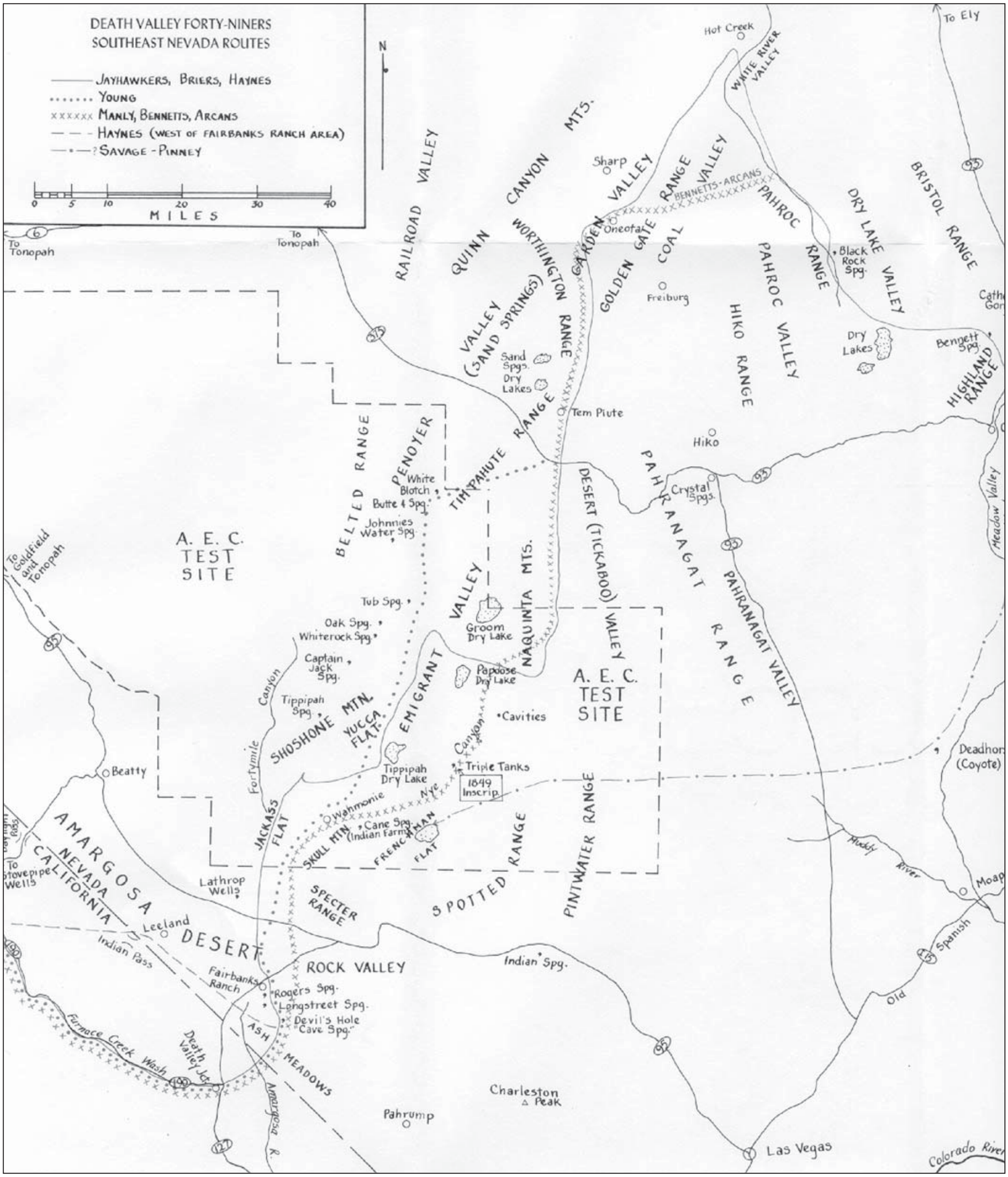
The Nevada Test Site nonetheless is where it is for good reason. Few areas of the continental United States are more ruggedly severe and as inhospitable to humans. The site and the immediate surrounding area have always been sparsely populated. Only once prior to 1950, and then very briefly, did more than a few hundred people call the site home. In most periods of habitation, far fewer have lived there. Although no locale can be said to be ideal or optimal for nuclear weapons testing, the Nevada Test Site was perhaps the best continental site available for avoiding collateral damage and radiation exposure to plants, animals, and, most importantly, human beings off site.[2]

Pre–History and History to 1940

Even with a climate that has varied considerably over the last dozen millennia, the area that is now the Nevada Test Site has never been particularly conducive to human habitation and exploitation. The earliest cultural remains discovered on the site date back 10,000 to 12,000 years. More recently, the area was home to widely scattered groups of hunter gatherers currently known as Southern Paiute and Western Shoshone. They practiced a subsistence strategy designed to cope with a severe and unforgiving environment. Scarcity of game forced the population to subsist primarily on seeds and other vegetable foods. By the early twentieth century, most of the free–roaming Native Americans had moved to surrounding towns or relocated to reservations.[3]

Native American petroglyphs can be found on the test site. Source: DOE, NNSA-Nevada Site Office.

Explorers and pioneers first crossed the area in the mid-1800s but did not stay. The Old Spanish Trail, which was neither old nor Spanish, passed through the Las Vegas Valley south and east of the area that became the Nevada Test Site. First traversed in the winter of 1829–1830, the Old Spanish Trail served as a primary means of reaching the Pacific Coast until the termination of the war with Mexico in 1848. The earliest recorded entry onto the present test site was by an ill–fated group of emigrants known as the Death Valley '49ers. Bound for the California gold fields in fall 1849, a party of Mormon families left the Salt Lake Valley too late in the season to cross the Sierra Nevadas on the more direct route across northern Nevada. They elected instead to head first toward southern California on the Old Spanish Trail. Persuaded by rumors of a shortcut, a splinter group left the trail near Enterprise, Utah, and headed west into unknown territory. Further splits



Probable routes taken through the test site by the Death Valley '49ers. Note that on the map the entirety of what is now the Nellis Air Force Range is labeled as the "A.E.C. Test Site." Source: Reprinted from George Koenig, *Beyond This Place There Be Dragons: The Routes of the Tragic Trek of the Death Valley 1849ers through Nevada, Death Valley, and on to Southern California* (Glendale, CA: The Arthur Clark Company, 1984).

Remnants of Ranchers and Miners on the Test Site

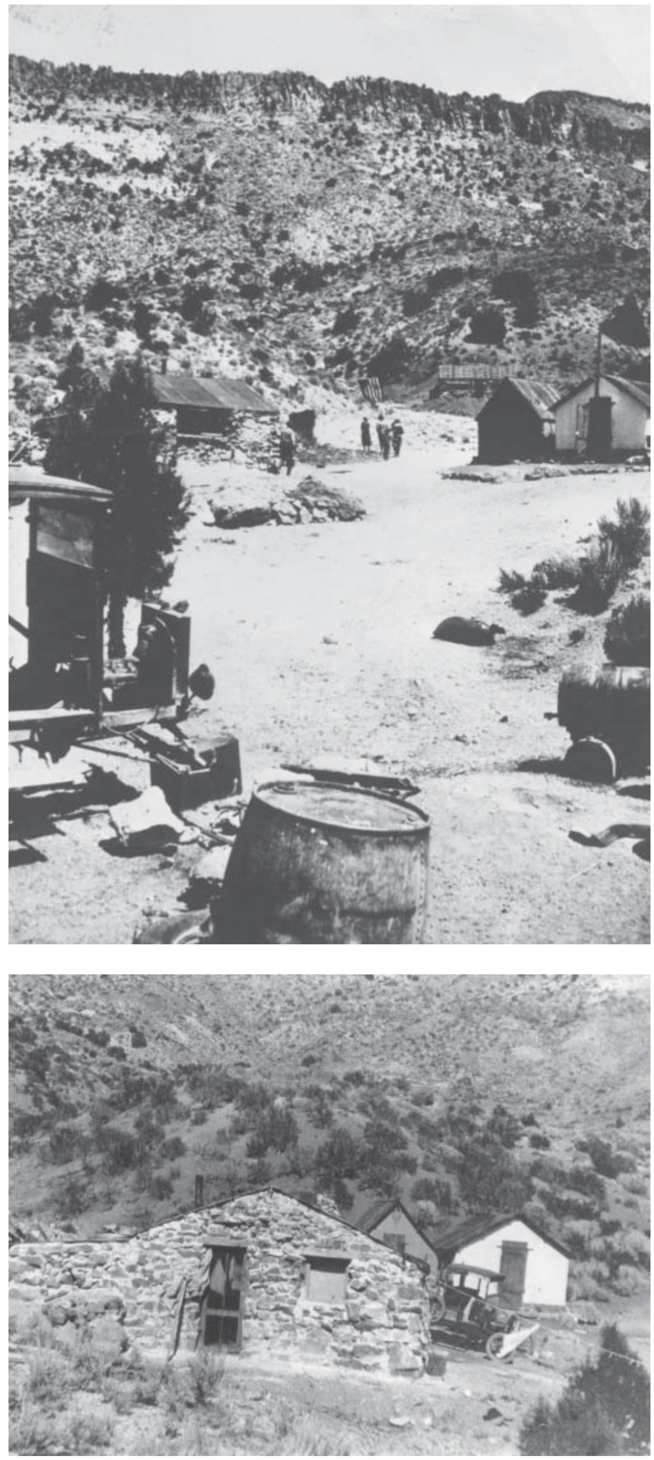
Stone cabin at Whiterock Spring, top, with the remains of a corral and abandoned 1928 Buick. Source: DOE, NNSA-Nevada Site Office.

Tippipah Spring, top, with water storage tanks made from a boiler. Source: DOE, NNSA-Nevada Site Office.

occurred in the wayward group as it became clear that there was no easy or readily distinguishable way. Although the exact routes taken remain debatable, all of the splinter parties clearly passed through the test site. One group entered the site via Nye Canyon on the eastern boundary, crossed over Frenchman Flat, and camped for nine days at Cane Spring, where from a nearby summit one member described the "most wonderful picture of grand desolation one could ever see." Other groups crossed over Yucca Flat immediately to the north. All groups eventually left the site at Jackass Flats prior to their rendezvous at Death Valley where they remained stranded for several months. Fortunately, nearly all of the '49ers, after enduring extreme hardship, belatedly reached their destinations in California.[4]

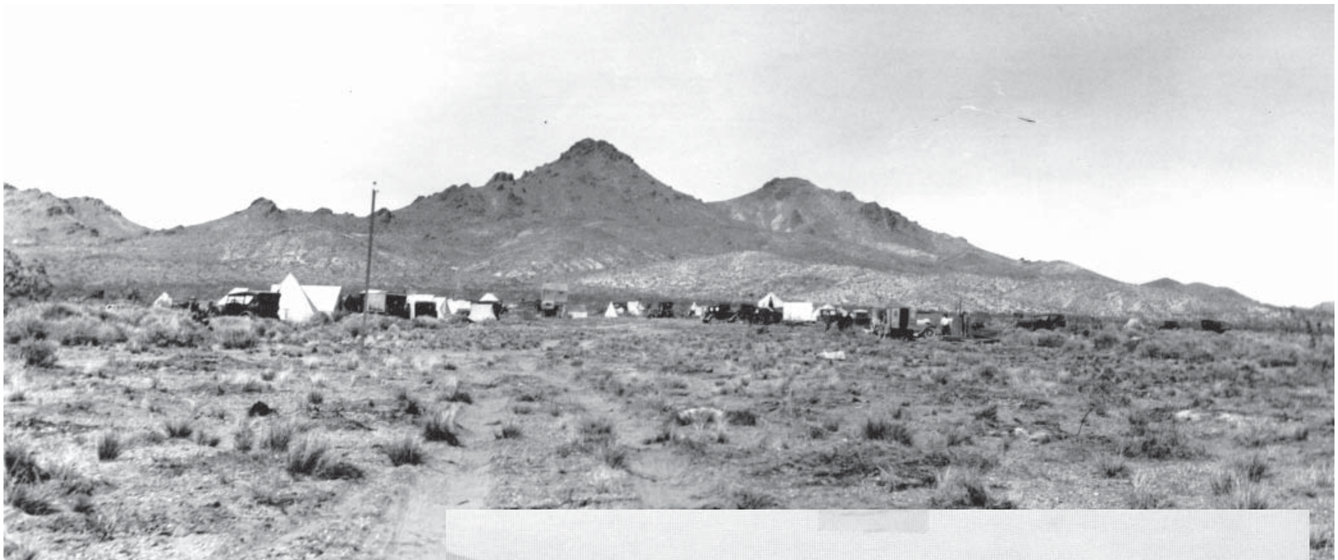
Mining and ranching prompted the first meager settlement. During the last half of the nineteenth century, prospectors combed through virtually every valley, canyon, and outcropping in the American West. Although mining boom towns—Tononpah, Goldfield, and Rhyolite—sprang up to the west of the site in the first decade of the twentieth century, few discoveries of precious metals were made on the site itself. The earliest known claims were filed in March 1889 near Oak Spring, at the south end of the Belted Range in the far northern reaches of the site. Mining in this district continued off and on for the next fifty years, with turquoise and small amounts of gold and silver being the initial attraction. In 1917, copper ore containing some silver was shipped from the district as were minor amounts of tungsten. In the late 1930s, demand for tungsten, which was used in the production of armaments, increased with the approach of the Second World War, and several mining companies conducted sampling operations in deposits near Oak Spring. The site became known as the Climax Mine.[5]

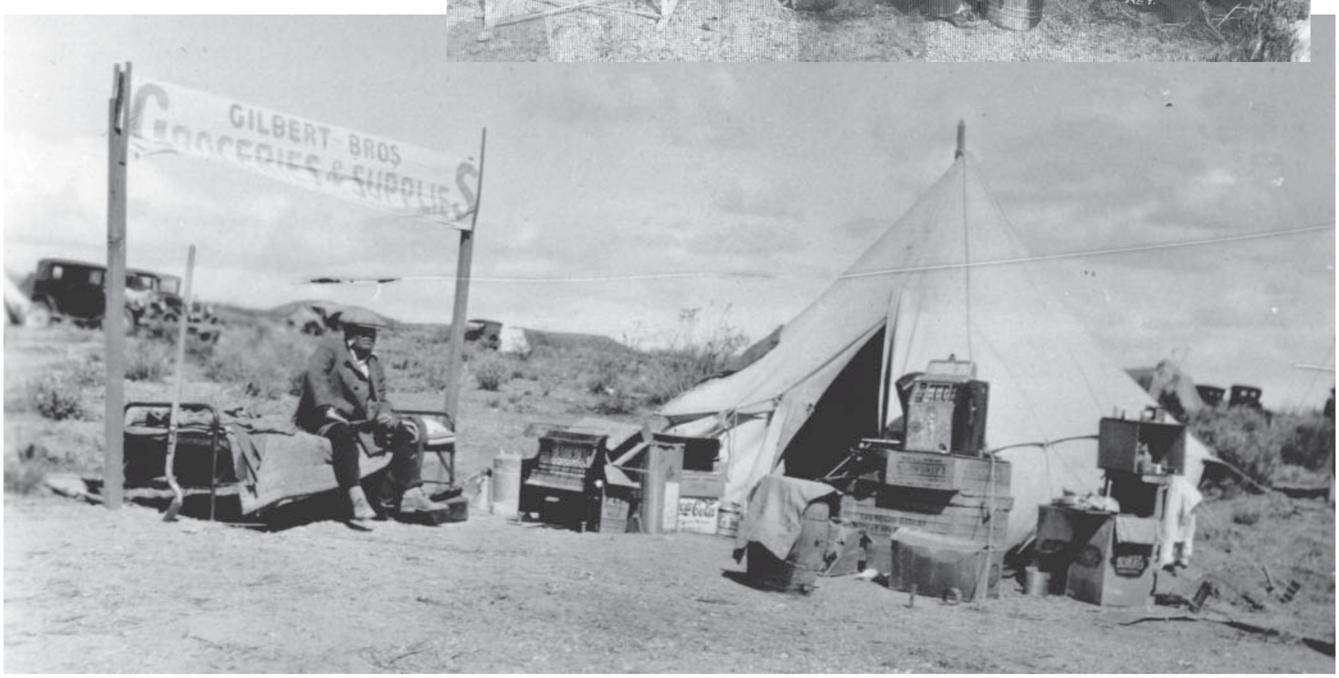
Nevada's last major mining rush occurred in the late 1920s at Wahmonie, located on what is now the test site west of Cane Spring and on the eastern edge of Jackass Flats. Mining operations in the area dated back at least to 1905, but the area remained



Mining activity at Oak Spring, 1920s. Source: Alvin McLane, from the Estate of B.M. Bower.

Wahmonie





Wahmonie, Nevada, 1928: top, in the early days of the strike; middle, first women and first gas station in Wahmonie; bottom, outdoor vendor supplying Wahmonie's miners. Source: top and bottom, Nevada Historical Society; middle, Atomic Testing Museum.

quiet until the discovery of high–grade silver–gold ore in 1927. Established in February 1928, the Wahmonie mining camp grew to a population of some 500 within a month. Some miners arrived hauling small houses on trucks. Others came in cars loaded with provisions or even on foot pushing wheelbarrows tied down with goods. Many miners lived in small tents, but Wahmonie soon had boarding houses, tent stores, and cafés. Thirsty miners could avail themselves at the Silver Dollar Saloon or the Northern Club. Wahmonie's population peaked, however, in early summer at some 1,000 to 1,500, and by the end of the year it was clear that the strike was not as rich as had first been thought. Optimism faded, people began leaving, and the town went bust. Deterioration of Wahmonie began soon after the mines were abandoned when mining equipment was moved to other locations. The townsite nonetheless still retains some of its original features, including mine shafts, roads, tent pads, discarded lumber, and scattered mining debris.[6]

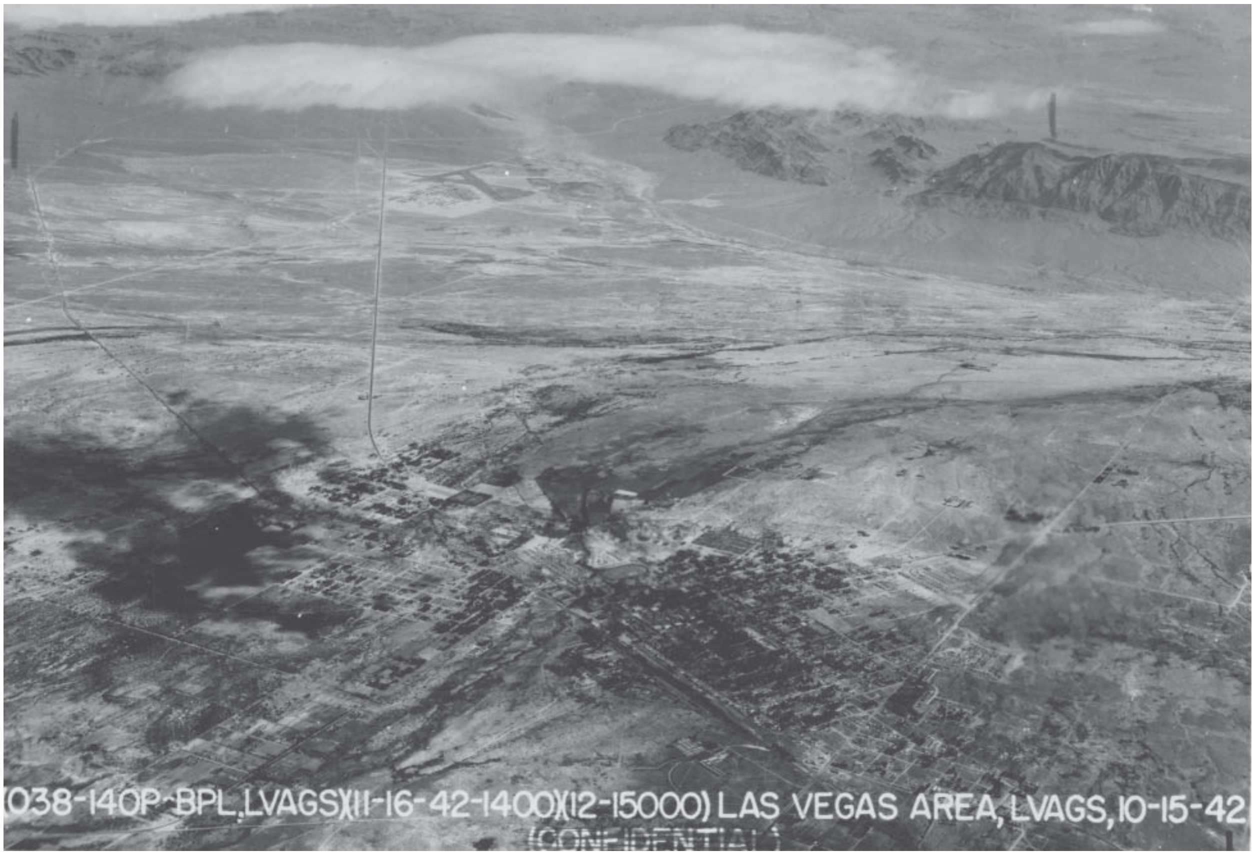
The only other viable economic activity on what became the test site was open–range grazing. Ranching on the site began in the late 1800s. Suitable forage grounds existed for both cattle and sheep, but access to water was a problem. Flow from the widely scattered springs was often minimal, and ranchers, to augment the supply of water, modified some springs and constructed water storage tanks. The remains of one such tank, made from a boiler, are found at Tippipah Spring, located near the center of the site. While ranchers and their families tended to live in nearby communities outside the present site boundaries, they built and maintained some structures on the site. At Whiterock Spring, in the north central portion of the site, an abandoned 1928 Buick still rests near stone cabins. Remnants of corrals can be found at a number of the springs on site.[7]

The Las Vegas Bombing and Gunnery Range

In the nearly hundred years since the '49ers first rumbled through on their way to Death Valley, not much interest had been shown, aside from the occasional prospector and intermittent grazing, in the area that would become the Nevada Test Site. In 1940, however, the precise characteristics that had made the region generally so unattractive—the desolation, lack of water, and general uninhabitableness—brought it to the attention of the federal government. With war looming, the United States had begun a major rearmament program. Part of this program involved locating bombing and gunnery training ranges for the Army Air Corps. On October 29, 1940, President Franklin D. Roosevelt established the Las Vegas Bombing and Gunnery Range. Encompassing more than three–and–a–half–million acres north and west of Las Vegas, the range stretched almost to Tonopah and included all of what is now the test site. More than ninety percent of the range was in the public domain, but a number of grazing, homestead, and mining claims made it difficult to take possession. In August 1941, the government began condemnation proceedings against the outstanding parcels of land.

B-24 following an emergency landing. Source: Nellis Air Force Base, History Office.

World War II



Military photograph of Las Vegas, Nevada, 1942. Airfield can be seen in background. Source: University of Nevada, Las Vegas, Special Collections. Document declassified per E.O. 12958, Sec. 2-4.

Las Vegas Army Air Field flightline, 1945. Source: Nellis Air Force Base, History Office.

The Army Air Corps decided to use most of the newly acquired range for an aerial gunnery school. Appropriate conditions for such a school existed, as one general put it, "to a superlative degree." The range offered excellent year–round flying weather, a strategic inland location, nearby mountains that could provide natural backdrops for cannon and machine gun practice, dry lake beds for emergency landings, and an existing airfield conveniently located on the outskirts of Las Vegas. Although the "possible morale and morals hazard" associated with the legal gambling and prostitution of Las Vegas gave the military pause, the advantages of the location far outweighed the disadvantages. Operations began in October 1941 as the courts finalized the land condemnations and federal marshals cleared the remaining stragglers off the range.

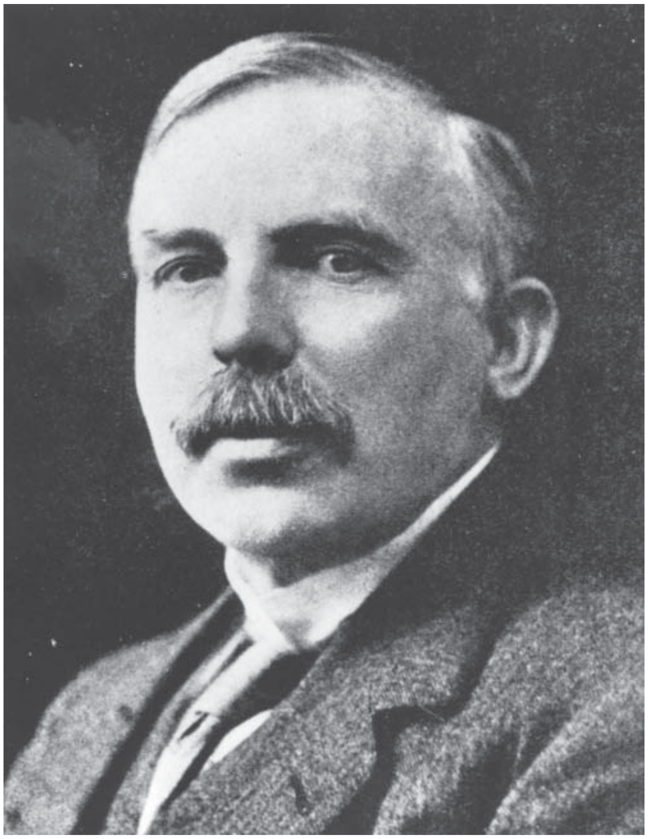
The test site area's role was to serve as a setting for air–to–air gunnery practice. Gunners on airplanes used "frangible" bullets that broke upon impact, spattering paint so that gunners could see where their bullets had hit, as well as live fire against targets towed by other airplanes. This at times proved hazardous, and the site's backup role was to provide emergency landing services. The Army set up four emergency landing strips on the range. One was on Groom Lake east of the site. Another was on Pahute Mesa toward the north and west part of the site. The remaining two landing strips were further to the north and west on the range. The dry lake beds at Frenchman and Yucca flats could also serve as emergency strips. In addition, the Army established a forward base with a landing strip and other facilities at Indian Springs, a small hamlet with a service station and general store on the highway some ten miles southeast of the site.

The end of the Second World War closed out training activities on the bombing and gunnery range. The Las Vegas Army Airfield briefly deactivated before reemerging, in response to political pressure and the growing Cold War threat, as the Las Vegas Air Force Base in 1948, with a mandate to train pilots of single–engine airplanes. The following year, the Air Force expanded the base's functions by adding a gunnery school. In April 1950, the base was renamed Nellis Air Force Base. As for the bombing and gunnery range, it stood largely unused throughout much of the late 1940s.[8]

Neutrons, Fission, and Chain Reactions

The Nevada Test Site might have remained a bombing and gunnery range forever had it not been for the revolutionary discoveries and insights of modern physics. In the early twentieth century, physicists conceived of the atom as a miniature solar system, with extremely light negatively charged particles, called electrons, in orbit around the much heavier positively charged nucleus. In 1919, the New Zealander Ernest Rutherford, working in the Cavendish Laboratory at Cambridge University in England, detected a high–energy particle with a positive charge being ejected from the nucleus of an atom. The proton, as this subatomic particle was named, joined the electron in the miniature solar system. The number of protons in the nucleus of the atom determined what element the atom was. Hydrogen, with one proton and an atomic number of one, came first on the periodic table and uranium, with ninety–two protons, last. This simple scheme did not, however, explain everything. Many elements existed at different weights even while displaying identical chemical properties. In other words, atoms of the same element, identical in every other way, could vary slightly in mass.

The existence of a third subatomic particle, the neutron, so–named because it had no charge, explained the differences. First identified in 1932 by James Chadwick, Rutherford's colleague at Cambridge, neutrons within the nuclei of atoms

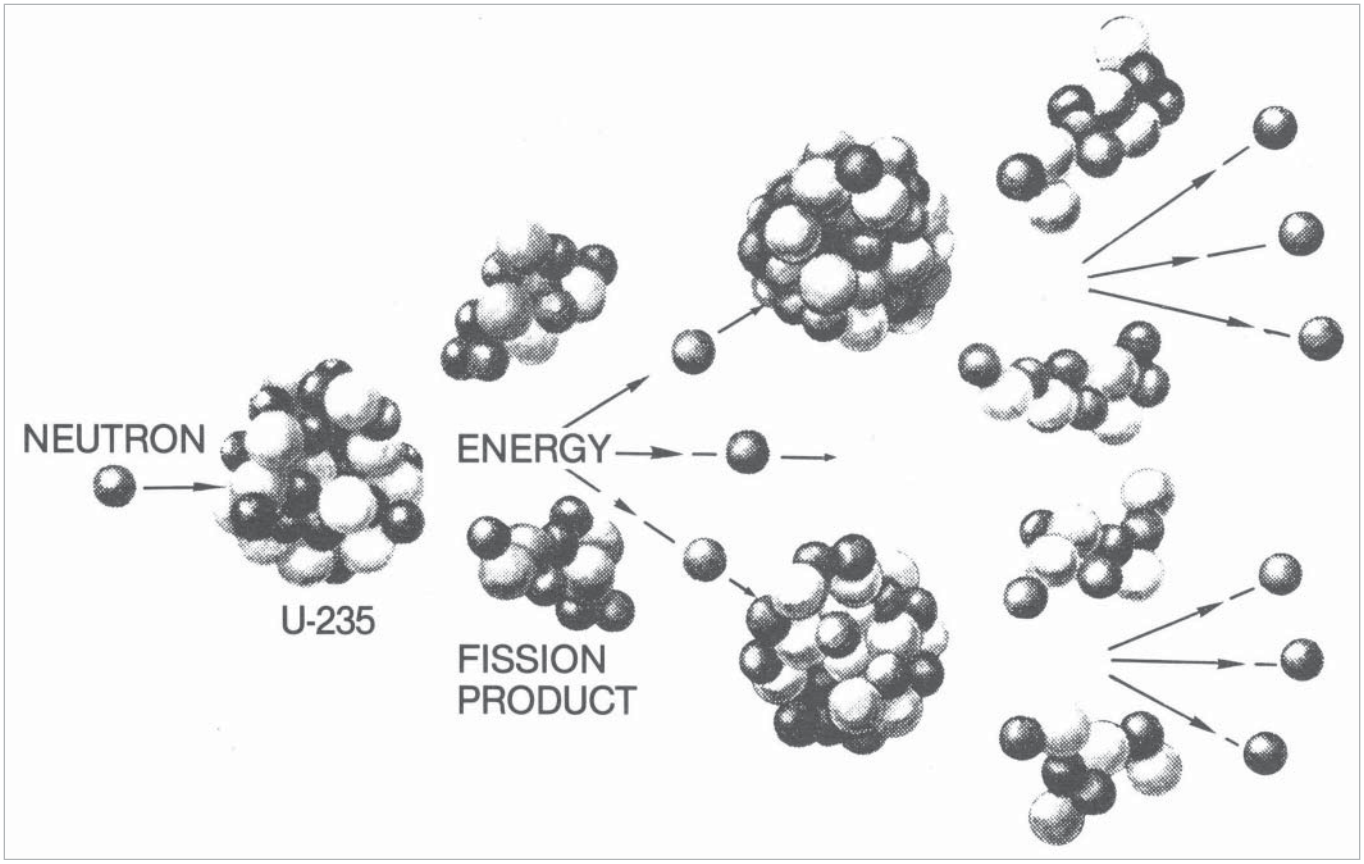


Ernest Rutherford. Source: Argonne National Laboratory.

of a given element could vary in number. The different types of atoms of the same element but with varying numbers of neutrons were designated isotopes. The isotopes of uranium, for instance, all have ninety–two protons in their nuclei and ninety–two electrons in orbit. But uranium–238, which accounts for over ninety–nine percent of natural uranium, has 146 neutrons in its nucleus, compared with 143 neutrons in the rare uranium–235, making up only seven–tenths of one percent of natural uranium.

These insights aided greatly in the understanding of the building blocks of the elemental world, but an unexpected discovery by researchers in Nazi Germany just before Christmas 1938 radically changed the direction of both theoretical and practical nuclear research. In their Berlin laboratory, the radiochemists Otto Hahn and Fritz Strassmann found that when they bombarded uranium with neutrons the uranium nuclei changed greatly and broke into two roughly equal pieces. The pieces were lighter elements, one of which was a radioactive isotope of barium. Even more significantly, the products of the experiment weighed less than that of the original uranium nucleus. From Albert Einstein's formula, $E=mc^2$, which states that mass and energy are equivalent, it followed that the mass lost during the splitting process must have been converted into energy in the form of kinetic energy that could in turn be converted into heat. Calculations made by Hahn's former colleague, Lise Meitner, a refugee from Nazism then staying in Sweden, and her nephew, Otto Frisch, led to the conclusion that so much energy had been released that a previously undiscovered kind of process was at work. Frisch, borrowing the term for cell division in biology—binary fission-–named the process fission.

Lise Meitner and Otto Hahn in their laboratory at the Kaiser Wilhelm Institute in Berlin. Source: Argonne National Laboratory.



Uranium-235 fission chain reaction.

Fission of the uranium atom, it soon became apparent, had another important characteristic besides the immediate release of enormous amounts of energy. This was the emission of neutrons. The energy released when fission occurred in uranium caused several neutrons to "boil off" the two main fragments as they flew apart. Given the right set of circumstances, physicists speculated, these secondary neutrons might collide with other atoms and release more neutrons, in turn smashing into other atoms and, at the same time, continuously emitting energy. Beginning with a single uranium nucleus, fission could not only produce substantial amounts of energy but also lead to a reaction creating ever–increasing amounts of energy. The possibility of such a "chain reaction" completely altered the prospects for releasing the energy stored in the nucleus. A controlled self–sustaining reaction could make it possible to generate a large amount of energy for heat and power, while an unchecked reaction could create an explosion of huge force.[9]

The Atomic Bomb and the Manhattan Project

The possible military uses that might be derived from the fission of uranium atoms were not lost on the best and brightest of the world's physicists. In August 1939, Einstein, with the help of Hungarian émigré physicist Leo Szilard, wrote a letter to President Roosevelt, informing him that recent research showed that a chain reaction in a large mass of uranium could generate vast amounts of power. This could conceivably lead, Einstein wrote, to the construction of "extremely powerful bombs." A single bomb, the physicist warned, potentially could destroy an entire seaport.

Albert Einstein and Leo Szilard. Source: Institute for Advanced Study.

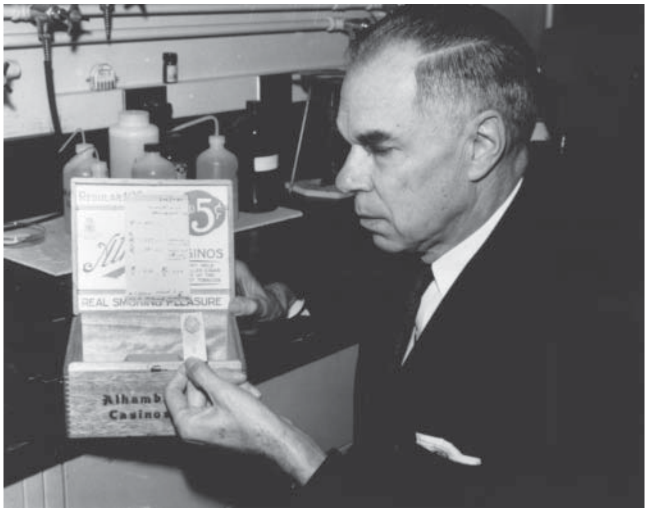
In response to Einstein's letter, President Franklin D. Roosevelt initiated government-sponsored research on uranium and fission. Source: Franklin D. Roosevelt Presidential Library.

Einstein called for government support of uranium research, noting darkly that Germany had stopped the sale of uranium and German physicists were engaged in uranium research.[10]

President Roosevelt and his advisors reacted cautiously to the Einstein letter, providing only limited initial federal funding for isotope separation and chain reaction research. No one as yet knew whether an atomic bomb was even possible and, if it was, whether a bomb could be produced in time to affect the outcome of the war. Researchers discovered early on that uranium–238 could not sustain a chain reaction required for a bomb. Uranium–235, they knew, still might be able to, but separating uranium–235 from uranium–238 would be extremely difficult and expensive. The two isotopes were chemically identical and therefore could not be separated by chemical means. And with their masses differing by less than one percent, other means of separation would be very difficult. No proven method existed for physically separating the two in any quantity.

At the same time, a second possible path to a bomb gradually emerged. Researchers studying uranium fission products at the Radiation Laboratory at the University of California in Berkeley discovered another product, a new transuranium, man–made element, named neptunium, with an atomic number of 93, created when uranium–238 captured a neutron and decayed. Neptunium itself decayed to yet another transuranium element. In February 1941, the chemist Glenn T. Seaborg identified this as element 94, which he later named plutonium. By May he had proven that plutonium–239 was 1.7 times as likely as uranium–235 to fission. The finding suggested the possibility of producing large amounts of the fissionable plutonium in a uranium pile, or reactor, using plentiful uranium–238 and then separating it chemically. This might be less expensive and simpler than building isotope separation plants.[11]

Not until 1942, after the Japanese attack on Pearl Harbor had thrust the United States into World War II, was the decision made to proceed with a full-scale program to build an atomic bomb.



Discovery of plutonium by the University of California, Berkeley, chemist Glenn T. Seaborg suggested a second path toward building an atomic bomb. Source: Department of Energy.

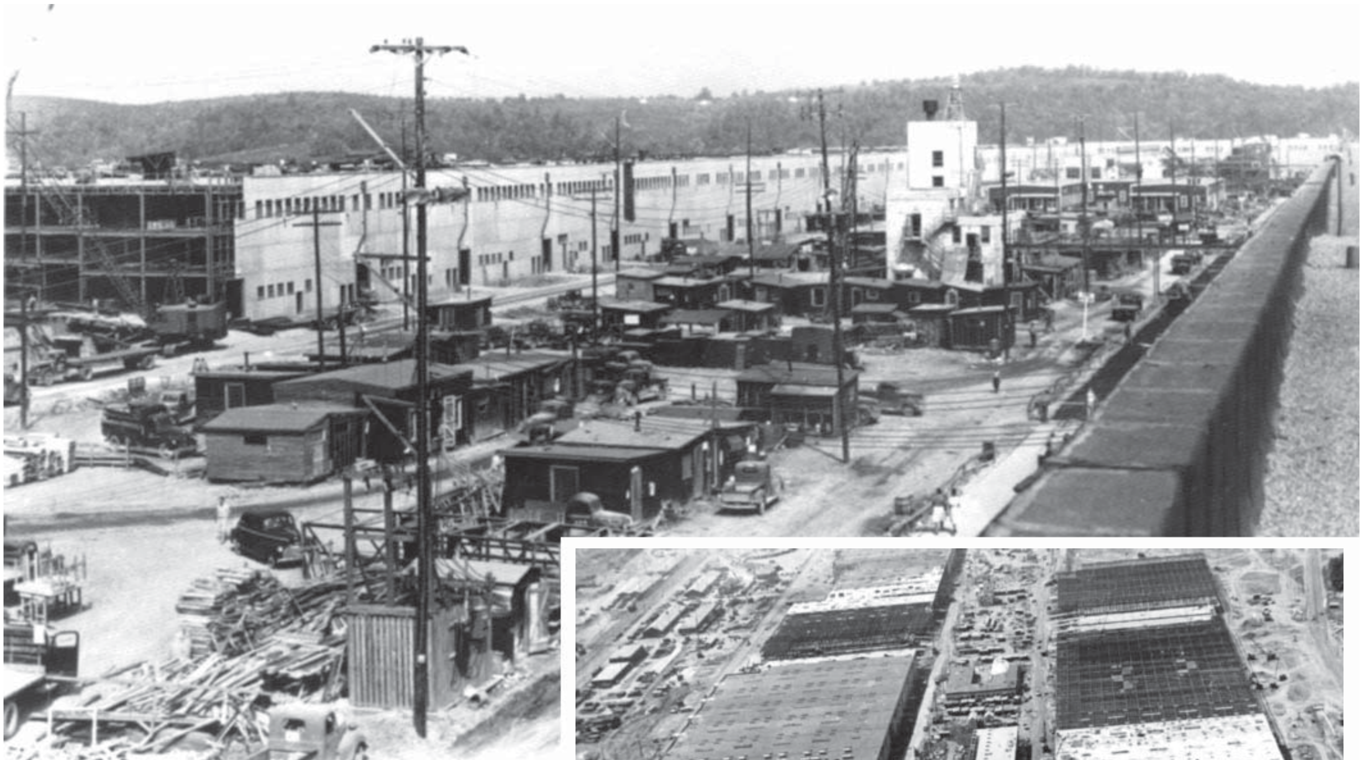
James Chadwick and General Leslie R. Groves. Source: Department of Energy.

Security requirements suggested placing the atomic bomb project under the Army Corps of Engineers. The Corps set up the Manhattan Engineer District commanded by Brigadier General Leslie R. Groves. The Manhattan Engineer District operated like a large construction company, but on a massive scale and with an extreme sense of urgency. Unique as well was the investment of hundreds of millions of dollars in unproven processes. By the end of the war, Groves and his staff expended approximately $2.2 billion on production facilities, towns, and research laboratories scattered across the nation. Secrecy and fear of a major accident dictated that the production facilities be located at remote sites. Due to ongoing uncertainties as to which processes would work, two distinct paths were chosen to obtain a bomb.

One involved isotope separation of uranium–235. Groves located the production facilities for isotope separation at the Clinton Engineer Works, a ninety–square–mile parcel carved out of the Tennessee hills just west of Knoxville. (The name Oak Ridge did not come into widespread usage for the Clinton reservation until after the war.) Groves placed two methods into production: 1) gaseous diffusion, based on the principle that molecules of the lighter isotope, uranium–235, would pass more readily through a porous barrier; and 2) electromagnetic, based on the principle that charged particles of the lighter isotope would be deflected more when passing through a magnetic field. Later, in 1944, Groves approved a production plant using a third method, liquid thermal diffusion, in which the lighter isotope concentrated near a heat source passing through the center of a tall column. Convection, over time, carried the lighter isotope to the top of the column.

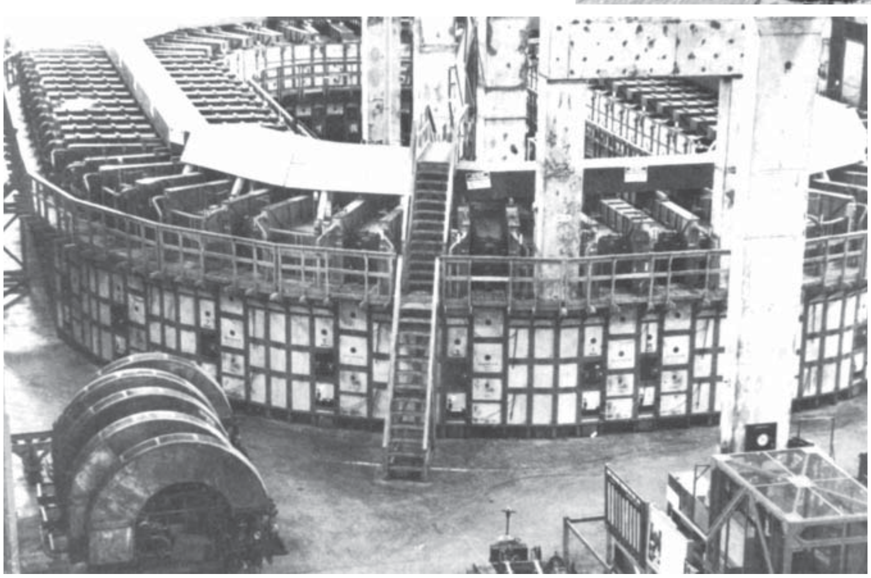
The second path chosen to build the bomb focused on producing large amounts of fissionable plutonium in a uranium pile. On December 2, 1942, on a racket court under the west grandstand at Stagg Field of the University of Chicago, researchers headed by the Italian-émigré physicist Enrico Fermi achieved the first self–sustaining chain reaction in a graphite and uranium pile. Groves built a pilot pile and plutonium separation facility at the X–10 area of Clinton. Space and power generating limitations, however, precluded building the full–scale production facilities at the site. Groves chose an alternate site near Hanford, Washington, on the Columbia River, because of its isolation, long construction season, and access

Manhattan Project Facilities



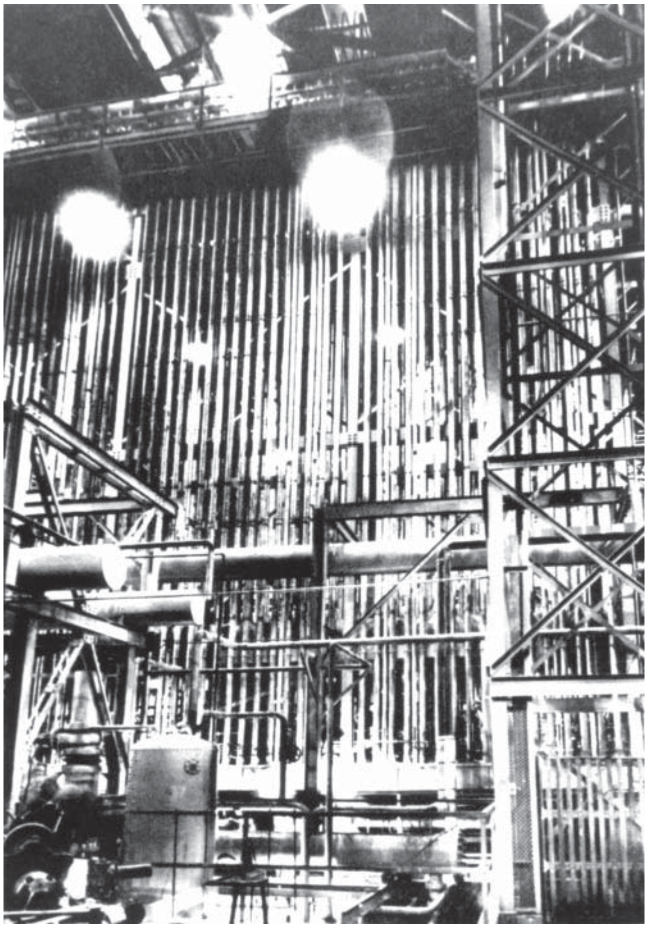
K-25 Gaseous Diffusion Plant under construction at Clinton (Oak Ridge). Source: Department of Energy.

K-25 from opposite end. Source: Department of Energy.

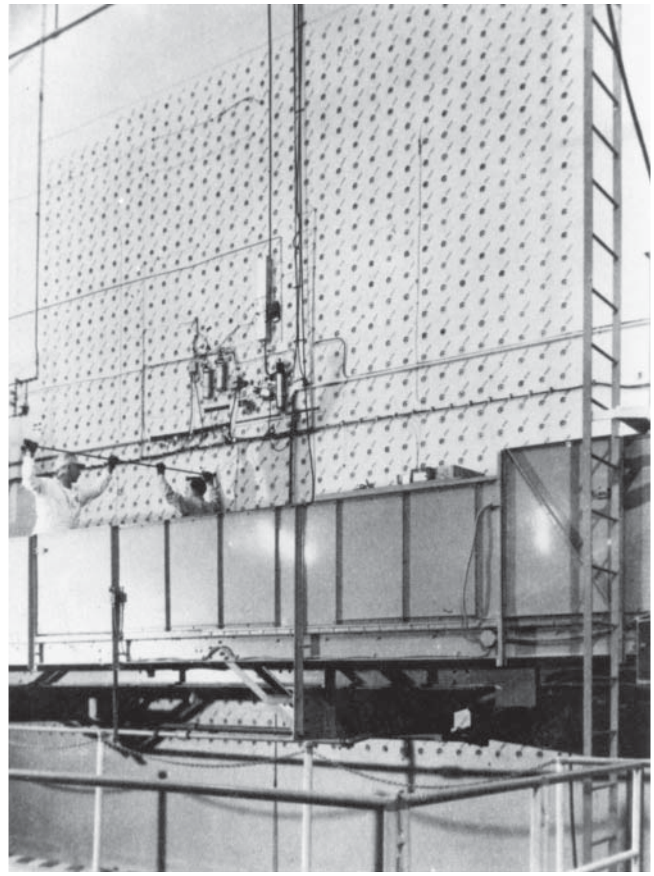


Y-12 Alpha Racetrack at Clinton used the electromagnetic method to separate uranium isotopes. Spare magnets in left foreground. Source: Department of Energy.

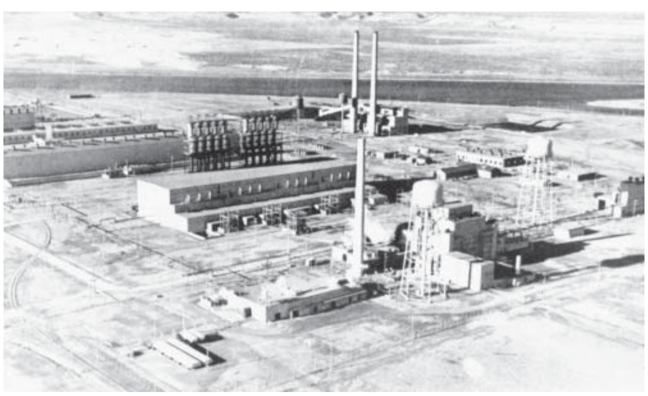
Manhattan Project Facilities



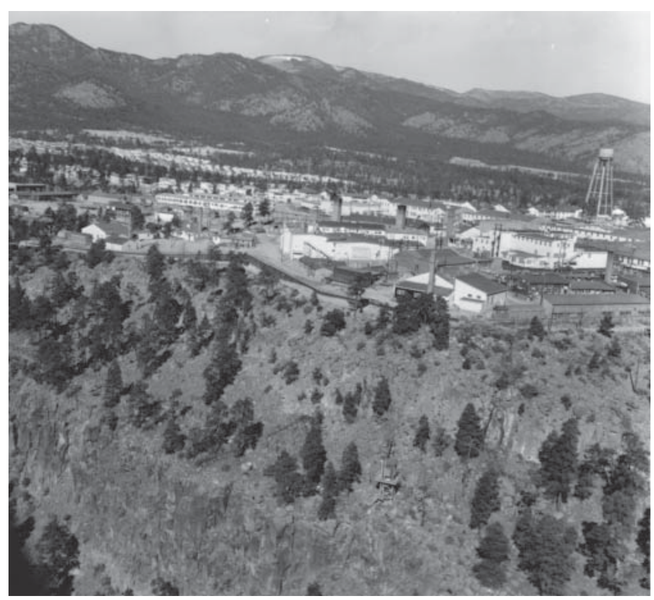
Section of S-50 Liquid Thermal Diffusion Plant at Clinton. Source: Department of Energy.



Workers loading uranium slug into face of air-cooled pile at the X-10 area of Clinton. Source: Department of Energy.



Pile D at Hanford. Pile in foreground, water treatment plant in rear. Source: Department of Energy.



Los Alamos laboratory mid-1940s. Source: Los Alamos National Laboratory

West end of Stagg Field at the University of Chicago. Location of CP-1, the world's first nuclear pile or reactor. Source: Argonne National Laboratory.

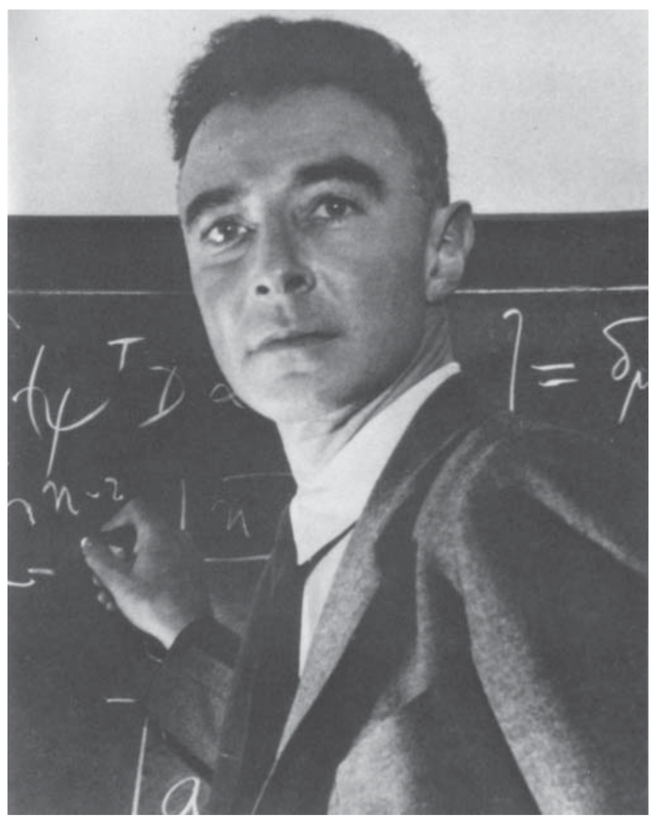
to hydroelectric power. Three water–cooled reactors, designated by the letters B, D, and F, and corresponding separation facilities were built at the Hanford Engineer Works.

Much of the research work on producing plutonium, including design of the piles, took place at the Metallurgical Laboratory (Met Lab) in Chicago. Design and fabrication of the first atomic bombs were the responsibility of the newly established Los Alamos Scientific Laboratory, located at a virtually inaccessible site high on a mesa in northern New Mexico. The laboratory, headed by J. Robert Oppenheimer, attracted a remarkable array of scientists from universities across the United States.[12]

Bomb Design

Designing the bomb, or "gadget" as it came to be known, was not an easy task. Precise calculations and months of experimentation were required to obtain the optimum specifications of size and shape. For the bomb to work, sufficient fissionable material needed to be brought together in a critical mass, which would ignite a chain reaction that would release the greatest possible amount of energy before being blown apart and dispersed in the explosion. The simplest way to accomplish this, which became known as the gun method, brought two subcritical masses of fissionable material together at high speed to form a supercritical mass. This was done using conventional artillery technology to fire one subcritical mass into the other. The gun method was used for the uranium–235 bomb.

Los Alamos scientists discovered, however, that the gun method would not work for plutonium. Impurities in the plutonium would set off a predetonation after a critical mass had been reached but before the optimum configuration had been attained. The result would be an ineffective, wasteful fizzle. As an alternative, scientists turned to the relatively unknown implosion method. With implosion, symmetrical shockwaves directed inward



J. Robert Oppenheimer. Source: Reprinted by permission of the J. Robert Oppenheimer Memorial Committee.

would compress a subcritical mass of plutonium, releasing neutrons and causing a chain reaction.

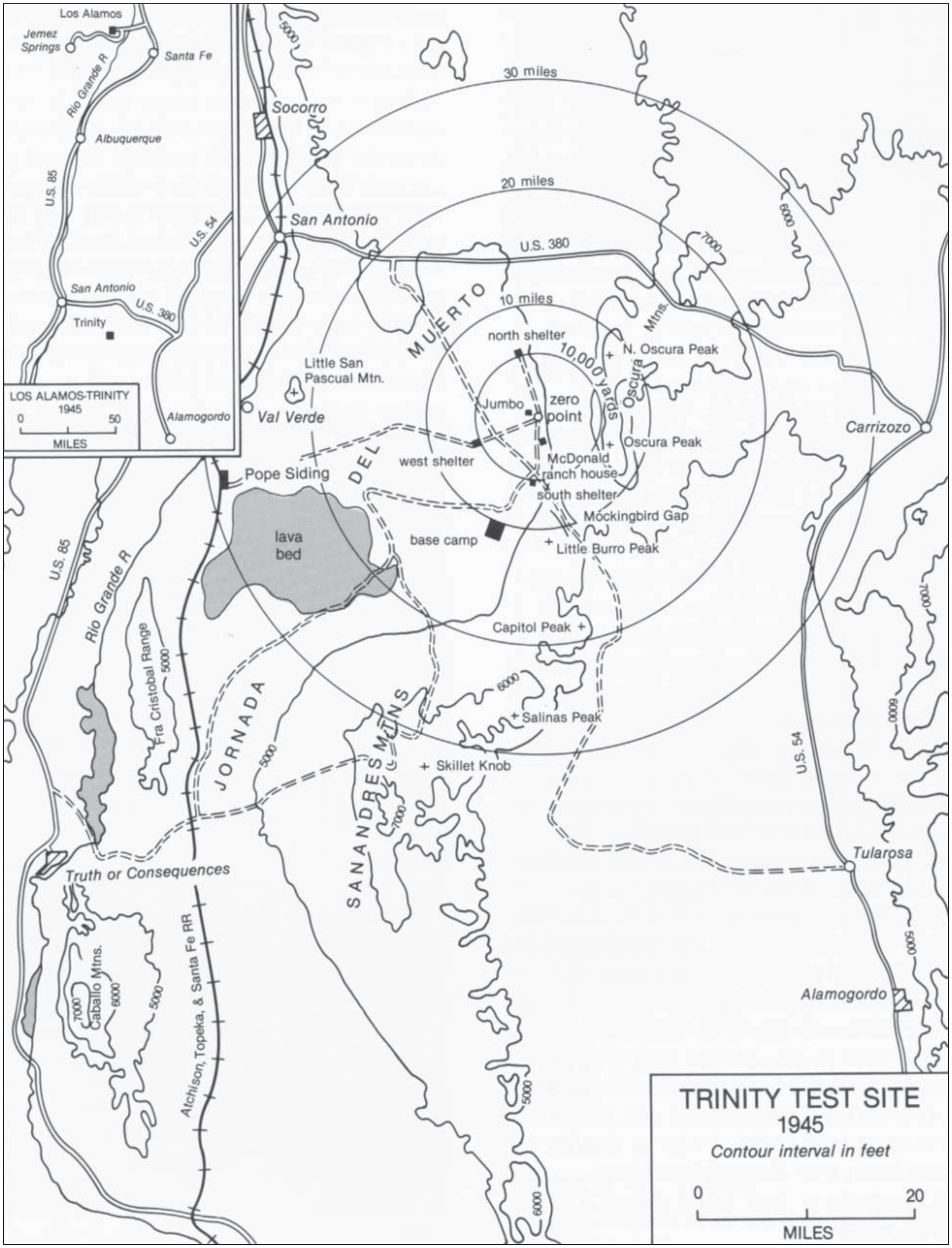
Los Alamos, working with the Army Air Force, developed two bomb models by spring 1944 and began testing them, without the fissionable materials, with drops from a B–29 bomber. The plutonium implosion prototype was named Fat Man. The uranium gun prototype became Little Boy. Field tests with the uranium prototype eased remaining doubts about the artillery method. Confidence in the weapon was high enough that a full test prior to combat use was seen as unnecessary. The plutonium device was more problematic. It would have to be tested before use.[13]

The Trinity Test

The test shot, dubbed Trinity by Oppenheimer, was the most violent man–made explosion in history to that date. Detonated from a platform on top of a 100-foot high steel tower, the Trinity device used about 13½ pounds of plutonium. The Trinity test also posed the most significant hazard of the entire Manhattan Project. Test planners chose a flat, desert scrub region in the northwest corner of the isolated Alamogordo Bombing Range in southern New Mexico for the test. The site was several hundred miles from Los Alamos, and the nearest off-site habitation was twenty miles away. Scientists, workers, and other observers, during the test, would be withdrawn almost six miles and sheltered behind barricades. Some apprehension existed that there would be a large–scale catastrophe. Los Alamos scientists discussed the possibility that the atmosphere might be ignited and the entire earth annihilated but dismissed this as extremely remote. Dangers from blast, fragments, heat, and light, once one was sufficiently removed from ground zero, evoked little concern.

Tower for Trinity test. Source: Department of Energy.

Not so with radiation. Prior to Trinity, scientists were well aware that the blast would create potential radiation hazards. Plutonium in the device would fission into other radionuclides. Neutrons would strike various elements on the ground and turn some into active nuclides. This radioactive debris would be swept with fission products into a growing fireball and lifted high into the air. Once in the atmosphere, they would form a cloud of intense radioactivity. Immediate radiation from the explosion and residual radioactive debris initially caused faint worry because of dilution in the air and the isolation of the site, but as the test drew closer planners realized, with some sense of urgency, that radioactive fallout over local towns posed a real hazard. Groves, in particular, feared legal culpability if things got out of hand. As a result, Army intelligence agents located and mapped everyone within a forty–mile radius. Test planners set up an elaborate off-site monitoring



Trinity Test Site. Source: Reprinted from Vincent C. Jones, *Manhattan: The Army and the Atomic Bomb* (Washington, D.C.: Government Printing Office, 1985).

Trinity device being readied. Source: Department of Energy.

system and prepared evacuation plans if exposure levels became too high.[14]

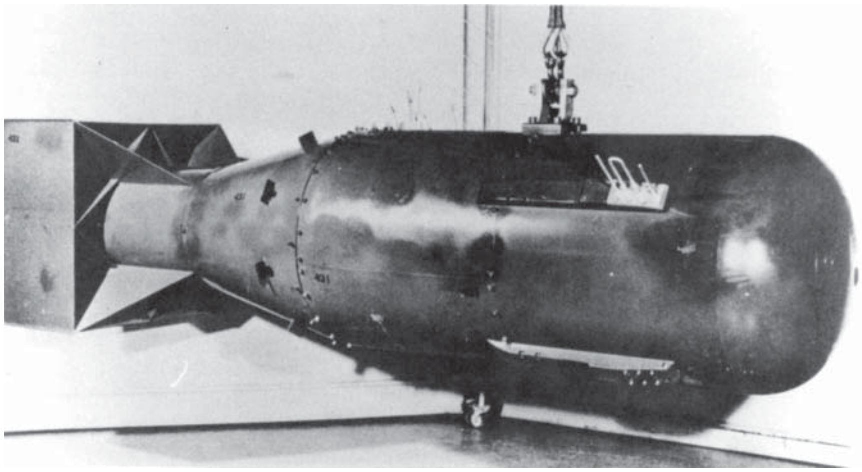
On July 16, 1945, the Trinity device detonated over the New Mexico desert and released approximately 21 kilotons of explosive yield. The predawn blast, which temporarily blinded the nearest observers 10,000 yards away, created an orange and yellow fireball about 2,000 feet in diameter from which emerged a narrow column that rose and flattened into a mushroom shape. The blast scoured the desert floor, leaving a shallow crater, 10 feet deep and some 400 yards across, in which radioactivity far exceeded pretest estimates. More efficient than expected, the shot dropped little fallout on the test site beyond 1,200 yards of ground zero. Most radioactivity was contained within the dense white mushroom cloud that topped out at 25,000 feet. Within an hour, the cloud had largely dispersed toward the north northeast, all the while dropping a trail of fission products. Off-site fallout was heavy. Several ranch families, missed by the Army survey, received significant exposures in the two weeks following Trinity. The families, nonetheless, evidenced little external injury. Livestock were not as fortunate, suffering skin burns, bleeding, and loss of hair. The test, as Stafford Warren, the Manhattan District's chief medical officer, informed Groves, had been something of a near thing. "While no house area investigated received a dangerous amount," he noted, "the dust outfall from the various portions of the cloud was potentially a very dangerous hazard over a band almost 30 miles wide extending almost 90 miles northeast of the site." The Alamogordo site, Warren concluded, was "too small for a repetition of a similar test of this magnitude except under very special conditions." For any future test, he proposed finding a larger site, "preferably with a radius of at least 150 miles without population."[15]

Remains of Trinity tower footings. Oppenheimer and Groves at center. Source: Department of Energy.

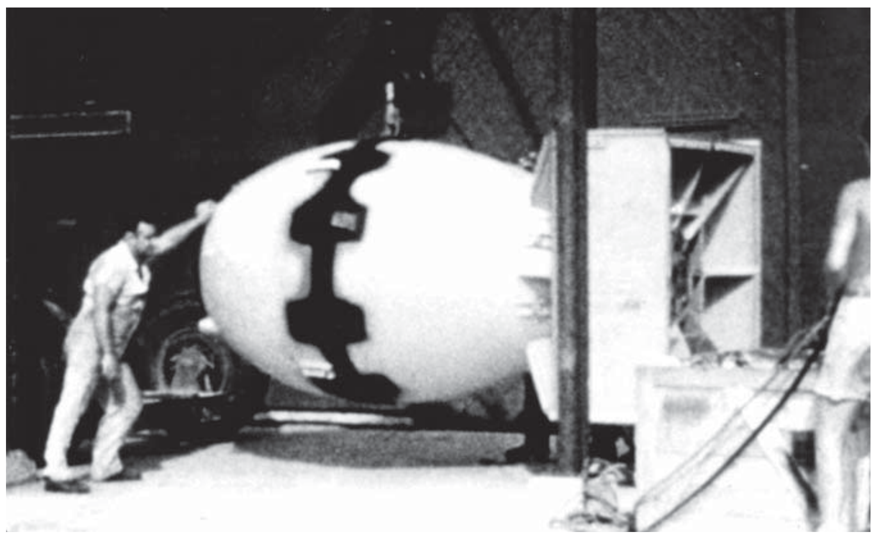
From the Second World War to the Cold War

Three weeks after the Trinity test, on August 6, 1945, Little Boy, the untested uranium bomb, was dropped at Hiroshima, Japan. The plutonium weapon, Fat Man, followed at Nagasaki on August 9. Use of the bombs helped bring an end to the war in the Pacific, with Japan surrendering on August 14.[16]

War’s End



Model of Little Boy uranium bomb. Source: Department of Energy.



Fat Man plutonium bomb being readied at Tinian in the Pacific. Source: Los Alamos National Laboratory.

Oak Ridge workers celebrate the end of World War II. Source: Ed Westcott.

The end of the Second World War brought with it a whole new set of issues and problems, not least of which revolved around the dilemma of what to do with the nuclear genie now that he had been let out of the bottle. Certainly, there was no getting him back in. The United States could not now return to a simpler time when atomic bombs, let alone the knowledge of the physics behind atomic bombs, did not exist. The discovery of nuclear energy, as President Harry S. Truman told Congress in October 1945, "began a new era in the history of civilization." And while this new era held the promise of perhaps limitless energy for peaceful purposes, the prospect of every nation with its own bomb was terrifying, to say the least. Clearly, some sorts of controls over nuclear energy were optimal and necessary. In the immediate aftermath of the war, the United States sought with mixed success to implement regimes for controlling and regulating the atom at both the domestic and international levels.[17]

On the domestic front, Truman called for the establishment of an Atomic Energy Commission to take over the Manhattan Project's material resources and "to control all sources of atomic energy and all activities connected with its development." Following often bitter debate over civilian–versus–military control, Congress passed legislation creating the new agency, and Truman signed it into law on August 1, 1946. The Atomic Energy Act of 1946 transferred authority from the Army to the new Atomic Energy Commission (AEC) composed of a five–member civilian board serving full–time. Oppenheimer headed up the General Advisory Committee to assist the Commission on scientific and technical issues. The Military Liaison Committee was organized to assure input by defense officials. The act also created the Joint Committee on Atomic Energy within Congress to exercise control over nuclear affairs. As inheritors of the Manhattan Engineer District's far–flung scientific and industrial complex, the Atomic Energy Commission continued the government monopoly in the field of atomic research and development.[18]

Efforts to implement international control were less fruitful. As the culmination of discussions that had begun within government circles even before the end of the war, Bernard Baruch, an "elder statesman" who had served American presidents in various capacities since the First World War, unveiled the United States plan in a speech to the United Nations on June 14, 1946. Baruch proposed establishing an international atomic development authority that would control all activities dangerous to world security and possess the power to license and inspect all other nuclear projects. The Soviet Union, the United States's erstwhile ally during the Second World War, rejected the Baruch Plan because it wanted to develop its own nuclear weapons and would not give up veto power over the development authority's activities.

Bernard Baruch presents the American plan for international control to the United Nations, June 14, 1946. Source: United Press International.

The impasse over international control of the atom was part of the onset of a new global struggle, this time with the Soviet Union. The breathing space between two wars—the Second World War and the Cold War—was very brief. Already in March 1946, Winston Churchill warned of an "iron curtain" that had descended on Eastern Europe as the Soviet Union sought to expand its influence. A year later, President Truman proclaimed the Truman Doctrine and asked for funds for overseas military assistance. On the issue of control of nuclear weapons, the United States, believing that Soviet troops posed a threat to Western Europe and recognizing that American conventional forces had rapidly demobilized, refused to surrender its atomic deterrent without adequate controls. In an atmosphere of mutual suspicion, the Cold War set in.[19]

Nuclear Weapons Testing: Crossroads

If nuclear weapons were going to become a cornerstone of Cold War military strategy, military officials needed to know more about the effects produced by these weapons. Following the Trinity test and the bombings of Hiroshima and Nagasaki, officials still knew very little about weapon effects, especially on naval targets. Accordingly, the Joint Chiefs of Staff requested and received presidential approval to conduct a test series during summer 1946. Vice Admiral W. H. P. Blandy, head of the test series task force, proposed calling the series Operation Crossroads. "It was apparent," he noted, "that warfare, perhaps civilization itself, had been brought to a turning point by this revolutionary weapon." Experience with the radiological hazards of Trinity and the two bombs dropped on Japan strongly influenced the decision to locate Crossroads at Bikini Atoll in the Marshall Islands, which was far from population centers in the middle of the Pacific. Bikini was a typical coral atoll. With a reef surrounding a lagoon of well over 200 square miles, the atoll offered ample protected anchorage for both a target fleet and support ships. As a test site, Bikini held three drawbacks. The distance from the continental United States made extraordinary logistical demands; the humid climate created numerous problems for sophisticated electronic and photographic equipment; and the atoll was inhabited. The military removed the native population of 162 to another atoll and brought in a large, invited audience of journalists, scientists, military officers, congressmen, and foreign observers.

Shot Able, a plutonium bomb dropped from a B–29 on July 1, performed as well as the two previous plutonium devices, at Trinity and Nagasaki. Able nonetheless failed to fulfill its pretest publicity buildup. Partly this was because expectations had been too extravagant and observers were so far from the test area that they could not see the target array. Partly it was because the drop had missed the anticipated ground zero by some distance and the blast sank only three ships. In any event, the general conclusion reached by the media at Bikini was that the "atomic bomb was, after all, just another weapon."

Baker proved much more impressive. Detonated ninety feet underwater on the morning of July 25, Baker produced a spectacular display as it wreaked havoc on a seventy–four–vessel fleet of empty ships and spewed thousands of tons of water into the air. As with Able, the test yielded explosions equivalent to 21,000 tons of TNT. Baker, as the historians Richard Hewlett and Oscar Anderson note, "helped restore respect for the power of the bomb."[20]

Baker also created a major radiation problem. The test produced a radioactive mist that deposited active products on the target fleet in amounts far greater than had been predicted. As the Joint Chiefs of Staff evaluation board later noted, the contaminated ships "became radioactive stoves, and would have burned all living things aboard them with invisible and painless but deadly radiation." Decontamination presented a significant radiation

Crossroads

Able test of the Crossroads series, July 1, 1946. Note the shock wave sweeping out around the lagoon. Source: Department of Energy.

Baker test of the Crossroads series, July 25, 1946. Source: Department of Energy.

hazard, and, as a result, over a period of several weeks personnel exposure levels began to climb. A worried Stafford Warren, who headed the testing task force's radiological safety section, concluded that the task force faced "great risks of harm to personnel engaged in decontamination and survey work unless such work ceases within the very near future." With exposure data in hand, Warren prevailed and decontamination operations ceased. A planned third shot, to be detonated on the bottom of the lagoon, was canceled.[21]

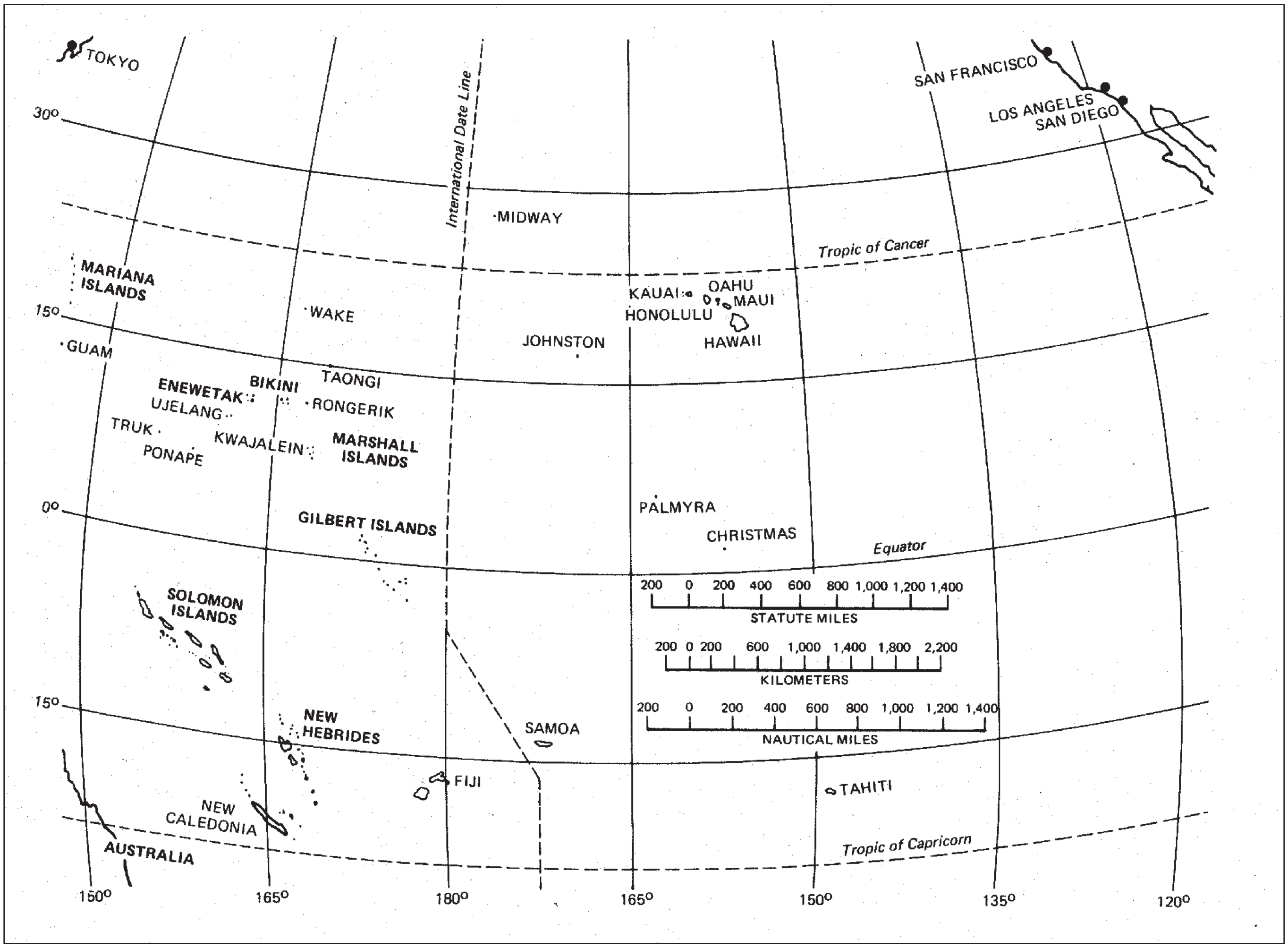
Nuclear Weapons Testing: Sandstone

As the Cold War intensified, so did the demand for nuclear weapons. The nation's nuclear stockpile in 1947 consisted of only thirteen weapons, and, as Atomic Energy Commission Chairman David E. Lilienthal told President Truman on April 2, none of these were assembled. The paucity of bombs was partly attributable to the scarcity of weapons–grade fissionable materials. Theoretical advances made by Los Alamos bomb designers suggested ways to use these materials more efficiently—and thus provide for more weapons—but confirmation could only come from full–scale testing. Los Alamos therefore proposed a three–test series to the Atomic Energy Commission. Unlike Crossroads, the series would concentrate on bomb performance and the validation of three new weapon designs and not on weapon effects.

The location for the test series, called Sandstone, fostered some debate. The Marshall Islands in the Pacific again seemed the logical choice, but the State Department, for good reason, feared foreign criticism. Administered by Japan between the two world wars under a mandate from the League of Nations, the Marshall Islands were now a trust territory of the United States under an agreement with the United Nations. The agreement allowed military use of the islands but also imposed special responsibilities for native welfare. It was hard to argue that relocation of the natives and nuclear weapons testing were to their benefit. The Bikini islanders had been moved to Rongerik Atoll, which was too small and barren to support them, and the United States apparently had done little to help. Indeed, when the poor record of American stewardship became public in fall 1947, it aroused sufficient worldwide protest that action by the United Nations seemed possible. In any event, whatever the public and foreign relations ramifications, few alternatives to the Marshall Islands existed. The Joint Chiefs of Staff strongly opposed a return to the Trinity site in New Mexico because, as General Dwight D. Eisenhower observed, of the public fear that a continental site would engender. Lilienthal also noted that testing at Trinity would "require elaborate super–atmosphere investigations that take time." In the end, the Atomic Energy Commission favored a Pacific site for technical reasons and, with Truman opposed to continental tests, that view prevailed.[22]

The question of where in the Pacific to conduct Sandstone also was not a given. Los Alamos initially suggested returning to Bikini, but the atoll lacked certain features needed for long–term use. Its reef islands were too small and their land surface too limited to support the instrumentation demanded

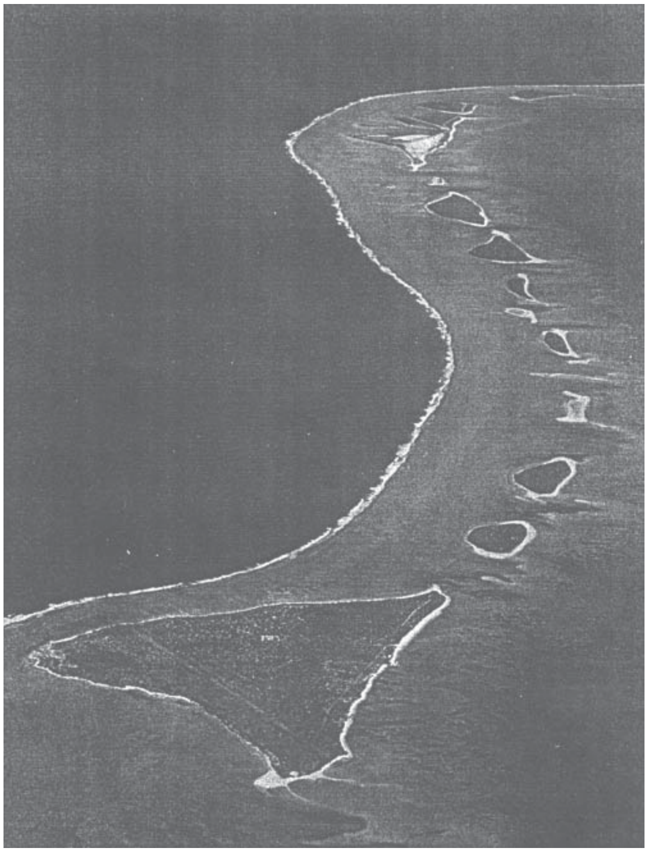
Bikini islanders loading their belongings into a transport ship in preparation for evacuation prior to Crossroads. Source: Defense Threat Reduction Agency/Navy.



The Central Pacific. Source: Reprinted from L.H. Berkhouse, et al., *Operation Crossroads, 1946*, DNA 6032F (Washington: Defense Nuclear Agency, May 1, 1984), p. 20.

by proof–testing. Further study narrowed the choice to Kwajalein or Enewetak, similar but larger atolls located south and west of Bikini respectively. Kwajalein possessed operating air and naval bases, which implied lower set–up costs but at the same time might be a hindrance to radiological safety. Enewetak, by contrast, offered greater and more widely dispersed land area, greater isolation, and less rain. Perhaps a decisive factor in choosing Enewetak was that it required the relocation of only 142 native islanders versus five times that number at Kwajalein.

The military and the Atomic Energy Commission, recalling the fanfare at Crossroads, preferred to hold secret tests but realized that in peacetime this was not possible. They nonetheless held security very tight. The public was informed in December 1947 only of the staffing of the proving ground and the formation of a joint task force. No further notification of nuclear testing was given out until the series concluded the following May. The military, because of security and logistical needs, headed up the joint task force while Los Alamos was responsible for the actual tests. The task force, carrying its precious cargo of fissionable material and most of the nation's skilled bomb designers, sailed on near–war footing, complete with destroyer screen, constant air cover, zigzag course off the main sea–lanes, and crews on round–the–clock alert. Growing tensions with the Soviet Union following the communist coup in Czechoslovakia



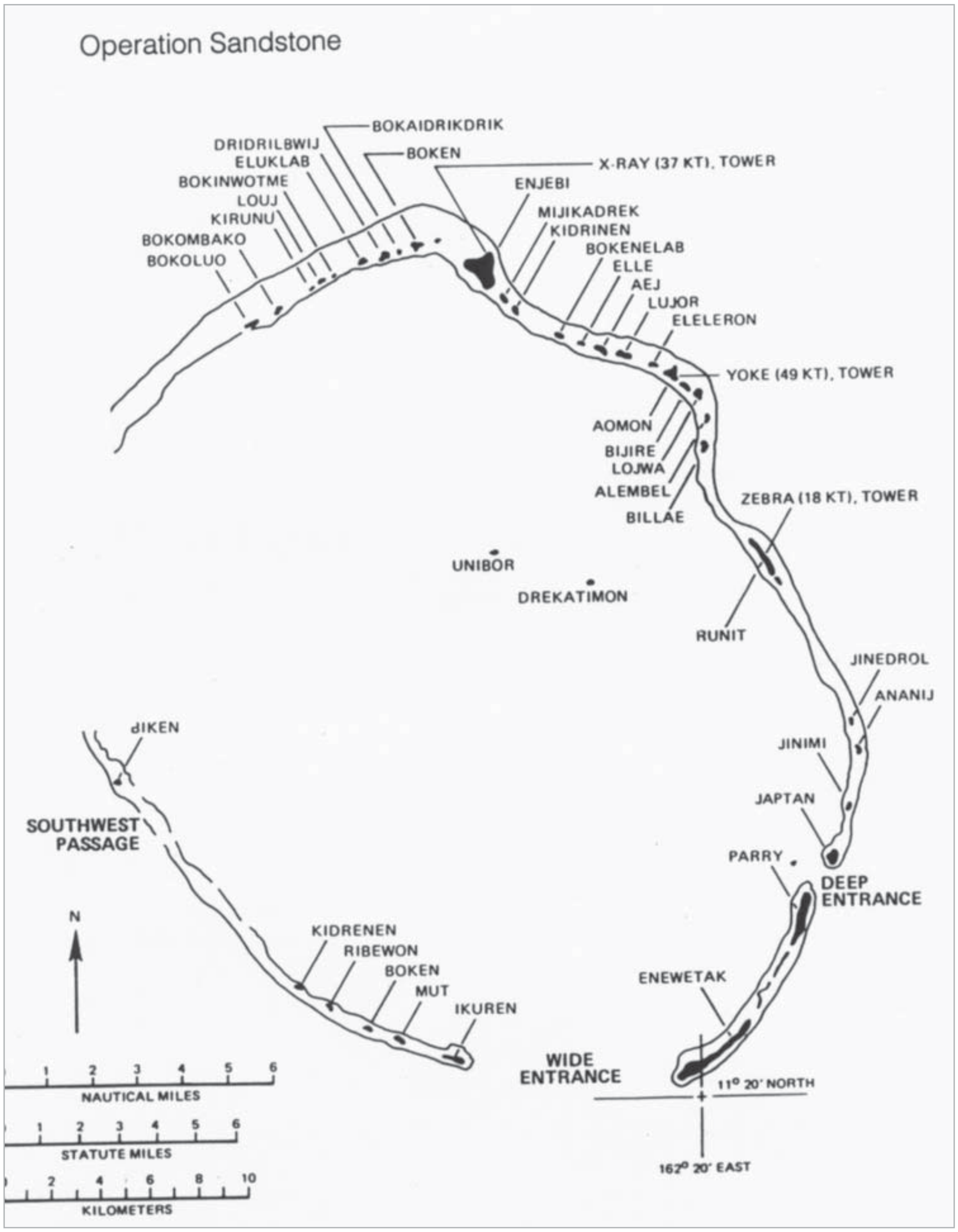
Sandstone series tests took place on the islands making up the northeastern rim of Enewetak Atoll. View from the northwest to the southeast. Source: DOE, NNSA-Nevada Site Office.

Sandstone test at Enewetak. Source: DOE, NNSA-Nevada Site Office.

With the completion of Sandstone, temporary structures were torn down and burned. Source: Reprinted from Clarence H. White, ed., *Operation Sandstone: The Story of Joint Task Force Seven* (Washington: Infantry Journal Press, 1949), p. 64.

and the impending crisis over Berlin raised fears of a surprise attack, a possibility that seemed not entirely groundless after unidentified submarines were sighted in the area. The task force was given orders to use depth charges against any undersea intruders. Officials in Washington even discussed postponing Sandstone and returning both bombs and scientists to the United States.

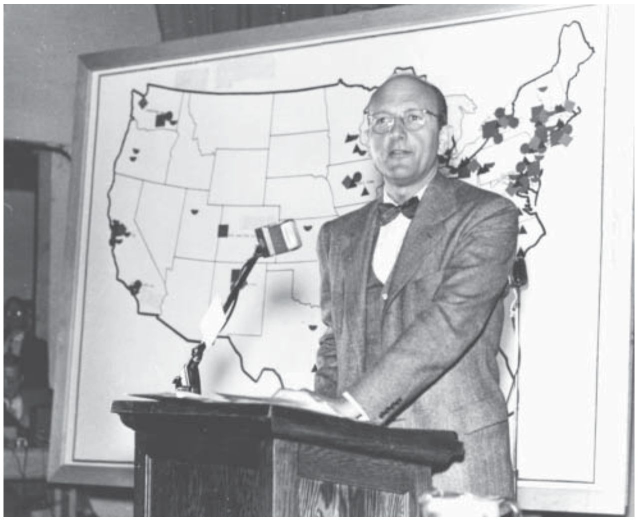
Amidst such distractions, the test series, conducted from April 15 to May 15, 1948, proved an overwhelming success. The three tests performed as expected and fallout remained largely localized. The second shot, Yoke, at forty–nine kilotons, provided the largest explosive yield yet achieved, over twice the size of the Trinity test. More importantly, the new bomb designs translated into more efficient use of fissionable materials. From thirteen weapons in 1947, the nuclear stockpile increased to fifty in 1948. As for Enewetak, despite the expressed intent to make it a permanent proving ground, the task force left few structures standing. For security reasons, work crews systematically destroyed anything providing evidence of possible test results. Upon leaving, the task force arranged to keep the area closed and secure, guarded by a fifty–man garrison.[23]



Enewetak Atoll, 1948. Note locations and yields of tests on the atoll's northeast rim. Source: L.H. Berkhouse, et al., *Operation Sandstone, 1948*, DNA 6033F (Washington: Defense Nuclear Agency, December 19, 1983), p. 20.

Continental Test Site Reconsidered: Project Nutmeg

As successful as Sandstone was, logistics, weather, and security and safety concerns during the operation prompted the military to query the Atomic Energy Commission regarding its opinion on developing a continental test site. Although AEC Chairman Lilienthal thought both "policy and psychological considerations" weighed "strongly against the possibility of holding future tests of atomic weapons inside the United States," he admitted that a continental site might have "certain advantages" over Enewetak for some types of tests. A continental site's "ease of access" would allow greater flexibility in preparation for and conduct



David E. Lilienthal, first chairman of the Atomic Energy Commission, 1947-1950. Source: Department of Energy.

of the tests. In addition, operations might be logistically less expensive, although these savings could be offset by costs for increased safety and security measures that would be required at a continental site. Despite these advantages, Lilienthal again stressed the significant disadvantage, that a continental site would "obviously pose difficult domestic and possibly international relations problems." The "magnitude of these problems," he added, could change "in the event of a national emergency." Lilienthal concluded that the Commission found it "desirable" that an initial study of possible sites be conducted, but he warned that, given the "dangers inherent in a misunderstanding of the status of this proposal," the study should be "carefully safeguarded by maintenance of the classification 'Secret.'"[24]

The Armed Forces Special Weapons Project (AFSWP, pronounced Af–swop), established in early 1947 from the specifically military remnants of the Manhattan Project and tasked with overseeing nuclear weapons doctrine, training, and logistics for the entire military establishment, codenamed the continental test site study Project Nutmeg. AFSWP selected Navy Captain Howard B. Hutchinson to conduct Nutmeg, which had a limited scope of study. As a "highly qualified meteorologist" who had been at Enewetak, Hutchinson was asked only to assess the "physical feasibility" of conducting nuclear weapons tests within the continental United States. He was to determine "how, when, and where," as he put it, tests could be conducted without radioactive fallout causing "physical or economic detriment to the population."[25]

Hutchinson concluded that at "properly engineered sites, under proper meteorological conditions" continental testing would "result in no harm to population, economy or industry." A properly engineered site consisted of a prepared surface and a sufficiently high tower from which to detonate the devices so that "the formation of a crater or the indraft of sand and soil and water into the rising column of hot gases" would be prevented. Given these efforts to minimize the creation of radioactive products, most of the remaining radioactivity would enter the column of hot gases and ascend to the high levels of the atmosphere where it would be "diffused and dispersed over vast areas" depending on meteorological conditions. At Enewetak, he observed, radioactive fallout had been measured within a radius of 600 miles and never exceeded "conservative values of human tolerance" except where rainwater concentrated activity at the ground surface. Besides precipitation, wind conditions and atmospheric stability determined meteorological suitability for testing. Under suitable conditions, Hutchinson stated, it did "not seem probable that harmful concentrations of soluble radio isotopes" could result from nuclear testing.

Determining that testing would not be harmful, Hutchinson turned to locating the optimal continental site. He narrowed his analysis down to the arid southwest and the humid southeast. Of these two areas, he thought the southwest was "more favorable" for "purposes of planning and logistics." Sites remote from population centers and with sufficient surrounding uninhabited space could be chosen so that tests could be conducted "during two–thirds of the year, fully 40% of the time, in perfect safety." Nevada, Arizona, and New Mexico seemed to "offer the optimum conditions as to meteorology, remote available land and logistics," with New Mexico as the most logical choice because it was "a state conditioned to nuclear work" and home to Los Alamos and the "center of atomic bomb storage" at Sandia outside Albuquerque.

The arid southwest, however, possessed one major drawback. A "certain amount" of radioactivity, Hutchinson noted, would fall out of the atmosphere to the eastward, off site, following atomic tests due to prevailing winds. This would not, he reiterated, "harm the population, the economy nor the industry of the nation." If "this negligible possibility" of fallout on inhabited areas nonetheless could not be accepted for sites in the southwest, he reasoned, the eastern coast of the United States offered suitable sites where radioactivity would be harmlessly blown out to sea. A testing site could be located on the coasts of Maine, Delaware, Maryland, or Virginia, but the relatively denser populations, currents that would keep deposited radioactivity closer to shore, and economically valuable fisheries in these states and off their shores favored choosing a site further south on the Carolina coast. Most ideal would be a site somewhere between Cape Hatteras and Cape Fear where "the population is not dense, meteorology is favorable during two–thirds of the year between 20% and 30% of the time, and the waters of the Gulf Stream will remove the waste products to the open Atlantic with no possibility of second order effects through biological processes."[26]

The Project Nutmeg report proposed no specific location as a test site. Nor did it consider in detail, as one official noted, problems involving "real estate, public relations, soil composition, safety, physical security and logistics." Although in agreement with the general conclusions of the study that, at least as far as meteorological and oceanographic factors were concerned, tests could be conducted safely on the Carolina coast, the Atomic Energy Commission remained wary. As Acting Chairman Sumner T. Pike noted, flights over the Carolina coast by officers of the Commission's Division of Military Application revealed that "almost all land which would be useful as a test site is inhabited and improved." As a result, "a considerable number of people would require relocation; some permanently, others for the duration of tests." Pike further pointed out that "considerable ocean going shipping," both domestic and foreign, would have to be controlled during test periods. Considering these factors, the Atomic Energy Commission in early March 1949 concluded that, excepting "a national emergency," a continental site was "not desirable."[27]

Apollo 9 photo of Cape Hatteras, North Carolina, jutting far out into the Atlantic. Cape Lookout is at the bottom left. Cape Fear is about the same distance further to the southwest. Source: National Aeronautics and Space Administration.

The Cold War Resuscitates a Continental Test Site

A national emergency was not long in coming. Relations with the Soviet Union continued to deteriorate, and in late August 1949 the Soviets tested their first fission bomb. The Russian test prompted surprised government officials to look for measures to counter the newly perceived threat. One response was to expand production facilities. A second was to move to the next generation of nuclear weaponry, making what Commissioner Lewis L. Strauss called a "quantum jump" in nuclear technology to thermonuclear weapons, which could increase the explosive yield of the bomb a hundred or even a thousand fold. Advent of the Soviet bomb had reduced the absolute advantage of the United States in nuclear weaponry to a relative advantage based strictly on numbers. In Strauss's view, the thermonuclear weapon, also known as the hydrogen bomb or the "Super," would restore the absolute advantage. Following an intense internal governmental debate on the possibility, wisdom, and morality of the Super, in which Lilienthal and the Oppenheimer–led General Advisory Committee opposed while Strauss, the Hungarian–émigré physicist Edward Teller, and key members of Congress favored moving forward, Truman on January 29, 1950, approved accelerating development of the thermonuclear weapon. Although the concept, in which a nuclear fission bomb would serve as detonator to ignite fusion, dated back to early in the Manhattan Project, no one knew if a thermonuclear weapon could be built due to the formidable technical difficulties that remained.

The first Soviet nuclear test, dubbed Joe-1 by the Americans in reference to Josef Stalin, detonated on August 29, 1949. Source: Peter Kuran, Visual Concept Entertainment, VCE.com, via Atomic Testing Museum.

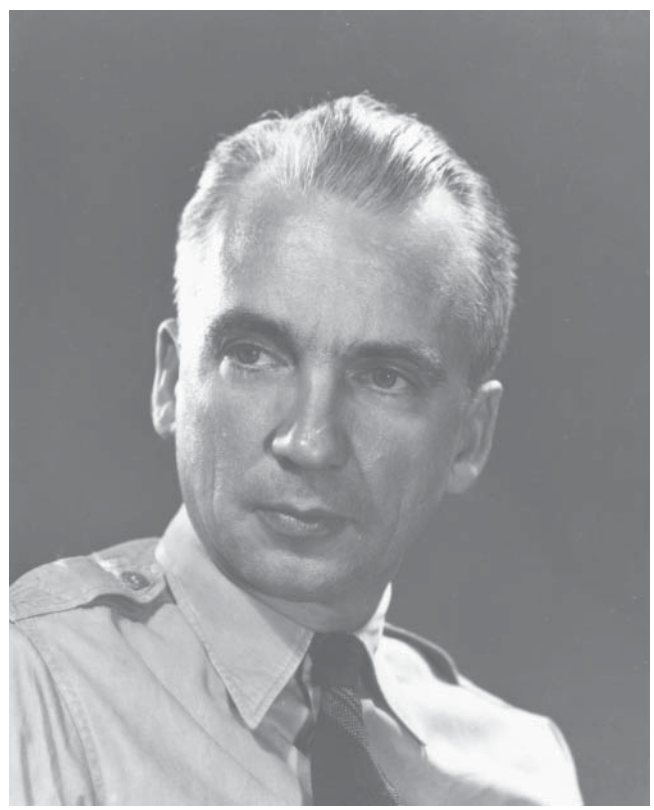
Nuclear testing would be essential in determining the feasibility of the Super. Planning for a new test series in the Pacific had begun shortly after Sandstone ended. By January 1950, test planners envisioned a four–shot series, codenamed Greenhouse, to be conducted at Enewetak in spring 1951. Greenhouse would not involve the testing of a thermonuclear device. But two of the four planned tests would explore some of the principles of fusion. One would demonstrate that small amounts of thermonuclear fuel could boost the yield of a fission bomb. The second would prove that a fission explosion could trigger a thermonuclear reaction. As with Sandstone, a joint task force was set up to conduct the series.[28]

Edward Teller and Louis Strauss successfully pressed to accelerate the development of the thermonuclear weapon. Source: Department of Energy.

Plans for Greenhouse were almost complete when the outbreak of war in Korea threatened to unravel everything. With the armed forces largely unprepared for conflict, the logistics of fighting a war in far–off Korea caused severe strains on the military. Greenhouse seemed unlikely to survive as support for testing appeared far less urgent than the demands of combat. Secretary of Defense Louis A. Johnson informed the Atomic Energy Commission that consideration was being given to the "necessity for postponement" of Greenhouse.[29]

The possible loss of the Pacific test site and series revived Nutmeg. Less than three weeks following the outbreak of hostilities in Korea, the Atomic Energy Commission asked the Department of Defense to join in a renewed study of a continental test site. Within a week, the Armed Forces Special Weapons Project and the AEC had narrowed the list down to a handful of potential sites. AFSWP rejected North American sites outside of the continental United States because of "inaccessibility, lack of required harbors or facilities, unsuitability of the physical features, or adverse geographical environment." Canadian sites possessed the added disadvantages of "expense, limited working season, and probability of drawn–out international negotiations beforehand." Both Alaska and Canada, AFSWP further observed, presented difficulties in the control of "wandering groups" such as trappers and prospectors. The North Carolina coast and the Gulf of Mexico coast in Texas made the final five list of potential sites but were of lower "desirability," as Los Alamos Director Norris E. Bradbury put it, because of the "lack of Government–owned land and large distances from Los Alamos." AFSWP estimated that obtaining the land would take at least one year. The Gulf of Mexico coast held the added drawback, according to AFSWP, of prevailing on–shore winds.

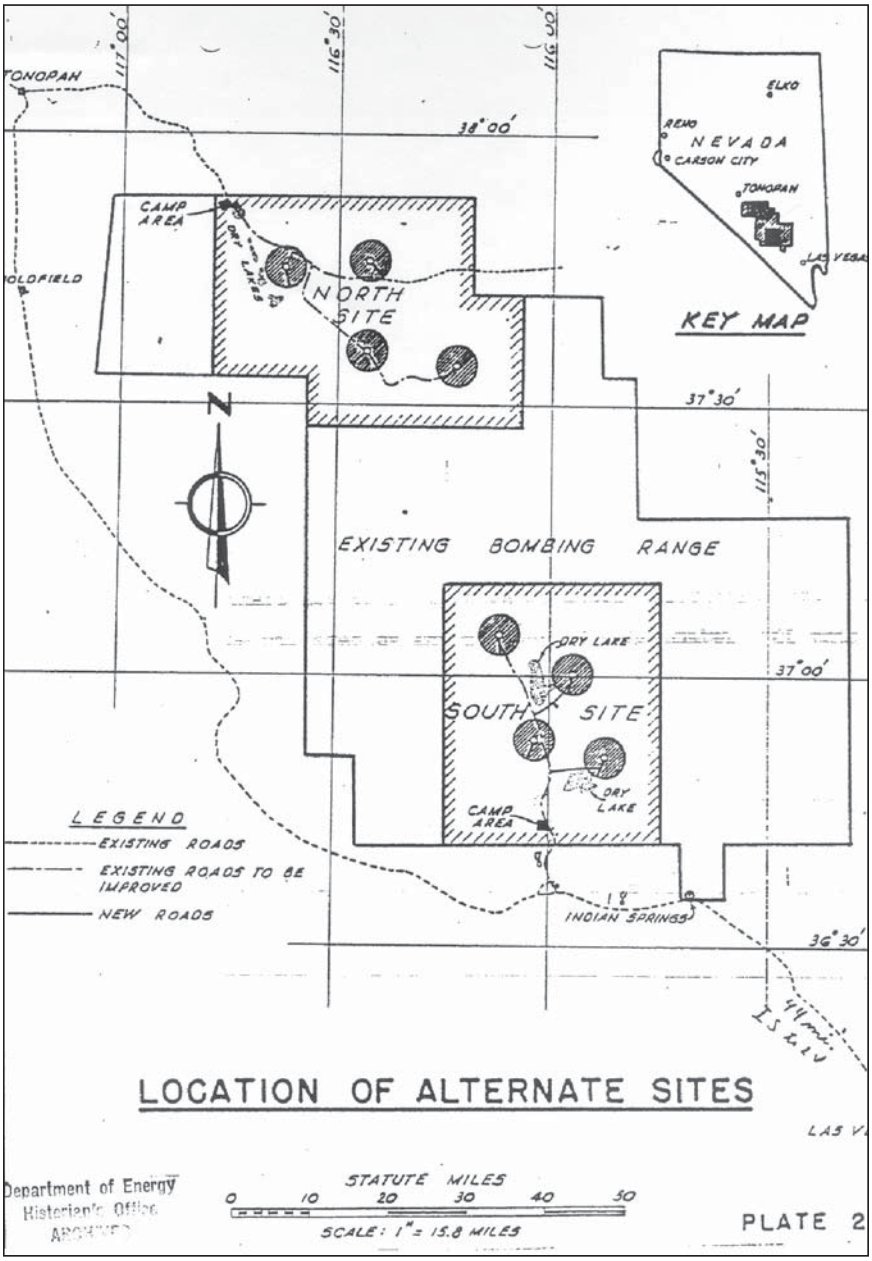
The final three candidate sites were under military control. The Dugway Proving Ground–Wendover Bombing Range in western Utah received low marks primarily because of the relative proximity of Salt Lake City. Based on the 1940 census, AFSWP placed the population downwind within a 125–mile radius of the site at over 350,000. This was the area within which a "possible emergency evacuation" might have to be conducted on ten hours' notice. Of the two remaining sites, AFSWP initially favored the Alamogordo–White Sands Guided Missile Range in New Mexico where the Trinity device had been tested. Closeness to Los Alamos counted in the site's favor, but laboratory officials were concerned about possible variations in wind directions that might endanger "major population centers" such as El Paso, just outside the 125–mile radius due south. Instead, Los Alamos leaned toward the area between Las Vegas and Tonopah, Nevada, somewhere on the Las Vegas Bombing and Gunnery Range.[30]



Norris E. Bradbury, director of the Los Alamos Scientific Laboratory. Source: Department of Energy.

Fallout and the Continental Test Site

Radiological hazards—and the "public relations problem related thereto"—were the primary consideration underlying Los Alamos's preference for the Nevada location. Assuming that the actual test site would be toward the northwest portion of the bombing and gunnery range, only 4,100 people lived downwind from the site within a 125–mile radius. This did not include Las Vegas, and, as such, the site compared very favorably with both the Dugway and White Sands sites, with the latter claiming a population of over 15,000 within a similar radius downwind. In addition, the bombing



Holmes and Narver map showing the location of the North and South sites. Source: Holmes and Narver, "Report Covering the Selection of Proposed Emergency Proving Ground for the United States Atomic Energy Commission," August 14, 1950.

and gunnery range allowed a greater margin for error than the other two sites, possessing the widest arc across which winds of an unanticipated direction might blow without dropping fallout on any nearby town. These initial considerations led Bradbury in late July to confidently predict that tests in Nevada could be conducted with "a degree of public radiological safety which would considerably exceed that of the Alamogordo operation."[31]

The Nevada site also held other advantages. Immediately to the south of the bombing and gunnery range was a government–owned airfield at Indian Springs, with runways 6,600 feet in length and housing for about 300 to 500 people. Convinced of the viability of the Nevada site, the AEC asked Holmes and Narver, its contractor for operations at Enewetak, to perform a quick survey to locate a specific testing site within the range and estimate the costs of shifting Greenhouse to the continental site. The company found "two general areas," designated as the "North Site" and the "South Site," meeting the overall criteria for a proving ground. Located in the extreme northwest corner of the gunnery range approximately 35 miles southeast of Tonopah, the North Site was situated in a basin known as Cactus Flat, at an elevation of about 5,330 feet, with the Kawich Valley adjoining it on the southeast. The South Site consisted of two large valleys, Frenchman Flat and Yucca Flat. Holmes and Narver determined that the South Site held "significant advantages" over the North. The facilities at Indian Springs were much closer. Sources of material supplies were nearer, permitting less haulage and more economical construction. Unlike the North Site, natural barriers screened viewing from public roads at the South Site and permitted easier and more effective security enforcement.

Selection of the South Site, however, would place Las Vegas well within a 125–mile radius. Frenchman Flat, at the southeast corner of the South Site, was only 65 miles from downtown Las Vegas as the crow flies. This raised concerns about possible radiological hazards, and on August 1 a group of experts, including Teller and Enrico Fermi, met to discuss the issues. The group concluded that a "tower–burst bomb having a yield of 25 kilotons could be detonated without exceeding the allowed emergency tolerance dose . . . outside a 180^{o} test area sector 100 miles in radius." The test area sector ran north and east of a line roughly running from Las Vegas to Tonopah. The panel also assumed that "meteorologists would pick the actual shot days." Wind direction and no rain were the critical factors in making the decision. Favorable wind direction was particularly important in the winter when prevailing winds from the northwest blew from the site toward Las Vegas. Meteorologists further needed to "predict within 99.9% accuracy that there would be no rainfall in the general vicinity of zero for a period of 10 hours following the shot." But even on the

Enrico Fermi at work in the laboratory. Source: Argonne National Laboratory.

best of days, the panel realized, there likely would be measurable off-site fallout. Fermi suggested that at the upper end of the "emergency tolerance dose," inhabitants subject to exposure should be warned to stay indoors, take showers, and the like. The panel thought that the risk for exposed off-site inhabitants was "not a probability that anyone will be killed, or even hurt . . . but . . . the probability that people will receive perhaps a little more radiation than medical authorities say is absolutely safe."[32]

President Truman Hesitates and the Joint Chiefs Decide on Enewetak

When Secretary of Defense Johnson took the issue of a continental test site to the White House on August 7, President Truman postponed making a decision. At the same time, the Atomic Energy Commission persuaded the Joint Chiefs of Staff that there was no real alternative to Greenhouse. It seemed unlikely that any alternative site to Enewetak could be made ready for use for spring 1951, and the projected magnitude of at least one proposed Greenhouse test made it potentially unsuitable from a safety perspective for a continental site. In mid-September, the Joint Chiefs decided they could spare the resources for the test series.[33]

Proceeding with Greenhouse as planned did not, however, end discussions on the continental test site. Enewetak's availability had been a near thing, and test planners, relying on a single, far away test site, had been left with few options. They did not want to find themselves in such a position again. In addition, nuclear weapons testing, with ever–heightening international tensions, appeared on the verge of becoming an ongoing, permanent activity. As a result, the AEC continued to press hard for a continental site. With the South Site at the bombing and gunnery range remaining the preferable site, the Commission arranged in mid–September for the Army Corps of Engineers to conduct a thorough topographical survey and investigate sources of water supply. The Corps also was tasked with locating a one–mile square "camp area to house approximately 1500 men."[34]

President Truman Decides on a Continental Test Site

On October 25, 1950, as Communist Chinese forces poised to intervene in the Korean conflict, Gordon E. Dean, who had replaced Lilienthal as chairman of the Atomic Energy Commission, discussed the issue of a continental test site with President Truman. With the new test series following Greenhouse now moved up to fall 1951, Dean convinced Truman of the need for an appropriate location that was more secure and accessible than Enewetak. The president assigned the National Security Council to lead the final

Gordon Dean, chairman of the Atomic Energy Commission, 1950-1953, at a press conference. Source: Department of Energy.

search. In mid–November the council asked Dean to head a Special Committee composed of the AEC and the Departments of State and Defense and tasked with locating a continental test site. The search, however, was essentially over. The major participants were already predisposed toward selecting the South Site.[35]

A week later on November 22, Los Alamos test officials recommended the Nevada site in glowing terms. They noted that the Frenchman Flat area, where the initial test series would be conducted, "is relatively free from radiation hazards, has a minimum of operational limitations, and offers many operational facilities for an atomic proving ground." Within the "sector of safety" to the north and east of the site into which a radioactive cloud might move with an "assurance of safety," population density was "so very small" that suitable controls could be established with "very little logistic effort." The site offered "no foreseeable radiation hazards," the Los Alamos testers observed, for shots "possibly as high as 50 KT and certainly none for a 25 KT detonation." In addition, the knowledge gained from "small yield weapons" might extend "maximum allowable yield." Logistics also posed "no operational limitations." Nearby Las Vegas possessed all of the facilities required for "transient living and general construction," with a sizeable labor pool, contractors with equipment, and rail and air terminals. A black–topped highway, U.S. Highway 95, passed only seven miles south of the "target area," allowing easy access from Las Vegas. The government–owned air base at Indian Springs, eighteen miles from the site, would allow "air traffic direct from Los Alamos" and could accommodate a peak load of over 1000 personnel. "It is recommended," the testers concluded, that "this area be made available, as soon as possible, for fall 1951 tests."[36]

The AEC concurred. At a Commission meeting on December 12, Division of Military Application Director James McCormack reported that while no site within the continental United States could be considered a "completely satisfactory alternate" to overseas sites, the Nevada location "most nearly satisfies all of the established criteria." The "most critical" of these criteria, he noted, dealt with radiological safety. "Not only must high safety factors be established in fact," he observed, "but the acceptance of these factors by the general public must be insured by judicious handling of the public information program." McCormack stated that the Nevada site would "permit a substantial improvement in predicted safety over the Trinity shot," and he recommended that it be selected for "immediate development and early use as a continental atomic test site." The Commission quickly accepted the recommendation, and three days later the Special Committee of the National Security Council followed suit. On December 18,

President Harry S. Truman made the final decision on locating the Nevada Test Site. Source: Harry S. Truman Presidential Library.

President Truman approved the choice. He directed that any "publicity attendant on the establishment" of the site be coordinated by the National Security Council.[37]

Part II

Early Atmospheric Testing, 1951-1952

Los Alamos Scientific Laboratory, Atomic Energy Commission, and Department of Defense officials connected with the nuclear weapons program. Front row, left to right: John Manley; Maj. Gen. K.D. Nichols; A.S. Alexander, assistant secretary of army; Norris E. Bradbury; Lt. Gen. T.B. Larkin, assistant chief of staff, G-4. Back row, left to right: Edward Teller; Alvin C. Graves; William Webster, chairman of the AEC's Research and Development Board; Brig. Gen. James McCormack, director of military application, AEC; Carroll L. Tyler; James Russell, Division of Military Application, AEC; Brig. Gen. S.R. Mickelson, deputy assistant chief of staff, G-4; and Col. A.W. Betts, Division of Research and Development. Source: Department of Energy.

The Need for an Immediate Testing Series

Before President Truman even signed off on the new continental test site, the Los Alamos Scientific Laboratory and the Atomic Energy Commission (AEC) were laying plans to conduct nuclear weapons tests there sooner than anyone imagined or thought possible. By November 1950, Los Alamos bomb designers realized that possible design flaws existed in the implosion devices slated to be tested during the Greenhouse series. They concluded that several test detonations needed to be made, if at all possible, prior to Greenhouse in order to "protect the Eniwetok program." By mid–December, "very intensive planning" was underway at Los Alamos for a series of three to five shots at the new test area—usually referred to as the Nevada Test Site, but sometimes as Site Mercury*—to be conducted in mid–January or early February 1951. Insufficient lead time existed to prepare for tower shots, so the tests would be "air bursts" dropped from an airplane.[1]

The Atomic Energy Commission moved quickly on the new test series, which George F. Schlatter, chief of the AEC's Test Activities Branch, dubbed the "Hurry–Up Operation" but officially became Ranger. On December 20, Commission Chairman Gordon E. Dean informed the Military Liaison Committee that Ranger would be a "relatively simple operation, requiring minimum support of a special or critical nature." Dean noted that the expected explosive yields from the tests would be relatively low, "in the range of a few KT, perhaps less that 1 KT in some instances." Ranger, nonetheless, could not be taken lightly. As Schlatter observed, some concern existed that "a small shot is not necessarily an equally small rad safety problem compared to former big shots." This meant, he continued, that "for complete safety (Public Relations) it may be well to organize a high capability for rad safety despite a low probability of needing same."[2]

* The name Mercury predates the test site and is derived from the Mercury Mine, which was located at the southern end of the site.

The Air Force agreed to provide assistance for the Ranger series. This included specialized areas such as cloud tracking and weather forecasting as well as conducting the flight missions that dropped the test devices over their targets. Air Force officials further agreed to provide "on a temporary basis only" certain logistical services. The AEC could use space at Nellis Air Force Base, outside Las Vegas, as a communications center for radiological safety activities. The Air Force consented to a "joint occupancy" of the Indian Springs "encampment" from January 1 to March 1, 1951. Barracks and a mess building would be made available for 200 to 250 people.[3]

Taking Possession and Initiating Construction Activities

The AEC's initial task was to take physical possession of the site. Agency officials quickly determined that only "one legitimate property owner" was involved, a rancher residing in Las Cruces, New Mexico, who held a grazing lease covering approximately two–thirds of the test area. On the leased grazing area, the rancher ran some 40 horses and 250 cattle. A "herdsman and wife" resided at Tippipah Spring, north and west of Frenchman Flat. For testing operations, officials decided to relocate the herdsman and confine the stock to the Yucca Flat area to the north. Officials also suspected that some "illegal people," as the AEC's Division of Military Application Director James McCormack put it, might be on or around the site, such as "a miner who lives in the ground that the Air Force has not been able yet to smoke out of his hole."[4]

Ruins of herdsman's cabin at Tippipah Spring. Source: DOE, NNSA-Nevada Site Office.

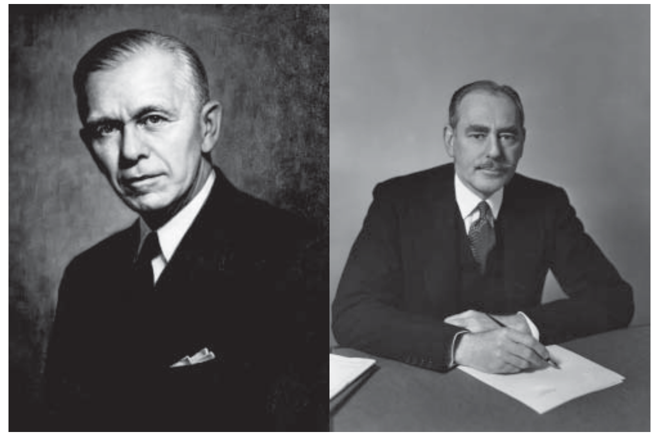
Atomic Energy Commission and Los Alamos officials were nonetheless extremely wary of publicly making their presence felt either on the site or in Las Vegas. No public release had been made of President Truman's approval of the use of the gunnery range as a continental test site for nuclear weapons. Nor had the president or the Joint Committee on Atomic Energy in Congress been informed, let alone had they approved, of going forward with the Ranger series. This severely constricted what the agency could do. The only option was to use the Air Force for cover. Commission officials authorized the commanding officer at Nellis Air Force Base to "make commitments not to exceed ten thousand dollars" for minor work at Indian Springs and the site. Nellis officials also issued a local release concerning increased construction activities on the gunnery range. Meanwhile, two of Los Alamos's building contractors, Robert E. McKee Company and Reynolds Electrical and Engineering Company, began work at the site. The McKee Company acquired a vacant garage building at 817 South Main Street in Las Vegas to serve as an in-town headquarters.[5]

Approvals and Public Relations

Following the new year, the AEC moved quickly to secure approval of Ranger. Two separate but related issues sparked controversy: the wording of a proposed press release and the mix of test shots that would make up Ranger. On the former, officials agreed that successful continental testing required convincing the American people that nuclear weapons testing was a routine activity and nothing out of the ordinary and that radiological safety was under control and nothing to worry about. An AEC-prepared two-page draft press release stressed that continental testing would result in a "speed–up" of the weapons development program that would be of "major importance to the national defense and security." The release did not state when testing would begin or what would be the makeup of the testing program. The entire second page of the release discussed radiological safety requirements for which "full consideration" had been given. Stressing the extensive monitoring that would be done and the various committees and panels that had given the test site a seal of approval, the release listed those individuals, including Enrico Fermi and Edward Teller, who had attended the radiological hazards meeting at Los Alamos in August 1950 and whose names would lend the most cachet to the safety of the test program.[6]

On January 4, Dean formally requested approval—from the Departments of State and Defense, as well as the Joint Chiefs of Staff, prior to submission to the president—of the testing program and the press release. Dean proposed a five–shot program, noting that the radiological safety program had received "expert approval" and that, from a safety perspective, the test series would "go forward shot by shot, the decision on each one being based on observations of the results of the preceding shots." Dean singled out the fifth shot, "Item F," for special attention. He stated that the fifth shot presented a "different radiological problem" because its yield, projected at thirty to forty kilotons, would be significantly higher, by a magnitude of three or four times, than any of the other four shots.[7]

Four days later, Dean learned that the press release and the test program were both in trouble. Two experts on the radiological safety panel, one of whom was Fermi, did not want their names listed on the release. More worrisome, Secretary of Defense George C. Marshall, who had replaced Johnson in September, did not want to approve the press release without a meeting with Dean and Secretary of State Dean Acheson. Marshall questioned the wisdom, in a tense international situation, of revealing that the United States had small nuclear weapons. In addition, the Joint Chiefs of Staff, Dean was informed, had "some very slashing recommendations" on the release. They wanted to eliminate all reference to radioactive danger and any "intensive" effort. The Joint Chiefs also opposed the fifth test in the series, not because of what it would reveal about small weaponry but because it was too big. Apparently they had promised Truman that there would be no big tests at the continental site. They did not, as Dean put it in his diary, "like the big 'F' test but they did like the little ones."



Secretary of Defense George C. Marshall and Secretary of State Dean G. Acheson. Source: U.S. Department of State.

Dean was dismayed. On the press release, he believed strongly that "we have a public relations problem here . . . that the JCS don't appreciate." Fearing a decision for no press release, however, he acquiesced to a rewrite of the release that was "somewhat misleading" in that it contained no reference to intensive tests and eliminated the list of names and the radiological safety information on page two. On Item F, Dean was less certain

ESTABLISHMENT OF CONTINENTAL PROVING GROUND

WARNING

January 11, 1951

From this day forward the U. S. Atomic Energy Commission has been authorized to use part of the Las Vegas Bombing and Gunnery Range for test work necessary to the atomic weapons development program.

Test activities will include experimental nuclear detonations for the development of atomic bombs – so-called "A-Bombs" – carried out under controlled conditions.

Tests will be conducted on a routine basis for an indefinite period.

NO PUBLIC ANNOUNCEMENT OF THE TIME OF ANY TEST WILL BE MADE

Unauthorized persons who pass inside the limits of the Las Vegas Bombing and Gunnery Range may be subject to injury from or as a result of the AEC test activities.

Health and safety authorities have determined that no danger from or as a result of AEC test activities may be expected outside the limits of the Las Vegas Bombing and Gunnery Range. All necessary precautions, including radiological surveys and patrolling of the surrounding territory, will be undertaken to insure that safety conditions are maintained.

Full security restrictions of the Atomic Energy Act will apply to the work in this area.

RALPH P. JOHNSON, Project Manager
Las Vegas Project Office
U. S. Atomic Energy Commission

Warning handbill distributed by the Atomic Energy Commission on the day of the continental test site announcement. Source: DOE, NNSA-Nevada Site Office.

from a technical standpoint—"What does that 5th shot do?" he asked McCormack—but willing to fight for it if his advisors deemed the "big bang" essential. He let McCormack document what would happen if the fifth shot was left out of Ranger. Dean, meanwhile, focused on the radiological safety aspects of the test. He asked Charles L. Dunham, medical branch chief in the AEC's Division of Biology and Medicine, if there were any radioactive hazards other than potential exposure to sheep. Dunham responded that with "a pretty good sized burst" there might be trouble if it rained heavily over a populated area within two hours of the shot. When Dean asked if that would mean minor skin burns, Dunham replied that this "would be the worst thing that could possibly happen to the people."[8]

Two days later, Marshall approved the press release, which excluded the material on rad safety but reinstated the clause on the speed–up of the weapons development program. On January 11, Truman officially approved both the test series, with the fifth shot, and the press release. That same day, the Atomic Energy Commission went public with the press release. In conjunction with the release, the AEC initiated a concerted effort to individually inform—"tipping them off two or three hours in advance," as Dean put it—members of Congress and state and local officials having special interest in the new Nevada Test Site and the impending series. "We must touch base," Dean noted, "with many people who, if not taken into our confidence, would misinterpret the whole program." The AEC also posted warning signs at the site and issued handbills. The handbills, headlined in big, black lettering with the word **WARNING**, stated that "NO PUBLIC ANNOUNCEMENT OF THE TIME OF ANY TEST WILL BE MADE."[9]

Public and press reaction undoubtedly pleased Dean. There had been "no adverse comments" to speak of from public officials or the press. The AEC's public relations people in Nevada reported overwhelmingly favorable reaction at the local level. The press generally reported the unveiling of the continental test site as a major story. The staid New York *Times* ran a small headline—"Atomic Bomb Testing Ground Will Be Created in Nevada"—over a two–column article, but other newspapers, especially those in the southwest, featured front–page stories with eye–popping headlines. The Salt Lake City *Deseret News*'s banner headline declared "Atom Blast Site Set Near Vegas." In an inch–and–a–quarter type, the Los Angeles *Times* announced "U.S. TO SET OFF ATOMIC BLAST NEAR LAS VEGAS." The Las Vegas *Review–Journal* headline simply said "Test A–Bombs at Indian Springs." Most of the articles were basically rewrites of the Atomic Energy Commission's press releases, but there was some speculation that the testing plan heralded "new atomic techniques." The Washington *Post* mentioned the possibility of "small scale atomic explosions," and Joseph Myler, a reporter for United Press, noted that the fact that the Atomic Energy Commission would continue to use Enewetak, presumably for hydrogen bomb weapons tests, indicated that the Nevada tests would be "special purpose" devices that were "more compact and more deliverable," such as "atomic missile and atomic artillery warheads" or "an atomic mortar shell."[10]

The Test Site Takes Shape for Ranger

Conducting a nuclear weapons test series, from conception through the final test, in only two months proved a daunting but not insurmountable task. Made all the more difficult by the total security and secrecy that surrounded the first month of the project, preparations were nonetheless well under way by the time President Truman approved Ranger and the impending use of the Nevada Test Site was made public. Following a visit to Los Alamos and the new test site in mid–January, the AEC's George Schlatter pronounced the preparations for Ranger "definitely under control." All major problems were being met, he noted, and "minor soft spots" were being quickly corrected. "I see no reason why," he stated, "the tentative dates cannot be met very closely." Schlatter predicted that the McKee Company would complete site construction by January 20, at which point Los Alamos technicians, assisted by personnel from Edgerton, Germeshausen and Grier, Inc. (EG&G), would arrive for final installation of diagnostic and experimental equipment.[11]

Announcement of the continental test site made big headlines.

Facilities at the test site were primitive at best. No existing structures were available for test personnel to use, so everything had to be brought in or built from scratch. Workers "re–erected" a surplus frame building from Los Alamos at the "control point," 8.9 miles south of the ground zero drop point, to serve as a technical command post. This hastily constructed building included a control room, administrative office, first aid station, and shower for personnel decontamination. The building was shored up as a precautionary measure prior to the first blast.

Construction workers and laboratory technicians at the test site devoted most of their efforts toward preparing the target area. As all of the drops would be made in the very "first light" of dawn, the target was cross–lighted from northeast to southwest and northwest to southeast at 100–, 300–, and 500–foot intervals. A red reference light was placed at ground zero in the center of the target. During the drop, all lights were turned off thirty seconds prior to burst time. Directly under ground zero, workers built a blast– proof alpha–recording shelter or blockhouse. Two photography stations were located two miles from zero, one to the southeast and the other to the northeast. To the north and west of zero lay the "field fortifications area." This area was used extensively for scientific experiments. Two miles to the south of zero, workers set up two diesel–driven generators located in a wooden shack. Although badly damaged after the first shot, the shack provided shelter for the generators throughout the test series. All cables and

South side of the control point building. Entrance to the control room is at right. Men on porch are looking north toward ground zero. Note braces shoring up the building. Source: Los Alamos National Laboratory.

Preparing the Site for the Ranger Series

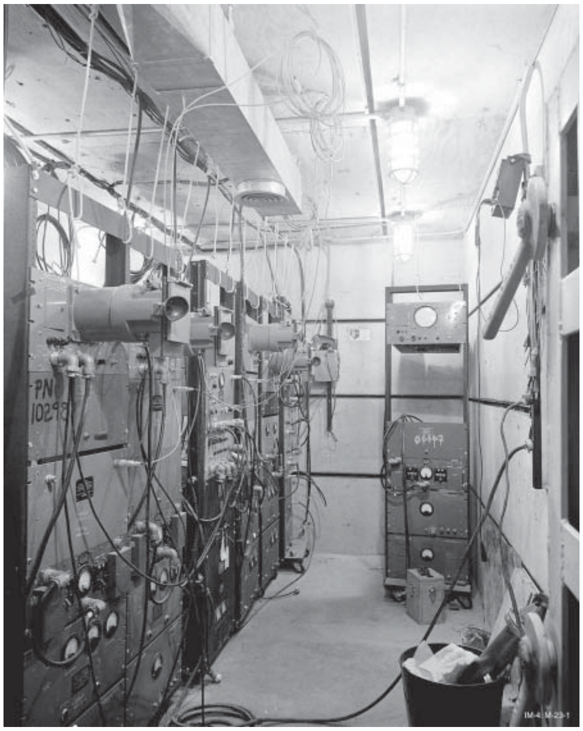
Control point area, looking toward the north. Source: Los Alamos National Laboratory.

Construction near ground zero. Source: Los Alamos National Laboratory.

Blockhouse under construction. Source: Los Alamos National Laboratory.

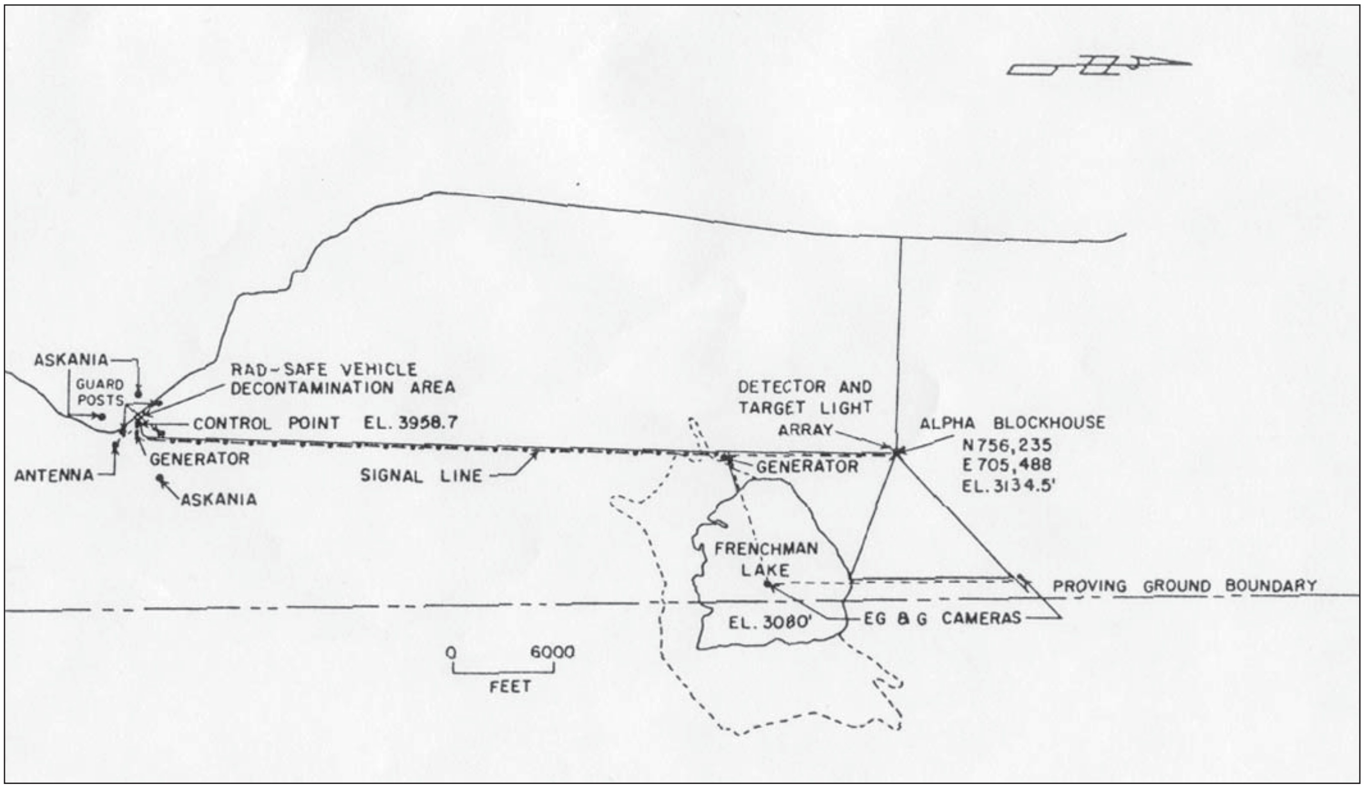
Preparing the Site for the Ranger Series

View toward the south and the control point from the top of the blockhouse at ground zero. Note the entrance ramp to the shelter. Dry Frenchman Lake is to the distant left. Source: Los Alamos National Laboratory.



Instrument room in interior of blockhouse. Source: Los Alamos National Laboratory.

Generator building under high tension wires. Blockhouse is in the distance toward the very center of the picture. Source: Los Alamos National Laboratory.

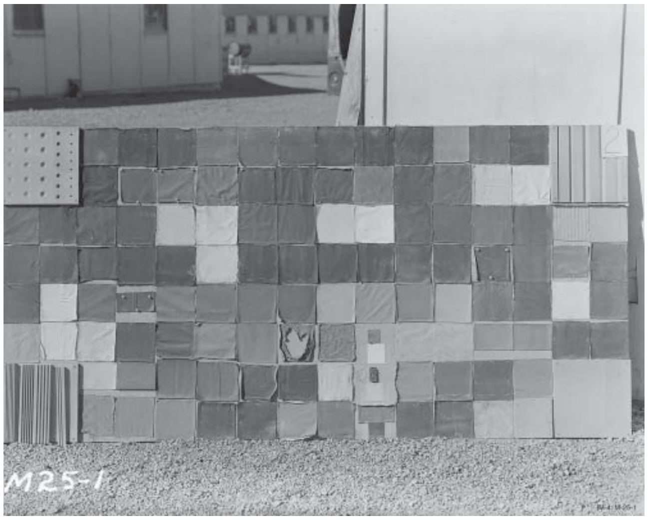


Map showing control point and target area. Source: Reprinted from John C. Clark, *Operation Ranger, Vol. 1, Report of the Deputy Test Director*, WT-206, September 1953 (extracted version, Washington: Defense Nuclear Agency, October 1, 1979), p.32.

electric lines up to two miles out from zero had to be buried underground.[12]

Sixteen experiments were set up and carried out during Ranger. Los Alamos directed most of the experiments, which primarily involved diagnostic measurements to determine yield and other information. Planning and construction time constraints limited the expansion of the experimental program much beyond these fundamental measurements. The military nonetheless sponsored several weapon effects experiments. In the field fortifications area, workers constructed fourteen foxholes, the nearest at zero and the farthest at approximately 6,000 feet. The unoccupied foxholes contained film badges to determine how much radiation would be received by dug–in troops suffering a near–direct hit. The Army's Office of the Quartermaster General conducted a thermal effects experiment designed to determine the thermal hazard of nuclear weapons to military uniforms and equipment of various materials and finishes. Before each shot, workers placed in the test area, in foxholes and on the

Foxhole at west end of blockhouse. Source: Los Alamos National Laboratory.



Panel two of forty-eight panels with samples of various materials. Source: Los Alamos National Laboratory.

ground, forty–eight panels, each supporting over 100 samples of textiles, plastics, and wood. Finally, the AEC's Division of Biology and Medicine sponsored Operation "Hot Rod" to determine the effectiveness of automobiles as shelters during an atomic attack. Five 1936 to 1939 sedan–model automobiles—a Buick, Oldsmobile, Chevrolet, Lafayette, and Plymouth—were variously oriented at one–half mile intervals from one–half to two–and–a–half miles from ground zero. Operation Hot Rod determined that at the half–mile location individuals in an automobile would probably be "killed twice," once by injury from a combination of blast and fire and a second time by radiation. At two miles or more, given "an atomic blast of roughly nominal size," chances of survival without injury were very good.[13]

Planning and coordinating the entire operation on such short notice was perhaps the single most difficult task of the Ranger series. John C. Clark, who as deputy test director took charge of the Nevada program while test group chief Alvin Graves concentrated on Greenhouse, remarked that it was "not exactly an experience [one] would like to repeat once or twice each year." Everything needed to be thought out, precisely coordinated, and implemented in a matter of

Deputy Test Director John C. Clark. Source: Los Alamos National Laboratory.

weeks. Organization was critical. The Test Group focused on core Ranger activities, consisting of the experimental program, radiological safety, meteorology, various cloud tracking and other special flights, and weapon preparation and assembly. Other groups provided support for these core activities. The Administrative Services Group oversaw housing, meals, medical facilities, motor transportation, travel arrangements, and the like. The Security Group provided not only surveillance and protection of the site but also traffic and access control, coordination with local law enforcement officials, and negotiations with the Civil Aeronautics Administration to clear all air traffic over and around the site on test days. Communications, personnel, and public information were major tasks in and of themselves.[14]

No facet of Ranger other than the performance of the test devices was as critical to the success of the series as radiological safety. Test planners

Operation Hot Rod

Buick four-door sedan placed at one-half mile from ground zero, with windshield oriented toward the blast. All windows were blown out, as was the rear of the car. The doors away from the blast were blown off their hinges, and the hood was blown some 50 to 100 yards from the car. Burning of the automobile was extensive. The rear tires were burned, and the car sank into the ground to the axle level. The front tires were undamaged and still inflated. The motor appeared to be undamaged. Source: Los Alamos National Laboratory.

Oldsmobile four-door sedan placed at one mile from ground zero, oriented at about a 45-degree angle to the blast. The windows on the blast side were broken. One was blown in and the other badly crushed. The windshield was cracked. The paint and tires on the blast side were charred, but the tires remained inflated. The side facing the blast was bashed in. The hood was lifted but not blown off. Apparently the door on the blast side had been left open, because there was a sharp line of demarcation of charred area visible on the upholstery. The motor seemed undamaged, as was the battery, given that the horn still operated. Source: Los Alamos National Laboratory.

Chevrolet two-door sedan placed one-and-a-half miles from ground zero still burning four hours after the shot. Oriented at about 60 degrees from the blast, the car was completely burned. The glass was destroyed as a result of the fire. The headlights were not broken, and the chrome was not charred. The top was warped. The front tires remained inflated and intact. Source: Los Alamos National Laboratory.

and radiological safety officials believed that there would be few radiological safety problems. They were confident that tests similar to Ranger's could be held at the Nevada Test Site, as Thomas L. Shipman, chief of the Los Alamos health division and director of radiological survey work for Ranger, put it, "almost at will, with no resulting radiological hazards in the surrounding countryside, provided certain basic meteorological conditions are respected." Partly this confidence was due to the nature of the devices and the method of detonation. The "models detonated in the Ranger series were particularly well suited" to continental testing, Clark later observed, and the "fact that all the shots were air detonations greatly simplified the operations and minimized the radiological fall–out problems." Partly the confidence was attributable to the geographical and meteorological conditions existing at the test site. These conditions were the primary reasons the site was located where it was, and "hypothetical tests" conducted on December 30 and January 8 helped confirm the belief that safe tests could be conducted under appropriate weather conditions. In any event, Shipman felt assured enough to set "permissible levels of exposure to external radiation" for personnel at less than half that allowed in the already completed Greenhouse plans. Greenhouse permitted weekly exposures of up to 0.7 roentgen.* Ranger allowed only 0.3 roentgen.[15]

Shipman anticipated that there would be only the most minimal exposure to off-site populations.

Thomas L. Shipman, chief of the Los Alamos Scientific Laboratory's health division and director of radiological survey work for the Ranger series. Source: Los Alamos National Laboratory.

Noting the "somewhat delicate public–relations aspect of the affair," he declined to set "arbitrary levels [that] could possibly result in more harm than good." The "guiding principle" he used instead was the "rather simple desire to assure ourselves that no one gets hurt." Figures "must be used as general guides," he admitted, but "no drastic action which might disturb the public should be taken unless it is clearly felt that such action is essential to protect local residents from almost certain damage." In an emergency, Shipman assumed that the general public could receive external exposure up to 25 roentgens without danger. This was no greater exposure, he observed, than "many people receive in an only moderately complete X–ray examination." For exposures between 25 and 50 roentgens, people would be requested to "stay in their houses, change clothes, take baths, etc." If exposure levels threatened to rise above 50 roentgens, Shipman concluded, "consideration

* The roentgen (R) measured exposure and, with some conversion, could be used to determine dose. By 1950, scientists had determined that a one–time, whole body dose of up to 25 roentgens would usually result in "no obvious injury." Doses up to 50 R would result in "possible blood changes but no serious injury." Between 200 and 400 R, injury and disability would be certain, with "death possible." 400 R would be fatal to 50 percent of the population. 600 R would be fatal to all. Higher total doses could be tolerated if stretched out over a period of time. Barton C. Hacker, *Elements of Controversy* (Berkeley: University of California Press, 1994), pp. 1–2; Samuel Glasstone, ed., *The Effects of Atomic Weapons* (Los Alamos, NM: Los Alamos Scientific Laboratory, September 1950), p. 342.

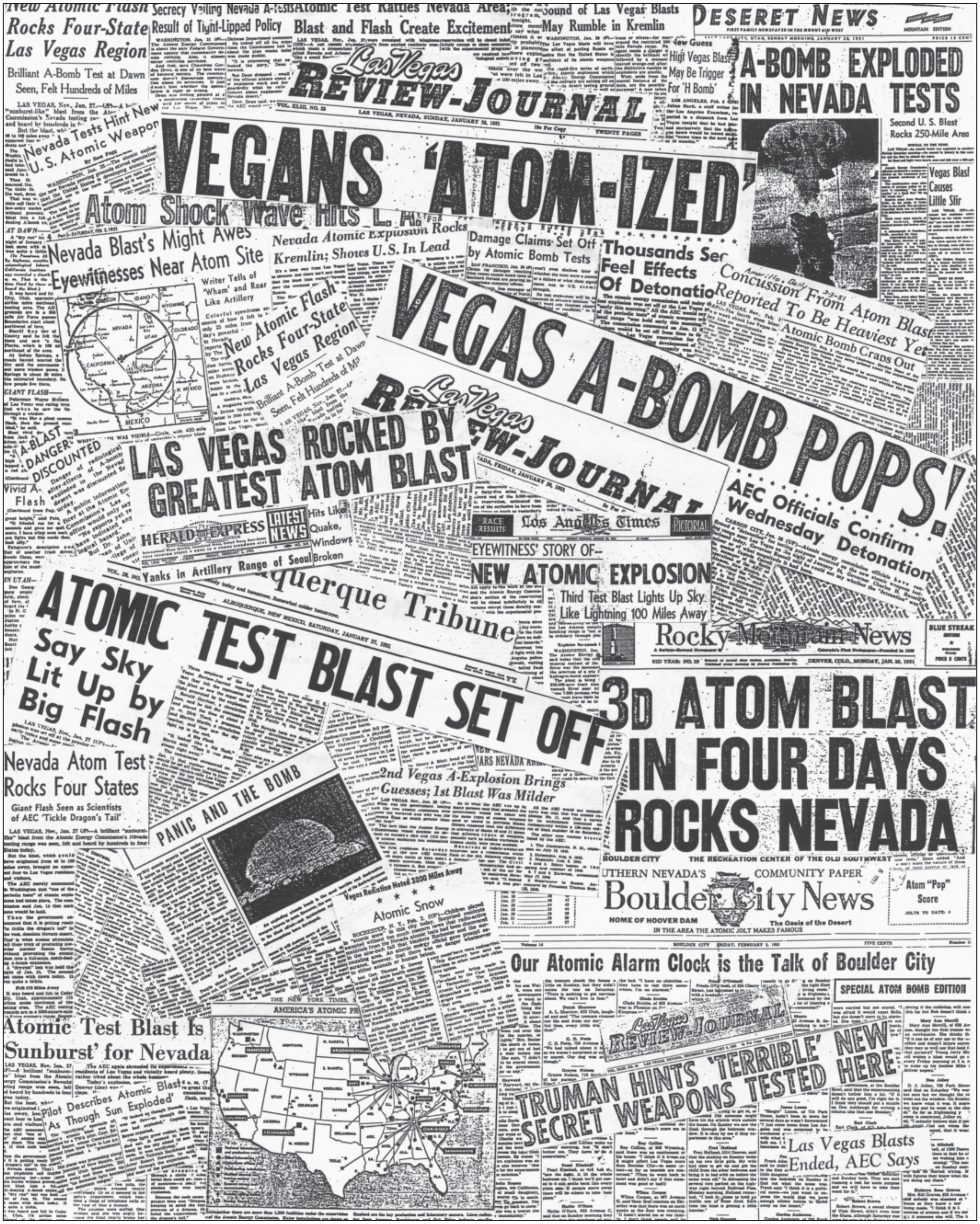
must of necessity be given to evacuating personnel." Shipman nonetheless regarded the need for any evacuation as "highly improbable."[16]

Ranger

In the early dawn of January 27, 1951, Able, the first shot in the Ranger series, detonated on schedule and as planned. At one–kiloton yield, Able, the world's tenth nuclear detonation, was much smaller than any prior shot and, as a result, provided a "lesser show." The "visual effects," according to one observer, seemed "less spectacular than those reported for previous detonations, with shorter duration of luminosity of the fireball, slower rise, faster cooling, no real thermal column formed, no mushroom head, and the fission–product cloud rising only to a fairly low altitude." Physical damage consisted of the breaking of some, but not all, of the target lights as well as two windows in the generator building and of the scorching of the sagebrush for several hundred yards in the vicinity of ground zero. Although an explosion equivalent to one thousand tons of TNT still demanded respect, radiological safety hazards were also minimal.[17]

Whatever panache Able might have lacked for veteran test observers, the news media appeared impressed enough. For officials watching the sky from Nellis sixty–five miles away, it had been "immediately obvious" that Able was no dud, so there was no hiding the test from the public. The Las Vegas *Review–Journal* ran a banner headline that declared in huge two-inch letters, "VEGANS 'ATOM–IZED'," with a sub–heading claiming, "Thousands See, Feel Effects Of Detonation."

View from top of blockhouse on January 27, 1951, following Able shot, as workers prepare for Baker. Source: Los Alamos National Laboratory.



Headlines proclaimed the advent of the Ranger series.

The "super solar light" generated by the blast, the *Review–Journal* noted, "lighted the sky so brilliantly that residents of southern Utah, scores of miles away, saw the flash." The paper also reported "'rumblings'—presumably the muffled sound of the distant blast" and related the vivid description provided by a truck driver who was at the top of Baker grade on the highway to Los Angeles as Able detonated. "A brilliant white glare rose high in the air and was topped a few instants later by a red glow which rose to great heights," the truck driver observed. "The bright flash blinded me for a few seconds and gave me quite a scare." In Las Vegas, the flash was followed by a mild earth tremor and a "blast of air like a windstorm" that was felt in "an irregular pattern" throughout the city.

Las Vegas residents nonetheless evinced little concern. Most slept through the early Saturday morning blast, and, although there was a "half–hour deluge" of calls to the Las Vegas police, the test, according to the Salt Lake City *Deseret News*, caused "little stir" in the town. A "prominent local citizen" stated that while residents were not exactly "blasé about it," there was not "any panic or anything like that." As an example of the gambling community's relaxed attitude, the *Review–Journal* cited a crap shooter at the Golden Nugget in downtown Las Vegas who, upon feeling the shock from Able, paused, looked around, said "Must be an atomic bomb," turned back to the table, and went on with the game.[18]

With weather conditions cooperating and minimal radiation levels in the target area so that technicians could "reestablish" experimental and diagnostic equipment, officials pushed ahead with Baker on January 28, only twenty–four hours after the Able test. Detonated, as with Able, at first light at a height slightly over a thousand feet, Baker with a yield of eight kilotons was a much more powerful device, although still small in comparison to other prior shots. The results of the test, noted one radiological safety observer, were "much more spectacular than those of the preceding day and more nearly approached the appearance of motion pictures and descriptions of bombs detonated previously." The fireball, "intensely brilliant, even through very dark goggles," rose rapidly while "diminishing in brilliance" over a period of about five seconds. This subsided to a "rosy glow which faded into a very brilliant blue–purple luminescence surrounding the mushroom head which formed at the top of a long thin column." The mushroom cloud, with its "dirty brown–yellow trailer," topped off at about 35,000 feet and drifted off to the east where it was broken up and dissipated by the winds. The blast wave "spanked" the ground beneath the shot and reached the control point, with a "sharp concussion" immediately followed by a second shock of "almost equal intensity and sharpness," some sixty seconds after the detonation. This was followed by the "reflected echoings and rumblings of the shock wave" from the surrounding mountains.[19]

Workers repairing the blockhouse on January 31, 1951, following Baker. Note the protective masks and foot coverings. Source: Los Alamos National Laboratory.

Baker also left a much greater impression than Able off site. The flash and the shock wave were significantly stronger. "The explosion woke up the whole town," stated a reporter for the Las Vegas *Review–Journal*, "except for people who were up in the casinos. A lot of them," he added, "said they saw flashes like chain lightning, and all the homes and buildings were jarred by two or three stiff shocks." One observer reported that the blast seemed like the "rumble of a monstrous truck" moving through the streets of Las Vegas. The national press speculated that the Atomic Energy Commission was experimenting with devices "much smaller than those employed heretofore." Smaller devices meant bombs and projectiles that could be used "against limited targets and for tactical purposes." This was, the Washington *Post* editorialized, "a most hopeful development." Bombs the size of the one dropped on Hiroshima could be used only for "indiscriminate mass destruction." Their impact, observed the *Post*, could not be "localized." Smaller weapons, by contrast, could be used against combat troops and might "prove to be a decisive weapon of defense." As defensive rather than offensive weapons, they could, the *Post* concluded, put a "stop to aggression [and] be . . . an effective deterrent to war."[20]

The Atomic Energy Commission soon learned, however, that the effects of even small devices like Able and Baker could not be entirely localized. One or both of the Ranger tests sent lighter radioactive debris into high–altitude winds blowing eastward. Lacking any distant monitoring network, Commission officials seemed surprised when, a few days following the tests, they received reports of radioactive snow falling in the Midwestern and Northeastern United States. Despite the widely proclaimed and accepted absence of any threat to health in the very low levels of radioactivity detected, AEC public relations suffered one of its first serious setbacks.[21]

Time-sequence photos taken of the Easy shot, February 1, 1951, by a *Life* magazine photographer near U.S. Highway 95, thirty-five miles southeast of the test. First two photos are within the first second of the blast. Third photo is fifteen minutes later in the fuller light of dawn. A "thin wisp" of smoke can be seen rising over the mountain ridge. Source: TimePix.

Ranger Fox

The next two shots—Easy and Baker-Two—were routine and largely uneventful, although Baker-Two, using the same device as Baker and with a yield of eight kilotons, produced at least two broken store windows in Las Vegas. This gave test officials some pause. Fox, the final and largest shot in the Ranger series, had an anticipated yield of as much as thirty–three to thirty–five kilotons. If the eight–kiloton–yielding Baker–Two broke windows in Las Vegas, officials wondered, what would a test over four times as powerful do? Deciding that the Baker–Two effects were an anomaly—"unexplained and freakish blast effects," according to one historian—officials pushed ahead with Fox. Just in case, however, they issued a public announcement urging people to stay away from windows at the time of any subsequent blast.[22]

Broken plate glass window in downtown Las Vegas from the Baker-Two shot. Source: AP/Wide World Photos.

Fox produced a somewhat less than expected yield of 22 kilotons. The "visual show" provided by the test was still "very spectacular" compared to the preceding four detonations. Observers at the control point, 8.9 miles to the south, felt a "distinct heat flash" at the instant of the burst. The surrounding mountains, from 20 to 50 miles distant, were "illuminated by blinding whiteness which was far more intense than noon daylight." The two "very solid shock waves" felt at the control point less than a second apart "produced about the same sensation as standing in the open next to a 16–in. coast–defense gun when it is fired." Although the control building had been rigidly braced, the blast wave knocked most of the equipment and clothing off the shelves inside the building. Following the blast, a dense dust cloud filled the entire valley. With visibility reduced to about 100 yards, the dust cloud persisted over the target area until late morning. Due to the increased height of the burst, induced radiation in the target area was somewhat less than for Baker and Baker–Two. The top of the mushroom cloud soared to 43,000 feet and then drifted south toward the Spring Mountains where its lower portion "practically invested Charleston Peak." Radiation levels, again, quickly fell when the cloud passed.[23]

Las Vegas escaped with limited damage. The blast wave, arriving not quite six minutes after the actual detonation, "splintered" big show windows in two automobile dealerships but did little more than shake buildings and frighten citizens. Gamblers reportedly ducked under tables

Fox shot, February 6, 1951. Source: Los Alamos National Laboratory.

Lighting the Sky in Las Vegas and Los Angeles

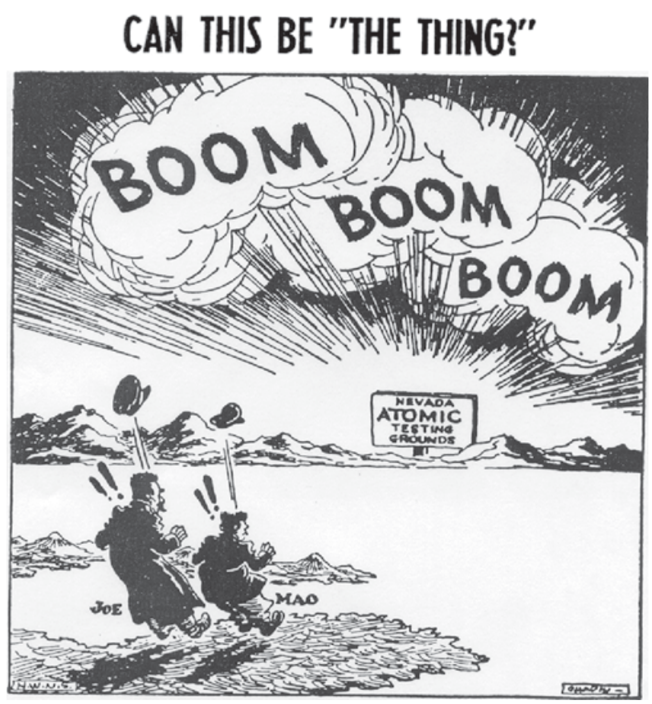
Fox shot seen from downtown Las Vegas, top, looking west over Fremont Street. Ranger shot seen from the roof of the Herald-Examiner building, Los Angeles, California, bottom. Source: AP/Wide World Photos and Los Angeles Public Library.

in one casino, and some witnesses said they were temporarily blinded by the brilliant flash. Indian Springs, however, 25 miles from ground zero and with a range of intervening hills, was particularly hard hit. More than 100 windows were broken. Doors were blown open and, in a few cases, were completely off the hinges. All equipment on shelves weighing as much as 5 pounds was thrown to the floor. A nearby house received an estimated $4,000 worth of damage that included windows broken, doors blown entirely out of casements, and roof damage. In the bathroom of the house, the blast wave knocked the plumbing fixtures loose from the walls, leaving them standing or hanging on the water pipes.[24]

By Fox, the tests had become something of a news sensation that brought with it, along with the fear and apprehension, an almost festive quality. Reporters flocked into Las Vegas to catch a glimpse of the detonations, with some driving out to Indian Springs to be closer to the action. Visitors and local residents were caught up in a kind of Fourth of July–type atmosphere, as if the tests were a grander and more spectacular form of fireworks or an added pyrotechnic side of the Las Vegas entertainment scene. After the first test, people from Los Angeles began arriving in anticipation of witnessing either a detonation or some of the imagined destruction wreaked by the blast. Atomic Energy Commission Chairman Dean remarked that the detonations, far from keeping people away from Las Vegas, accounted for one of the biggest tourist influxes that the city had ever had. Following Baker, Las Vegas residents started setting their alarm clocks so that they would be out watching at the 5:45 a.m. detonation time. Cars in the early morning hours began lining the roads at the best vantage points.[25]

As an added benefit with Fox, Los Angeles residents did not even have to leave home to see and feel the show. As early as Baker, the flash could be seen in the Los Angeles sky, and the press speculated that a test might actually be heard. "There's nothing to be nervous about," soothed the Los Angeles *Times*. Windows probably would not be broken, and it would be "just excitingly audible and spine–tingling." Fox produced the desired effect. Some twenty–four minutes after the actual detonation, the concussion rattled windows and doors in several locations in the Los Angeles area. "Atom Shock Wave Hits L.A.!" headlined the Los Angeles *Evening Herald–Express*.[26]

In a span of ten days, five tests were detonated at the Nevada Test Site, and then Ranger was over. At noon on February 6, Carroll L. Tyler, manager of the AEC's Santa Fe Operations office and lead Commission official for the conduct of Ranger, announced that "we have concluded the present series of test detonations at our site." He thanked the people of Nevada and particularly the local officials and residents in the vicinity of the site. They have, he said, "contributed to an important national defense effort." Declining to comment on the technical results of the tests, Tyler stated



Political cartoon on front page of *Washington County News*, March 1, 1951. "The Thing" refers to the title of a popular song of the time with a percussive effect that went boom, boom, boom.

that the AEC was "completely satisfied with the conduct of the test operation." He added that officials were "grateful today to report that there has not been a single incident of damage to humans either to those at the site during the tests or to persons elsewhere as a result of our test detonations." Noting that some personnel would remain to "construct permanent facilities and to maintain the test site," he said that most would be leaving Las Vegas soon.[27]

Roll–up was relatively quick and easy. Radiological surveys around the test site indicated "no hot spots or areas of significant activity." Total estimated costs for the entire Ranger series were approximately $2 million. This, Clark concluded, was "certainly only a fraction of that required for tests conducted at the Eniwetok Proving Grounds."[28]

Thermonuclear Weapons and Greenhouse

Information garnered from Ranger helped consolidate plans for the Greenhouse series scheduled for Enewetak in April 1951. Greenhouse would use fission devices to test, among other things, thermonuclear principles. Despite the success of Ranger, the outlook for developing a thermonuclear weapon remained uncertain. Calculations and computations, spearheaded by Los Alamos mathematician Stanislaw Ulam, indicated that a fusion reaction could not be sustained in the proposed design for the hydrogen bomb. Chemical explosives alone could not exert enough compression to cause fusion. The model being considered, Ulam noted, "is a fizzle." A few weeks after Ranger, however, Ulam and Teller proposed a radically new and more promising approach for starting and sustaining a fusion reaction. They proposed using x-rays produced by the fission primary, rather than other attributes from the detonation, to compress the secondary. This process, which allowed a faster and longer-sustained compression of the fusion fuel, became known as staged radiation implosion. Although design details of the devices to be tested at Greenhouse were already in final form and the devices themselves nearly fully fabricated by the time of Ulam's and Teller's proposal, the Greenhouse tests provided basic data in confirming thermonuclear principles for whichever method would by used for achieving a hydrogen bomb.[29]

Greenhouse consisted of four tests. The first two—Dog and Easy—were weapon development tests. The third—George—used a large fission yield to ignite, for the first time, a small mass of thermonuclear fuel. With an overall yield of 225 kilotons, George was the most impressive and largest shot to date, more than ten times the size of the Trinity blast. Greenhouse Task Force Commander Elwood Quesada declared it "the greatest spectacle within recorded history" as the "white day became dark by comparison with the brilliant light radiating" from George. "From the ashes of the exploded device," Quesada rhapsodized, "the mushroom catapulted upward to an altitude of 70,000 feet or more . . . . Boiling and seething as it rose." Less florid in tone but no less impressed, AEC Chairman Dean described

George shot of Operation Greenhouse, May 8, 1951. Source: DOE, NNSA-Nevada Site Office.

the "amazing destructiveness" wrought by George in the "complete disintegration and disappearance of the blockhouse" and the "vaporization of the 200-foot steel tower, together with 283 tons of equipment on top of the tower." Where the tower once stood was now a "crater filled with water." The fourth shot—Item—provided the initial demonstration of a technique called "boosting" in which a fission device contained some thermonuclear fuel that enhanced the yield of the fission explosion.[30]

Permanentization of the Test Site

The Greenhouse and Ranger series instituted a new, more flexible approach to nuclear weapons testing. The logistical demands of Greenhouse had been enormous, requiring dozens of vessels, protective air cover from a possible attack, and the participation of some 6,000 civilian and military personnel, including 2,580 scientists and technicians from the Atomic Energy Commission. Ranger, by contrast, had been comparatively easy and speedy. Smaller devices, increasingly in demand by the military, and those with a yield up to 60 kilotons would now be tested in Nevada, saving money and effort in comparison to the massive Pacific operations. Large tests that could not be conducted safely in Nevada would continue to be tested in the Pacific.[31]

Following the Ranger series, the AEC swiftly moved to turn the Nevada Test Site into a permanent proving ground for nuclear weapons. The next series, Buster, which would have inaugurated the new site had it not been for the hastily planned and implemented Ranger, was scheduled for fall 1951. In early spring, two months after the conclusion of Ranger, officials at the Santa Fe Operations office and the Los Alamos laboratory arrived at a "minimum construction program consistent with good operational results." They estimated that test series would be conducted at the site two or three times a year, with a six–week expected occupancy of the site for each series. The construction program contained "two main items." The control point consisted of a "system of buildings" housing scientific measurement equipment, weather monitoring installations, computing and communications rooms, and operational control and radiological safety facilities. The camp area, designed "minimal to needs" partly because it would be in use at most eighteen weeks during a year, consisted of barracks, a mess hall, and administration facilities for a "peak load of 412 men during operations." This provided "fifty square feet per person per room." Living space could be expanded by fifty percent with the use of double–deck bunks.

Interior view of 500 person temporary mess hall, Camp Mercury. Source: DOE, NNSA-Nevada Site Office.

Atomic Energy Commission and laboratory officials decided to move the target area northward, across an intervening ridge, onto Yucca Flat. They thus sought to avoid the blast effects "noticed" at Las Vegas during Ranger by moving ground zero further away. They located the control point on the north side of the ridge between the two valleys with a line of sight overlooking the Yucca Flat testing area. Officials originally planned the camp area for a site eight miles south of the control point in Frenchman Flat. As the AEC received "additional proposals for operations involving atomic weapons" from the Department

Camp Mercury

Security guards man the entrance to the Nevada Proving Ground near Mercury. Source: DOE, NNSA-Nevada Site Office.

Camp Mercury during construction. Source: DOE, NNSA-Nevada Site Office.

of Defense, however, they realized this made necessary the "retention of the Frenchman's Flat Area for development as an operational test area." They instead located the camp area south of the ridge running along the southern edge of Frenchman Flat where it would be protected from tests. Visible from U. S. Highway 95, the site became known as Mercury base camp. By fall 1951, the camp could accommodate over 1,100 residents, including Atomic Energy Commission and military personnel as well as a large number of construction workers.[32]

Buster-Jangle and Desert Rock

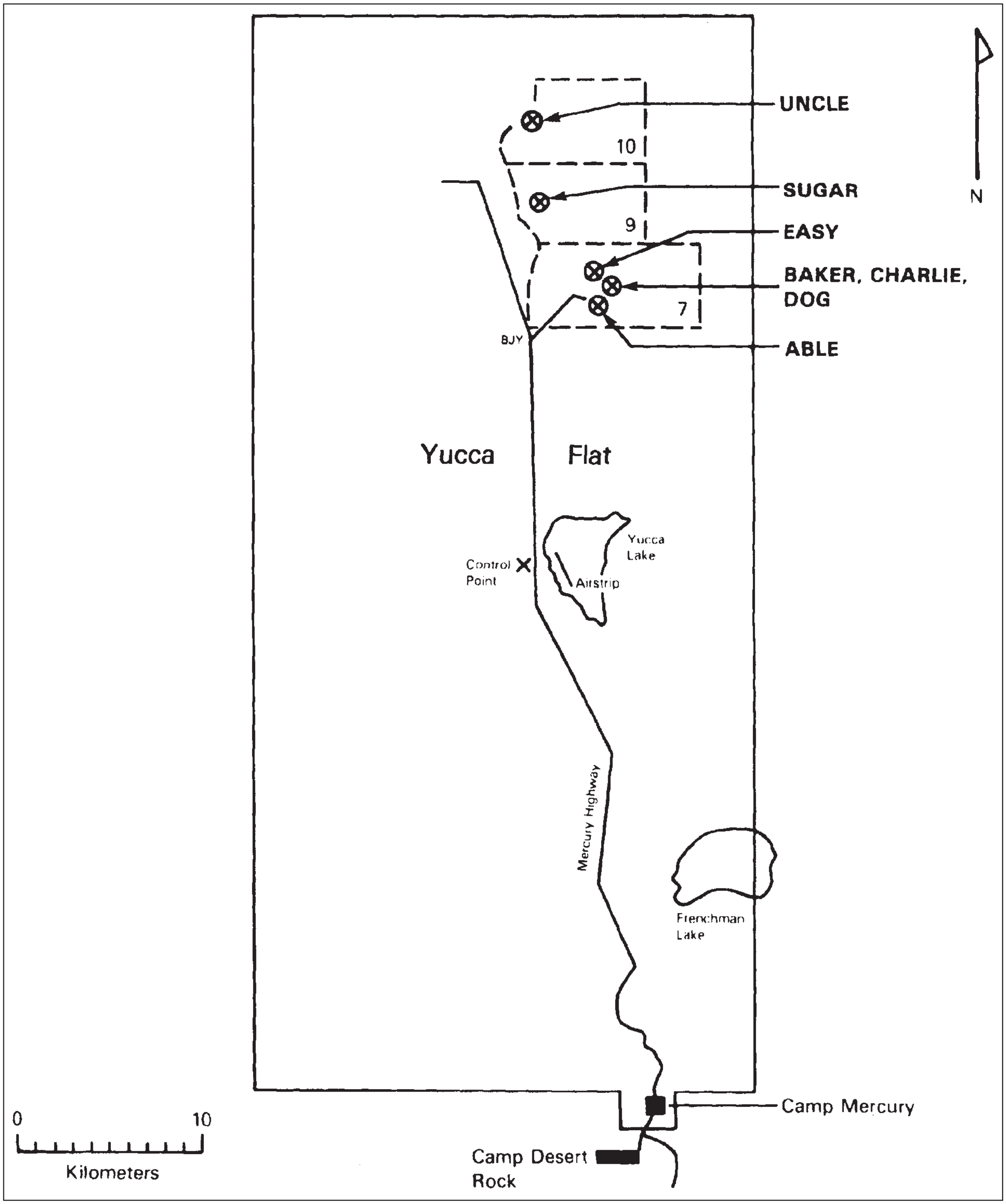
The "minimal needs" provided by Mercury proved insufficient for the next test series. This was not due to lack of proper foresight on the AEC's part. Operation Buster had been in the works since summer 1950, and planning was well-advanced for a series of four to six shots. One test would "proof-fire" a new stockpile weapon. The rest would be weapon development tests. One detonation would be from a tower. The rest would be air dropped. The largest device would have an estimated yield of twenty-five kilotons. Assistance required from the military would be minimal.[33]

What significantly increased participation in the test series and greatly complicated logistics and radiological safety activities was the military's interest in weapon effects tests that would include maneuvers involving thousands of troops. The Department of Defense, in essence, initiated its own test program. While the Atomic Energy Commission focused on weapon design and development, the military was concerned with the blast, radiation, and heat effects of nuclear weapons. Results of the Crossroads series underwater Baker shot had piqued interest in the effects of shallow underground detonations. By fall 1950, the Armed Forces Special Weapons Project (AFSWP) had formulated Operation Windstorm consisting of the testing of two 20-kiloton devices. Due to radiological safety concerns over potentially excessive amounts of contaminated dust that would be produced by ground-level shots, the tests would be conducted at Amchitka located in the remote Aleutian Islands. The military would conduct the tests, with Los Alamos providing only technical support. Amchitka, however, soon fell out of favor as a test site as the Department of Defense "recognized as doubtful the time-place practicability of Windstorm," and in February 1951 the military approached the AEC about conducting ground-level tests in Nevada. Initially refusing, the AEC eventually agreed to a pair of 1-kiloton shots. Renamed Jangle, the effects tests were joined with Buster for the fall test series.[34]

Complicating matters further, the Federal Civil Defense Administration (FCDA) also proposed an effects program of "considerable scope" directed toward resolving some of the "civil defense problems" presented by nuclear weapons. Buildings and housing were of primary interest to FCDA officials, with an emphasis on the "modes of failure of typical American wood frame houses" and "whether debris collapses into the basements." The program included a large number of "guest observers," ranging from all of the state governors to key civil defense officials from across the county, and perhaps "an entirely separate atomic test" for the FCDA. The AEC, again, was not keen on anything that would interfere with its "very heavy developmental test schedule" and "place a critical overload on the limited facilities at the Nevada site." Plus, the Department of Defense believed that the expenditure of "vital atomic weapons materials" solely for the benefit of the FCDA was not justifiable. The FCDA, as a result, submitted a "greatly reduced proposal" that AEC officials deemed more feasible.[35]

In mid-July 1951, the Military Liaison Committee submitted to the AEC its request for the participation in Buster-Jangle of 5,000 combat troops and 3,450 observers. The army

Operation Buster-Jangle



Nevada Proving Ground showing ground zeros for Operation Buster-Jangle. Source: Jean Ponton et al., *Operation Buster-Jangle, 1951*, DNA 6023F (Washington, DC: Defense Nuclear Agency, June 21, 1982), p. 7.

wanted troops to experience a simulated combat situation for "indoctrination in essential physical protective measures" and for "observation of the psychological effects of an atomic explosion." Despite logistical concerns, Chairman Dean informed the Military Liaison Committee that the proposal had the Commission's "complete concurrence." Dean warned the committee, however, that the "physical limitations of the local road and communications nets as well as the scarcity of water and other local facilities must be carefully considered," and he stressed that the AEC would not "assume the burden of furnishing facilities for their administrative movement, security control or support." As a result, the army handled its own logistics, setting up a tent encampment for the exercise, codenamed Desert Rock, at a site several miles to the south and west of Camp Mercury.[36]

The Atomic Energy Commission, nonetheless, retained ultimate responsibility for military activities at the test site. Dean told the Military Liaison Committee that the agency would "set the criteria of time, place, radiological safety and security necessary to prevent significant interference with the test program." In this regard, the AEC dashed army hopes of practicing battlefield tactics. For safety reasons, no troops would be allowed closer than seven miles to ground zero. They could entrench themselves much closer in, but then they had to leave their gear behind when the shot was scheduled to detonate. Film badges at the forward position would record the exposures they might

Camp Desert Rock during Operation Buster-Jangle. Source: DOE, NNSA-Nevada Site Office.

have experienced. Sheep confined in pens would reveal more graphic biological effects.[37]

Non-voluntary participation in Buster-Jangle by sheep, as well as dogs and rats, sparked considerable interagency controversy. Several proposed biomedical effects experiments involved using animals to determine the extent and degree of thermal burns. Carroll Tyler, who was the AEC's test commander for the series, expressed strong reservations about using these animals due to possible adverse public reaction. His test director, Alvin C. Graves, argued that similar data was available from Greenhouse or could be obtained by other means. The Department of Defense and the AEC's Division of Biology and Medicine disagreed and offered full support for the experiments. The issue soon became one of "responsibility and authority." The Department of Defense contended that military requirements were not matters for decision by either the AEC or its test organization. The AEC believed that the test director should be fully in charge, as the military task force commander had been at Enewetak. Not until early October—after the scheduled starting date for the series—was the matter resolved, with the AEC and military having authority in their "respective fields" during the "planning and preparational" phase of the series and the test director having "over-riding authority" during the operational phase. The biomedical experiments went forward as planned.[38]

Buster-Jangle began badly. Procurement and construction delays pushed the start of the series back several weeks, and the first shot and the only tower shot, Able, rescheduled for October 19, was "a dud." "They pushed the button and nothing happened," Dean noted. "It must have been an awfully funny feeling." An Army private participating in Desert Rock observed,

> we were marched around to the other side of the hill from our bivouac area to watch Able go off, but it had a misfire. It didn't establish much confidence with us for how these were going to go. We could see the tower which held the bomb and the guys climbing up the tower to see what had gone wrong.

Able's failure to fire was attributable to an electrical connection problem in the control circuit. Three days later, test officials tried again with Able. While firing appropriately this time, the device produced a less-than-spectacular detonation, with a yield of less than 0.1 kiloton. Subsequent Buster shots were more robust. Four devices were air dropped by Air Force B-50s (upgraded B-29s) over Yucca Flat during an eight day period. Yields for the air bursts, none of which occurred below 1,100 feet, rose progressively from 3.5 kilotons for Baker to 31 kilotons for Easy. The two Jangle shots, Sugar and Uncle, both with yields of 1.2 kilotons, took place ten days apart in late November. Detonated on the surface, Sugar formed a crater 21 feet deep and 90

The Buster-Jangle Charlie shot used a device yielding 14 kilotons that was dropped from a B-50 bomber on October 30, 1951, at Yucca Flat. Source: DOE, NNSA-Nevada Site Office.

Soldiers participating in Desert Rock watch the mushroom cloud. Source: DOE, NNSA-Nevada Site Office.

Desert Rock troops advancing on ground zero observe effects of the blast on military equipment. Source: DOE, NNSA-Nevada Site Office.

feet across. Uncle, buried 17 feet below ground, left a crater almost three times broader and deeper. Both shots, as anticipated, produced enormous amounts of radioactivity at ground zero. So high were the radioactivity levels—an estimated 7,500 roentgens per hour at the edges of both craters one hour after detonation—that monitors could not approach to take readings. These extremely high levels nonetheless fell rapidly.[39]

Desert Rock took place with few major problems. For Buster shots, troops came to within 500 yards of ground zero less than five hours after the detonations. None of the combat troops recorded exposure readings of more than 0.2 roentgen, which fell "well within the militarily acceptable limits." For Jangle, with its higher levels of radioactivity and apparent greater dangers, troops viewed the shots from a safe distance and then toured the forward areas on buses. These troops did not wear film badges, but high exposure levels presumably were avoided.[40]

Prelude to Tumbler-Snapper

Preparations for the next test series, codenamed Snapper and scheduled for late spring 1952 at the Nevada Test Site, were already well underway even before Buster-Jangle commenced. Plans called for weapon development tests involving a number of relatively low-yield atomic devices. Military and FCDA needs for weapon effects experiments and, as with Jangle, outright tests, however, still rankled top AEC officials. The test site had been "obtained" for development tests, the Acting Chairman Sumner T. Pike in November 1951 informed the Military Liaison Committee, and security and logistical problems arising from a combined effects and development program "force compromises which limit the effectiveness of such program." Pike recommended that the Department of Defense consider conducting a "special effects shot," which "for the sake of economy" could be conducted as part of some later, unspecified developmental test series. This was, in fact, not far from the military's thinking. Although certain "effects projects" of a limited nature could be included in development tests, AFSWP officials recognized the "inherent conflict" between the two types of tests "involving mutual interference, divergence of interests, competition for local facilities and labor, complexity of control or command, difficulty of accounting and general incompatibility." AFSWP proposed that the military conduct its own weapon effects test at the Nevada Test Site in spring 1953.[41]

This mutually agreed separation of effects and development tests did not last long. On December 12, 1951, less than two weeks after the last Jangle shot, the Commission was informed that several of the Buster shots had produced lower blast pressures than predicted. This was of concern for the Department of Defense because nuclear tactics depended on accurate data to determine proper heights for air bursts in achieving maximum destructive force. The military, the Commission was told, now wanted a special effects test as early as February. In spite of the "already great burden on the Commission's test facilities and personnel," the commissioners consented in principle to such a test as long as administrative control remained with the AEC. At a January 9 meeting at Los Alamos, AEC, laboratory, and AFSWP officials agreed to conduct an effects test, codenamed Tumbler, in conjunction with the Snapper series. Acquiescing to the effects test, AEC officials still harbored some doubts. Commissioner Henry D. Smyth, after hearing that the Joint Chiefs of Staff considered the matter of the "utmost importance," wondered if the pressure data might be achieved on a "model basis." Alvin Graves, test director for both Buster-Jangle and Tumbler-Snapper, complained to the Commission that Tumbler would be "costly . . . in terms of inadequate planning," and he noted that the "uncertainties of blast pressure measurements . . . did not alter the fact that Hiroshima and Nagasaki were destroyed by the pressures obtained from weapons of some 15 to 20 kilotons."[42]

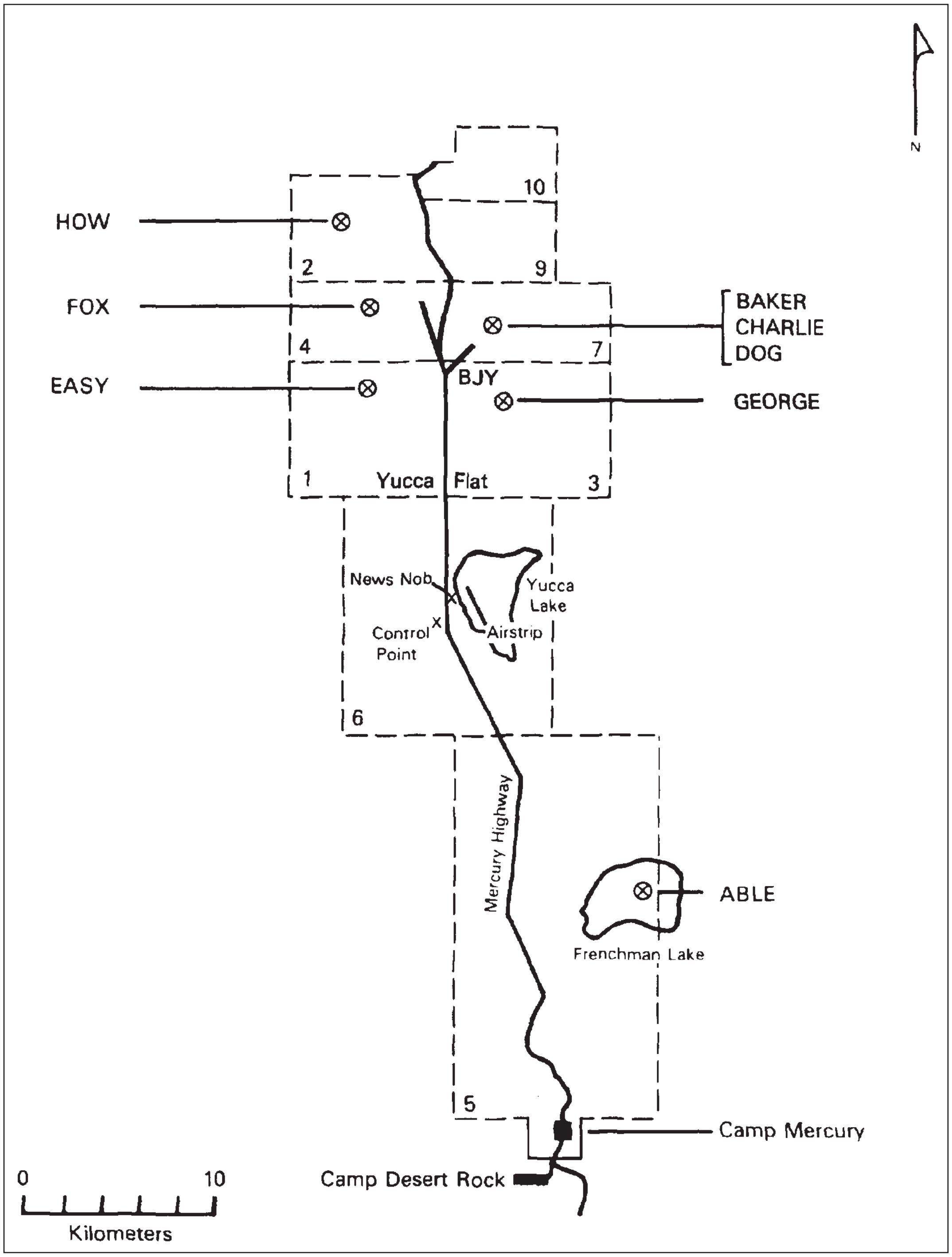
Desert Rock also carried over into Tumbler-Snapper. In late November 1951, Brigadier General Herbert B. Loper, head of AFSWP, informed

Brigadier General Herbert B. Loper, Armed Forces Special Weapons Project. Source: Defense Threat Reduction Agency (DTRA).

Colonel Kenneth E. Fields, director of the AEC's Division of Military Application, that the Army had a "vital requirement for participation to the maximum extent possible in all future atomic tests," including the upcoming Snapper series. Loper stated that the Army intended to occupy Camp Desert Rock, with a small maintenance force, until at least 1953. Fields replied that the Commission concurred in "limited troop participation" in development tests and had no objection to the "semi-permanent establishment" of Camp Desert Rock. He added that arrangements recently had been made by the AEC to supply the camp with electric power.[43]

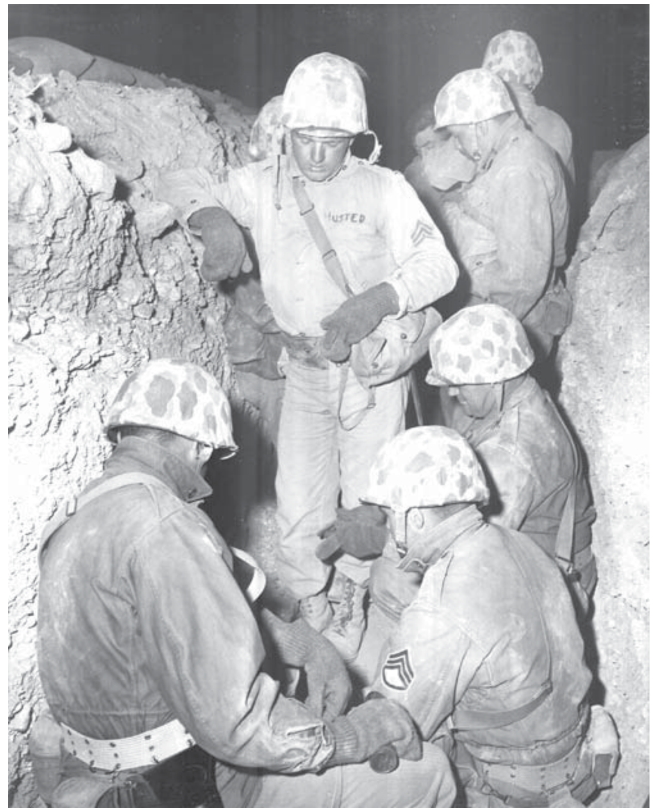
Desert Rock IV—Buster being I and the two Jangle shots II and III—complicated logistics for

Operation Tumbler-Snapper



Nevada Proving Ground showing ground zeros for Operation Tumbler-Snapper. Source: Jean Ponton, et al., *Operation Tumbler-Snapper, 1952*, DNA 6019F (Washington, DC: Defense Nuclear Agency, June 14, 1982), p. 10.

Tumbler-Snapper but, more significantly, raised important safety issues. Preliminary participatory numbers for Tumbler-Snapper, totaling about 4,500 troops and observers, provided to the AEC in mid-February caused little concern. In early March, however, Brigadier General Alvin R. Luedecke, AFSWP's deputy chief, informed Fields that the "Military Services" sought to revise the ground rules for troop maneuvers. The required withdrawal of troops to seven miles from ground zero during Buster-Jangle had proven "tactically unrealistic." For Tumbler-Snapper, the military proposed having troops occupy trenches located only 7,000 yards away from ground zero. Following the shot, the troops would make a "rapid advance, on foot or in a tactical formation, to the area beneath (or near) the point of explosion." This gave the AEC pause. Troops at 7,000 yards faced potential hazards that included eye damage—even blindness—from the flash, radiation exposure, thermal burns, "sand blasting" and other projectiles, and error in shot location due to early or late release of the bomb. Of these, bomb run error prompted serious concern "since it is clear that the only positive protection is to stay entirely away from the drop zone." Test Manager Carroll Tyler and Shields Warren, director of the AEC's Division of Biology and Medicine, refused to concur in the proposal.



Desert Rock troops occupy a trench during Tumbler-Snapper. Source: DOE, NNSA-Nevada Site Office.

Two soldiers get into their foxhole prior to the Charlie shot on April 22, 1952, during Operation Tumbler-Snapper. Source: DOE, NNSA-Nevada Site Office.

Safety could not be "guaranteed," argued Warren. The Nevada Proving Ground, renamed as such in February, was of "great value" and had been "accepted by the public as safe." "Accidents" attributable to a test, he concluded, would be "magnified by the press out of all proportion to their importance, and any injury or death during the operation might well have serious adverse effects."[44]

Pressure from the military, nonetheless, was considerable. The Marines stated that they would not participate in Desert Rock if the seven mile limit were imposed again. The Division of Military Application was not unsympathetic and considered the military's request for new limits "justified." Fields recommended that the Commission approve the proposal. Following two days of debate, the Commission agreed, and on April 2—the day after the first Tumbler-Snapper test—Chairman Dean informed Loper that the AEC had "no objection to stationing troops at not less than 7000 yards from ground zero." Noting the potential hazards, Dean added that the Commission "takes it for granted" that the military assumed the "responsibility in their placing and management of troops for protection" against these hazards.[45]

Tumbler-Snapper

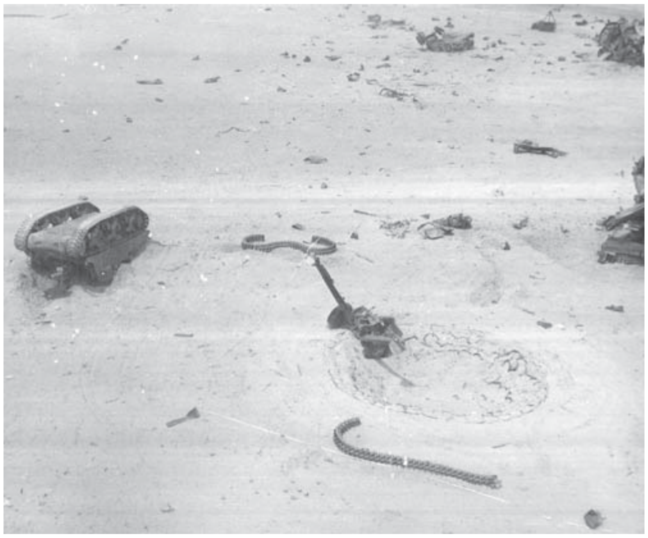
Tumbler-Snapper consisted of eight shots. The first three were air-dropped weapon effects tests designed to measure blast pressure, as well as ground shock and thermal radiation, "in all possible aspects and to include many cross checks of instrumentation." The first two shots, Able and Baker, had yields of a little over one kiloton. Able was detonated on April 1 at just less than 800 feet above the "smooth, thermal reflecting, dust and smoke free" surface of the dry lakebed at Frenchman Flat. To determine any "difference in results caused by varying target surface conditions," Baker was detonated two weeks later at just over 1,100 feet above a "thermal absorbing, smoke and dust producing area" on Yucca Flat. A week later, on April 22, at exactly the same location using the same instrumentation in order to "provide pressure vs. height information at large scaled height," Charlie produced a yield of 31 kilotons when detonated at a height of over 3,400 feet.[46]

The remaining five shots were Snapper weapon development tests. Considerable overlap existed, however, between the effects and development tests. Several tests counted as both Tumbler and Snapper, and Snapper had its own "military effects program" with "research and development" costs of over $1.5 million. The program consisted of a wide variety of measurements and experiments, including evaluations of effects on parked aircraft, army equipment, and trees, as well as biomedical experiments involving animal exposure containers, thermal radiation, and flash blindness.[47]

Tumbler-Snapper proceeded largely as planned. As in Buster-Jangle, one tower shot, Fox, reached "'Zero' time" with "no detonation" due to circuitry

Radar van and trailer following the Dog shot. Source: DOE, NNSA-Nevada Site Office.

Operation Tumbler-Snapper, Spring 1952



Aerial view of upended tank and other military equipment following the Dog shot on May 1. Source: DOE, NNSA-Nevada Site Office.

An Army colonel is swept off in an effort to rid him of radioactive dust following an inspection tour of the blast area. Source: DOE, NNSA-Nevada Site Office.

Desert Rock troops, above left and right, attack towards ground zero during a maneuver held by the Army following the George shot on June 1. Positioned in foxholes 7,000 yards from the blast, the troops advanced several thousand yards before being halted by radiological safety rules. Source: DOE, NNSA-Nevada Site Office.

Dog, and two tower shots, Fox and George. Dean, in his aftermath report to the Joint Committee on Atomic Energy, also reported mostly positive results for the Snapper development tests.[48]

From a testing perspective, perhaps the most noteworthy result was the increased move from airdrops to tower shots. The advantage of airdrops was that they were relatively easy and economical. Devices to be tested using this method, however, had to be constructed to withstand the accelerations experienced during airdrop and, thus, had to be much closer to a final stockpile construction. In addition, inaccuracies in bombing made it impossible to do many detailed experiments requiring close-in measurements. As a result, the last four Tumbler-Snapper devices, all with yields between 11 and 15 kilotons, were detonated from 300-foot towers. At least two of the devices required tower shots because no "ballistic case" existed for the system to be tested.[49]

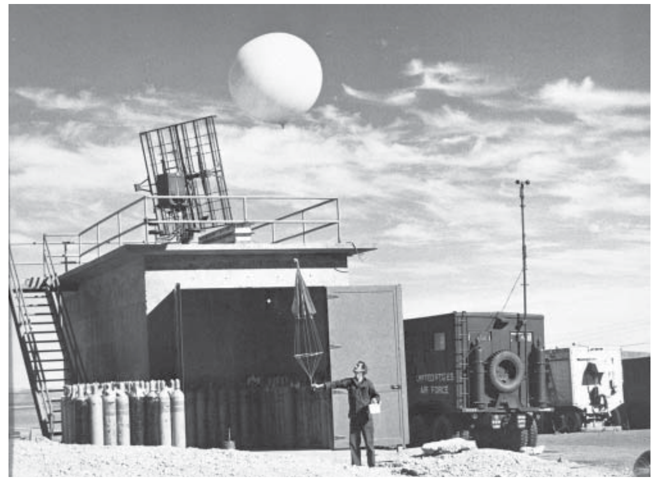
The downside of tower shots was increased local fallout. Detonations at such a low height

Three successive "ice caps" developed on the cloud column following the Fox shot on May 25. Source: DOE, NNSA-Nevada Site Office.

problems. Fox was successfully detonated on May 25 after a five-day delay. The eighth and last test, How, took place as originally scheduled on June 4. The Tumbler effects program, according to the Department of Defense, was "extremely successful" in obtaining information on blast pressures, and the uncertainties produced by the limited results from Buster were "to a large extent eliminated." The military obtained "extensive data" from the Snapper effects program. Desert Rock IV resulted in "further troop indoctrination," with maneuvers following two airdrops, Charlie and

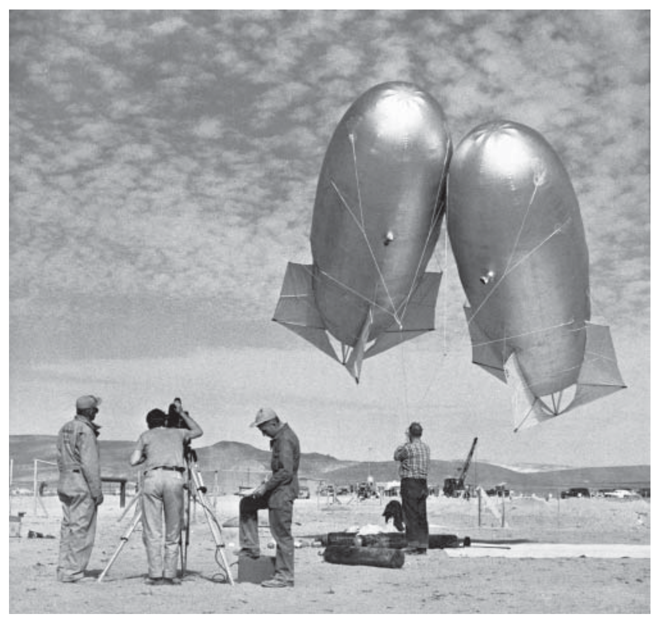
A tower used during the Tumbler-Snapper series. Source: DOE, NNSA-Nevada Site Office.

allowed the rapidly rising fireball to draw in large amounts of dust and debris that became coated with fission products. Due to strong upper-level winds, the first tower shot, Easy, dropped heavier than anticipated amounts of fallout to the northeast. Monitors at Lincoln Mine, a community numbering 110 located 45 miles from ground zero, recorded the most significant fallout over an inhabited area—registering briefly at 0.8 roentgen per hour—since the Trinity test. Much lower readings were collected at Ely, Nevada, 150 miles to the northeast, with traces found even further out at Salt Lake City. The AEC publicly dismissed the fallout levels as "primarily of scientific interest," but Warren advised the Commission to avoid testing when winds in the upper air reached high velocities. Test officials, as well, decided that "Lincoln Mine could be 'hit' only once more with the same intensity within a ten-week period." On-site fallout from Easy was even worse. Nearby sites for the next two tower shots, Fox and George, were so contaminated that the tests had to be postponed.[50]



Air Force weather station situated near the Control Point at the Nevada Proving Ground. A helium-filled Raob (radar-observer) balloon is being launched to the upper atmosphere prior to the Charlie shot to check on temperatures, dew points, humidity, and wind velocities. The radar tracking instrument, located on top of the weather station, charts wind velocities and directions to determine post-detonation paths of radioactive clouds and suspended particles. Source: DOE, NNSA-Nevada Site Office.

Fallout from the last three tower shots was more, albeit not entirely, contained. Following Fox, monitors at Groom Mine, not far from Lincoln Mine, recorded 0.19 roentgen per hour after a brief rain shower. A Las Vegas reporter who happened to be at the community to watch the predawn shot from an off-site vantage point became alarmed and asked for official comment. The AEC reassuringly responded that "peak radiation in the open [was] somewhat comparable to that a person would receive from a chest X-ray." Although the estimated exposures at Groom Mine "far exceeded anything an X ray might cause," the historian Barton Hacker has noted, they "still seemed low enough to preclude any great health hazard." Less easy to preclude were the first apparent livestock burns suffered since Trinity. "The reported injuries were . . . loss of hair and ulcerations down the middle of the animals' backs," Los Alamos Health Division chief Shipman told Graves, "suspiciously like the descriptions of the Trinity cattle."



Air Force weather personnel at Indian Springs AFB launch captive, helium-filled "Kytoon" balloons prior to Charlie. Hauled down minutes before the actual detonation occurred, the balloons obtained information concerning air pressure, temperature, and humidity. Last minute weather information was relayed by remote control to the AEC Test Director at the Nevada Proving Ground Control Point. Source: DOE, NNSA-Nevada Site Office.

Nonetheless, these seemed like somewhat minor problems at the time. As Philip S. Gwynn, head of Tumbler-Snapper's radiological safety group, concluded, the test series proved that "10 to 20 KT atomic bombs could be detonated from 300-foot towers at Nevada Proving Ground without creating a radioactive hazard to test personnel or the population in the vicinity of the test site, and without damage to plant or animal life."[51]

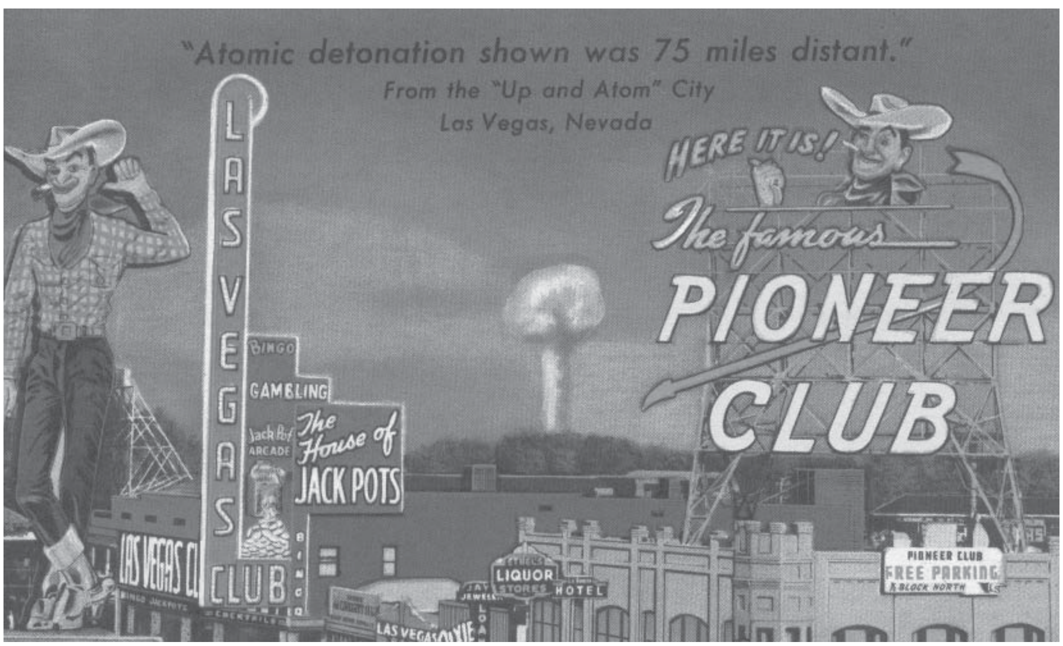
Community Relations and the Press

Community relations were the Nevada Test Site's Achilles heel. Without local as well as national public support, or at least acquiescence, continental testing became a questionable proposition. Perceived safety continued to be the key to maintaining public confidence, and AEC officials recognized the need to "allay unfounded fears" of radiation damage resulting from the tests.[52]

Local community support in Las Vegas and in smaller towns surrounding the test site was particularly important. In Las Vegas, the Ranger series, partly from the novelty of the experience, partly from the nature of the city, had produced a carnival-like excitement. By Buster-Jangle, the novelty had only slightly worn off. Testing still warranted front page headlines in the local Las Vegas press. Duly noted were the comings and goings of high officials and the Desert Rock troops, some of whom engaged in recreational pursuits in town. At one point, rumors were rampant that President Truman had checked into the El Cortez Hotel in downtown Las Vegas, with the Golden Nugget actually reserving a seat for him at one of their poker tables. The early, smaller Buster shots located some 25 miles north of where the Ranger detonations took place—and thus further away from Las Vegas—proved to be a disappointment for thrill-seeking locals and tourists. "I expected to see something like the fire that consumed the world," one tourist from California noted. The last two Buster shots, at 21 and 31 kilotons, were more spectacular. Dog shook Las Vegas "like an earthquake." The Las Vegas *Review-Journal* described the November 1 shot as a late-Halloween "treat" that gave the city "the long-awaited thrill of hearing windows rattle, the sound of rushing air from the blast wave, and the sight of a beautiful atomic cloud forming after the explosion." The tail of the cloud, the paper noted as an afterthought, "reportedly wafted over Las Vegas but there was no indication that it was dangerous to local residents because of radioactivity." The bigger Easy shot, although producing the "most brilliant flash" of the series, was "hardly felt" in Las Vegas.[53]

Smaller communities around the test site, including those apparently more in harm's way, lacked some of the enthusiasm of their Las Vegas neighbors but tolerated the blasts and demonstrated little concern for potential hazards. At 8:15 in the morning on November 5, fifteen minutes before the detonation of Buster-Jangle's Easy shot, the AEC alerted the local telephone operator in Caliente, a community of about 1,000 located to the east of the test site, that the town might be hit by blast effects. Within minutes, residents emerged from their homes and businesses, sheriff's officers "hustled" children from classrooms and schoolyards, and crowds gathered in the streets, as one reporter put it, "in an atmosphere of high excitement." Blast effects turned out to be minor, and the deputy sheriff, perhaps with a less sensationalist perspective than the reporter, observed that "nobody became excited, nobody became alarmed." Similar warnings issued by the AEC went out to Goldfield and Beatty, to the west of the test site. Again, effects were minimal. One Beatty resident noted that the blast with its mushroom cloud "sure is awful pretty," adding that he and his fellow citizens "wonder if something won't go haywire and cause some real damage some day." Even Lincoln Mines residents, doused by fallout from Tumbler-Snapper's Easy shot, showed "no excitement or

Postcard of the El Cortez Hotel on Fremont Street in Las Vegas. Site of the Atomic Energy Commission's public information office during the Ranger series. Source: University of Nevada, Las Vegas, Special Collections.



Postcard of the Pioneer Club in downtown Las Vegas with a mushroom cloud in the distance. Source: Atomic Testing Museum.

concern," according to a Public Health Service officer who visited the next day. "Their attitude was that they were not affected, so there was nothing to worry about." Ironically, the greatest public concern about Easy's fallout cloud came from Salt Lake City where the readings had been negligible.[54]

In fostering positive community relations, the press played a critical mediating role. Both Las Vegas newspapers actively supported the testing program. When some Las Vegas residents complained about Ranger's blast effects, Las Vegas *Morning Sun* publisher Hank Greenspun told his

Las Vegas *Sun* publisher Hank Greenspun. Source: Las Vegas *Sun*.

readers to "feel proud to be a part of these history-making experiments." Las Vegas, he noted, had "spent hundreds of thousands of dollars upon questionable publicity to exploit our area" and had "glorified gambling, divorces, and doubtful pleasures." Now the city had become "part of the most important work carried on by our country today. We have," he concluded, "found a reason for our existence as a community." Similarly, a columnist for the North Las Vegas *News* told city residents that they were "living within close proximity of historic experiments" and that it "may well be that what is happening at Frenchman's Flats means the survival of our way of life."[55]

The AEC, however, could not take the media for granted. Following Buster, the press complained that the AEC had permitted access to the site by 5,000 troops and scores of senators, congressmen, and other government officials but had excluded reporters. "We didn't invite you," AEC officials told the press at the beginning of the test series, according to *Time* magazine in an article entitled "AEC v. the Reporters," "and don't expect any information from us." Shut out from the test site, almost 100 reporters daily for three weeks "clambered up" the sides of Mt. Charleston, west of Las Vegas, and stood in five-inch snow, peering towards the test site and waiting for a blast. The Los Angeles *Times* described the policy as "inconsistent and obstructive." The Minneapolis *Tribune* called for the AEC to apologize to the American people for their "inexcusably bad handling of information."[56]

Stunned by the press criticism, the AEC decided to let reporters and representatives from civil defense organizations view Charlie, the third and largest shot of the Tumbler-Snapper series. The foreign press and "such publications as the *Daily Worker*" were excluded, but more than 400 "uncleared observers," as the AEC called them, took advantage of the offer. The AEC drew up an elaborate information plan that called for four days of activities, including briefings by, among others, Chairman Dean and Nevada Governor Charles Russell, a visit to Camp Desert Rock, lunch at Mercury, and a tour—"single file"—of the control and radio rooms at the Control Point. On April 22, the fourth and final day, the reporters and "FCDA guests" departed Las Vegas at 5:30 a.m. via chartered bus, paid for by the observers, and

Brig. General H. P. Storke, commanding general of Camp Desert Rock, addresses a group of correspondents during their tour of the site on April 21, 1952, prior to Charlie. Source: DOE, NNSA-Nevada Site Office.

arrived at the observer post, located across the road from the Control Point buildings at what came to be known as "News Nob."[57]

Charlie performed flawlessly but elicited decidedly mixed reactions from the observers. With a yield of 31 kilotons, tied with Buster Easy for the largest continental United States shot to date, Charlie produced a "stunning, tremendous display," according to one reporter, that "numbed the mind and shocked the senses." Others, however, described it as a "let down" or "anticlimactic." Charlie was "tremendously spectacular in its circus effects," noted a United Press reporter, but "did not, in intensity, live completely up to its advance buildup." Descriptions of the "sheer breathtaking beauty and magnificence" of the shot contrasted sharply with comments that "the blast was much more impressive statistically than visually," leaving one with a "sort of 'is that all feeling.'" Press interpretations of the meaning of it "all" also varied widely. The Santa Fe *New Mexican* declared Charlie "Worth the Cost" in terms of public confidence and public understanding, while the Salt Lake *Tribune* declaimed it as "Another Sickening Explosion in the Desert." The not-invited-to-the-party *Daily Worker*, predictably, denounced the event as a "day of shame and horror for our country." More insightfully, the Washington *Star* noted that Charlie "served to remind all of us . . . that a tremendous military revolution is taking place before our very eyes and that this revolution is converting military science into a thing capable of carrying war beyond the last limits of human endurance."[58]

Thermonuclear Weapons: Ivy Mike

Prospects for a thermonuclear weapon, meanwhile, had brightened considerably. Ulam's and Teller's radically new approach involving staged radiation implosion and the success of the George shot in the Greenhouse series in demonstrating a thermonuclear reaction now made a workable weapon likely. What was "a tortured thing that you could well argue did not make a great deal of sense," as J. Robert Oppenheimer observed, became by mid-1951 "technically so sweet that you could not argue about that." In June 1951, the AEC's General Advisory Committee, headed by Oppenheimer, met at Princeton with the Los Alamos weaponeers, the Commission, and other assorted officials and scientists to discuss the future direction of the program. The group,

Correspondents take pictures of a B-29 being decontaminated to remove radioactivity following the Charlie shot. Source: DOE, NNSA-Nevada Site Office.

Hans A. Bethe later recalled, "was unanimously in favor of active and rapid pursuit of work" on the thermonuclear weapon "with a test to be prepared as soon as it was clear what exactly was to be tested." Los Alamos favored moving directly to the testing of a full-scale experimental device and in September proposed conducting the test at Enewetak atoll in November 1952. This became part of the two-shot Ivy series. Mike, the thermonuclear shot, was to be followed two weeks later by King, the largest fission device ever tested with a yield of 500 kilotons.[59]

Mike was not a deliverable weapon. Fueled by deuterium cooled to a liquid state by a large cryogenics system external to the device, Mike stood 20 feet on end, with a diameter of almost seven feet, and weighed 82 tons. Mike's ground zero point was a six-story open air steel-frame structure on the small island of Elugelab on the north side of the atoll. Mike used a fission-fusion concept where radiation from a primary fission device was used to implode a liquid-deuterium secondary. This produced the fusion reaction.[60]

Hans Bethe. Source: Department of Energy.

Detonated on November 1, 1952, at 7:15 a.m., Mike culminated ten years of research and engineering and ushered in the thermonuclear age. Mike's yield was 10.4 megatons, almost 500 times the size of the Trinity test. The blast provided a terrible display of destructive power for observers located thirty-five miles away on the south rim of the atoll. A "brilliant light"—"many times" the strength of the sun—produced a "heat wave" that was felt immediately. The heat, even through clothing, was "about 180º F," noted an eyewitness, like a "momentary touch of a hot iron," observed another. "You would swear," one sailor stated simply, "that the whole world was on fire." The fireball, with a diameter of over three miles, was soon followed by "a tremendous conventional mushroom-shaped cloud . . . seemingly balanced on a wide, dirty stem." The dirt in the stem apparently was attributable to the 80 million tons of water, coral particles, and other debris that had been "sucked high into the air." After half an hour, the upper cloud was "roughly sixty miles in diameter with a stem, or lower cloud, approximately twenty miles in diameter. The top of the cloud rose to over 100,000 feet, and "as late as sunset . . . distant and high portions of the cloud could still be observed."[61]

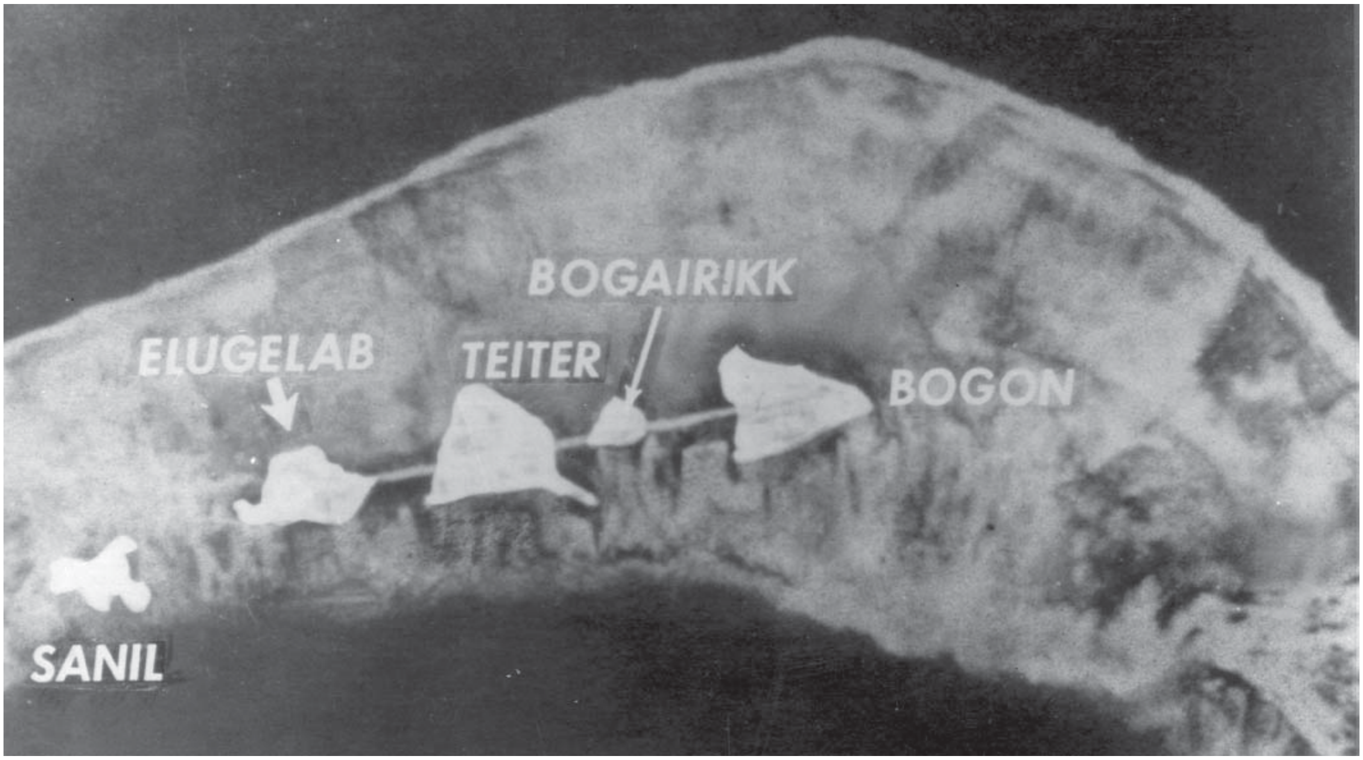
Elugelab disappeared. In the island's place was a deep, underwater crater almost a mile wide. Nearby islands were swept clean of flora and fauna. Only "stumps of vegetation" remained on Engebi, three miles to the east, along with fish carcasses, with burnt and missing skin from one side as if they "had been dropped in a hot pan." On Rigili, fourteen miles to the southwest from ground zero, "trees and brush facing the test site had been scorched and wilted by the thermonuclear heat." Many of the remaining birds "were sick, some grounded and reluctant to fly and some with singed feathers, particularly [those] whose feathers are dark in color."[62]

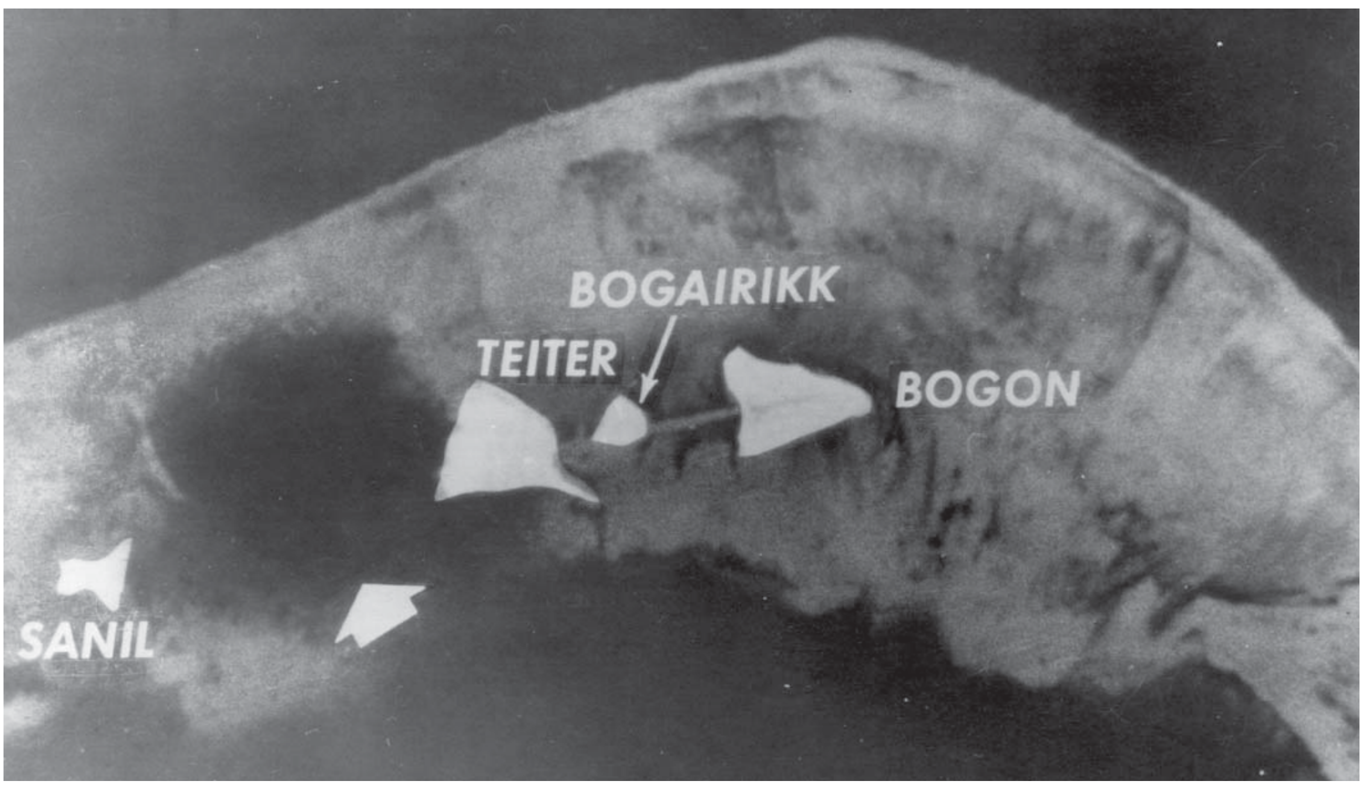
As awesome as the display was, some officials and scientists also found it deeply unsettling. "The

Two minutes after detonation, the cloud from the Ivy Mike shot rose to 40,000 feet. Ten minutes later, the cloud stem had pushed upward about 25 miles, deep into the stratosphere. The mushroom portion spread for 100 miles. Source: DOE, NNSA-Nevada Site Office.

heat just kept coming, just kept coming on and on and on," recalled Harold Agnew, who succeeded Norris Bradbury as director of the Los Alamos laboratory in 1970. "And it was really scary. And that's why I've advocated that every, five years, all world leaders should strip down and have to witness a multi-megaton shot. It would really put the fear of Allah, or God, or Mohammed, or Buddha, or somebody, in their veins. It's really quite a terrifying experience." Similarly, Herbert F. York, first director of the new weapons laboratory at Livermore, California, wrote of a "foreboding" that "always recurs" when he thinks back on Mike. The successful blast "marked a real change in history – a moment when the course of the world suddenly shifted, from the path it had been on to a more dangerous one. Fission bombs, destructive as they might have been, were thought of being limited in power. Now, it seemed, we had learned how to brush even these limits aside and to build bombs whose power was boundless."[63]

Elugelab Disappears





Elugelab disappears, November 1, 1952. The top photograph shows the Island of Elugelab in the Enewetak chain before Mike was detonated. The lower photograph shows the crater, more than a mile in diameter, created by the first thermonuclear detonation. Source: National Archives.

Part III

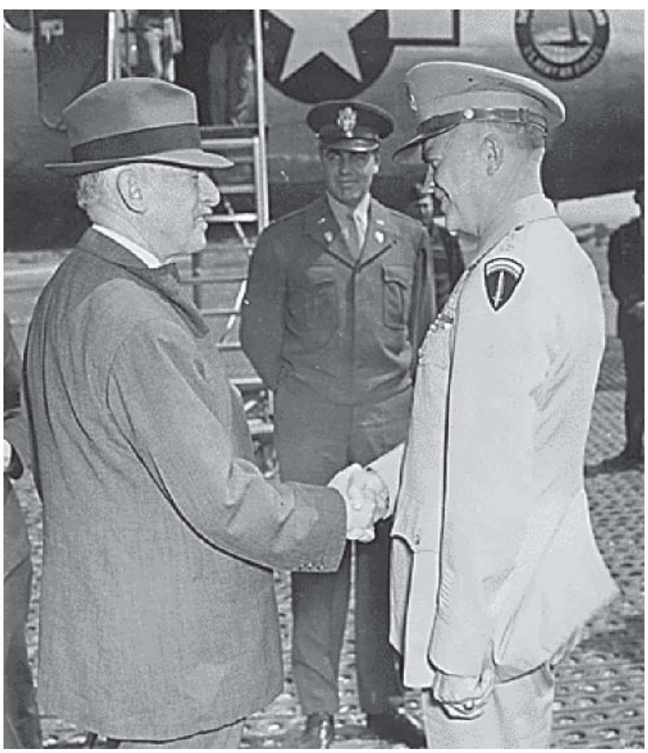
The Trials and Tribulations of Atmospheric Testing, 1953-1954

President Dwight D. Eisenhower. Source: Dwight D. Eisenhower Presidential Library.

Eisenhower and the Thermonuclear Age

Four days after the Ivy-Mike detonation, General of the Armies Dwight D. Eisenhower was elected President of the United States. A week later, Roy B. Snapp, secretary of the Atomic Energy Commission (AEC) and armed with a concealed pistol to protect the top secret document he carried from Chairman Gordon E. Dean, met with the president-elect at the Augusta National Golf Club in Georgia. The cover letter from Dean related details of the Ivy series, information of such importance that President Truman had asked Dean to convey the news at once to Eisenhower. "The significant event to date," Dean wrote, "is that we have detonated the first full-scale thermonuclear device." As Eisenhower read, Snapp told him that the United States would not have a deliverable weapon for at least a year. Eisenhower asked why, and Snapp explained that Mike was an experiment to determine if heavy isotopes of hydrogen could be "burned" in the fusion process. The device, as such, was much heavier and bulkier than could be carried in a bomber. When Eisenhower read on that Mike had produced a yield of about ten megatons and that the island "used for the shot—Elugelab—is missing," he paused to contemplate the implications. Favoring scientific research and understanding the interest of scientists in developing bigger and more efficient weapons but troubled by the growing power of nuclear weapons, he stated that there was no need "for us to build enough destructive power to destroy everything." "Complete destruction," he added, "was the negation of peace."[1]

Eisenhower was no stranger to war or nuclear weapons. As Commanding General in the European theater during the Second World War, he was briefed on possible German use of radioactive warfare. When informed of the successful Trinity test, he had told Secretary of War Henry Stimson that he hoped "we would never have to use such a thing." The Japanese were ready to surrender and there was "no need to hit them with that awful thing," Eisenhower explained, and he "hated to see our country be the first to use such a weapon." He also spoke to President Truman on the issue, but to no avail. Eisenhower knew more about nuclear weapons "in every respect," except for making the final decision, "than Harry Truman ever learned,"

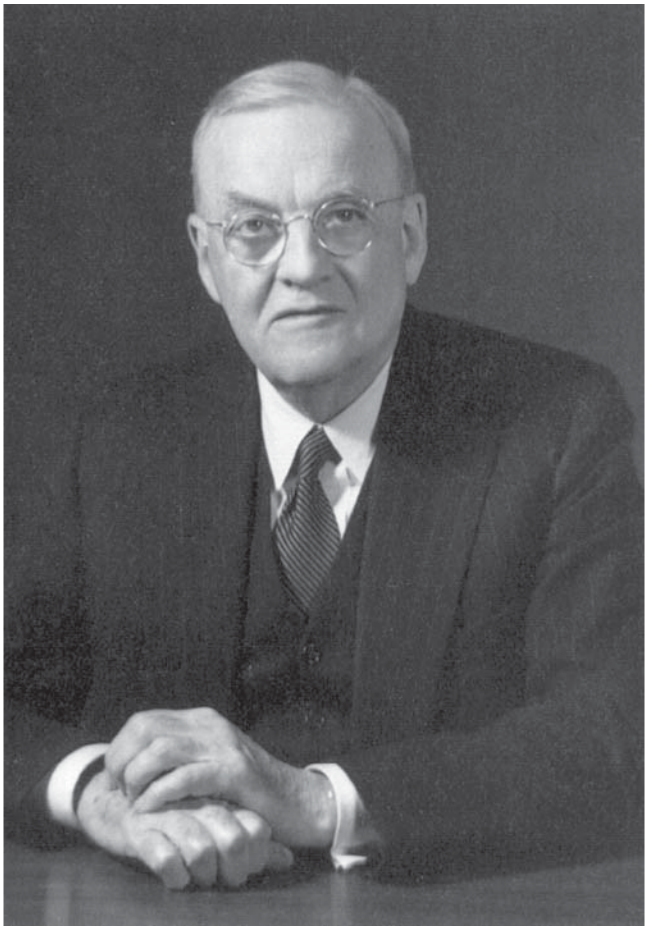


Eisenhower with Truman, top, and Stimson at the Potsdam Conference, ten days after the Trinity test. Source: Harry S. Truman Presidential Library.

according to McGeorge Bundy, who worked with Stimson in writing his memoirs and who later became special assistant for national security affairs for Presidents Kennedy and Johnson. Following the war, when Eisenhower was chief of staff for the Army, the Manhattan Engineer District reported to him. After the start of the Korean War, Truman recalled him to active duty to assume supreme command of North Atlantic Treaty Organization (NATO) forces in Europe.[2]

Despite his ambivalence toward nuclear weapons, President Eisenhower made them the centerpiece of his strategic policy. During Truman's second term, "international communism" seemed to be on the move, making great strides toward its perceived goal of world domination. The Soviet Union exploded its first atomic bomb; China fell to Mao Zedong and his Communist insurgency; and the Korean War became an ongoing drain on American resources. The Truman administration responded with a bold military expansion program, following up on the recommendations of National Security Council Paper Number 68 (NSC-68), commissioned by the President as part of his January 1950 decision to move forward with the development of the hydrogen bomb. NSC-68 essentially committed the United States to unilateral, worldwide defense of the "free world." Fearing that responding forcefully to every Communist challenge across the globe would ultimately bankrupt the United States and alter the very nature of its society, Eisenhower and John Foster Dulles, his secretary of state, instituted a program for the military called the "New Look," which sought to lower costs by emphasizing nuclear weapons—a "deterrent of massive retaliatory power . . . to deter aggression," as Dulles put it—and asymmetrical response. This meant that the United States would respond to a challenge using means, including possibly nuclear weapons, and at a time and location of its own choosing.[3]

Eisenhower first applied this new strategy in Korea. During the campaign, he had pledged to



Secretary of State John Foster Dulles. Source: National Archives.

bring the war to an early and honorable end. In spring 1953, the new administration "discreetly" let it be known that, in Eisenhower's words, "we intended to move decisively without inhibition in our use of weapons, and would no longer be responsible for confining hostilities to the Korean Peninsula." Truce negotiations soon began in earnest and an armistice agreement was signed in July, but it is debatable whether the implied nuclear threat or the death of Soviet leader Josef Stalin played the greater role.[4]

Expanding the Nuclear Weapons Complex

An expanding nuclear arsenal and weapons building capability made the New Look possible. Truman had avoided deliberate and public threats to use nuclear weapons. His administration never developed a coherent strategy for deriving political advantage from the nuclear arsenal, partly because of the limited number of available weapons. As late as 1949, doubts existed that the stockpile would be sufficient to repel a full-scale attack by the Soviet Union. By 1953, the situation had dramatically changed. Numbers had increased exponentially. Tactical weapons had been developed that could be used on the battlefield. Thermonuclear weapons—proven with Ivy Mike and soon to be operational—promised to be the ultimate strategic threat.[5]

Much more was on the way. Nuclear weapons were, as Eisenhower observed to Snapp, relatively cheap and getting cheaper. Expansion of the AEC's nuclear weapons complex initiated in the late 1940s, and accelerated with onset of the Korean War, was beginning to significantly increase production capabilities. Three additional plutonium production reactors had been built at Hanford, with two more scheduled for completion in 1955. Two new tritium and plutonium production reactors came on line at the Savannah River site in South Carolina in 1953, with three more following the next year. Additional gaseous diffusion plants were producing enriched uranium at Oak Ridge, and entirely new gaseous diffusion facilities at Paducah, Kentucky, and Portsmouth, Ohio, would be operational in 1954. A production center opened at Fernald, Ohio, in 1953 to provide feed for the reactors and diffusion plants. New weapons manufacturing and assembly facilities also had come on line. The Rocky Flats, Colorado, plant produced finished plutonium parts and assembled the nuclear cores for stockpile weapons. The Burlington, Iowa, and Amarillo, Texas, plants produced shaped charges for high explosives and assembled weapons. The Kansas City plant assembled mechanical and electrical components. The Mound Laboratory at Miamisburg, Ohio, made high-explosive detonators and neutron initiators. The Nevada Test Site, of course, was also part of the AEC's massive expansion effort.[6]

Most significantly for weapons design and testing, the Atomic Energy Commission in summer 1952 established a second weapons laboratory at Livermore, California. Part of the University of California Radiation Laboratory, the new Livermore laboratory was forced on a reluctant AEC, after a long struggle, by military and congressional pressure. Several factors came into play. Ernest Lawrence and his colleagues at the Radiation Laboratory sought increasingly to involve the laboratory in some useful way in weapons work. In addition, Edward Teller and Norris Bradbury and his senior staff at the Los Alamos laboratory did not agree on how the thermonuclear weapons developmental program should proceed. Teller finally concluded that a second laboratory was needed to pursue the program. The AEC opposed this because it would divert resources from Los Alamos and hinder the overall program. The Air Force and the Joint Committee on Atomic Energy, however, responded favorably to Teller's proposal, and the Air Force began consideration of setting up a second laboratory under its own auspices. With this, the AEC capitulated. Herbert York became the first director. In 1958, the laboratory was renamed the Lawrence Radiation Laboratory, later to become the Lawrence Livermore Laboratory and finally the Lawrence Livermore National Laboratory.[7]

Edward Teller and Norris Bradbury at Los Alamos. Source: Los Alamos National Laboratory.

Planning for Upshot-Knothole and Desert Rock V

Following Tumbler-Snapper, intensive activity continued at the Nevada Proving Ground in preparation for the next test series—Upshot-Knothole—scheduled for spring 1953. Between previous series, the site had basically shut down. After Tumbler-Snapper, however, much more needed to be done in terms of clean-up of test areas contaminated with radioactivity. Tumbler-Snapper "roll-up," as it was called, lasted five months. Concern about worker safety during the roll-up prompted AEC Chairman Dean to inquire about health and safety measures and their application. The AEC's Santa Fe Operations office provided assurances that appropriate standards were being applied, but the request from Washington also had asked for "an early study of the operational future" for the Nevada Proving Ground. Accordingly, Manager Carroll L. Tyler convened a special committee, headed up by Director of the Division of Military Application (DMA) Kenneth E. Fields and composed of headquarters and field officials and scientists, to assess current problems and determine if the results outweighed the costs.[8]

In its report, the Committee on the Operational Future of the Nevada Proving Ground confirmed that the test site was "vital" to weapon development. At "no point now foreseeable," the committee noted, would Los Alamos, as well as the incipient Livermore laboratory, "no longer require NPG for weapons development tests." Moreover, no other known continental site could match the program's "operational and safety requirements," and there was "no reason to consider alternative sites at this time." That said, the committee observed that the proving

Carroll L. Tyler, Manager, Santa Fe Operations, observes a test from the Control Point balcony overlooking Yucca Flat. Source: Los Alamos National Laboratory.

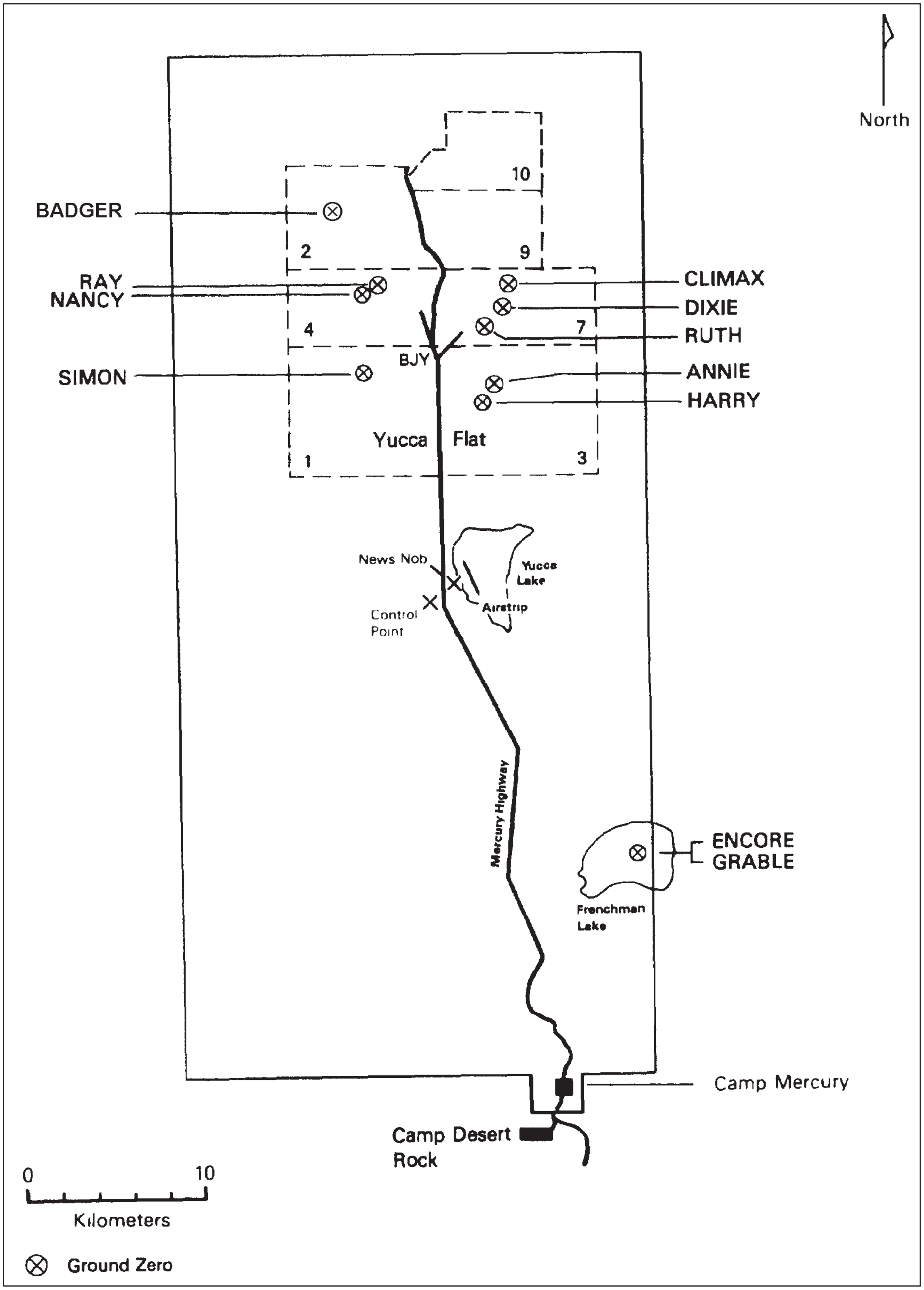
ground lacked "sufficient developed capacity," both technically and in living facilities, to meet even current requirements. Weapon effects experiments were a "valid extension" of the proving ground's "original purpose," but the committee recommended that there be no increase in "scope" of test activities or in "present participation." This included activities under consideration by the military, such as conducting effects tests in bad weather and in-flight nuclear warhead missile tests, that the committee considered a "public hazard." Indeed, public safety, the committee contended, was "the major factor restricting the type and size of devices" tested at the proving ground. Although long-range fallout was not considered hazardous, the committee admitted that "good fortune" had "contributed materially" to the fact that fallout had "not exceeded permissible exposure in the highest reading recorded in any nearby off-site inhabited locality." The local population had been "quite cooperative" so far, but a "latent fear of radiation" might "flare up given an incident or an accident." Yields for devices tested at the site, the committee advised, should therefore be limited. Unless a "very strong, overriding reason" existed, surface and sub-surface shots should not go over one kiloton, with tower shots held to thirty-five kilotons and airbursts to fifty kilotons. Contamination also could be reduced by developing new firing sites and using existing firing sites less frequently, by using higher towers constructed of aluminum, and by soil stabilization beneath the towers.[9]

The Committee on the Operational Future of the Nevada Proving Ground submitted its report to headquarters in May 1953. As the first phase of study, the report would be followed by additional work taking into account the results of Operation Upshot-Knothole. Since plans for the test series essentially were complete by the time the committee met, and the series itself almost complete by the time the report reached headquarters, the committee's efforts, in the short term, served primarily as an evaluation of the potential hazards posed by Upshot-Knothole.[10]

As with the previous two test series, Upshot-Knothole merged Upshot development tests with Knothole military effects tests. Of the ten planned shots, eight were weapons related. Two of these tests represented the initial efforts of the new Livermore laboratory. Of the two Knothole effects tests scheduled for Frenchman Flat, the first would be an air drop shot and the second a nuclear artillery shell, already a stockpile weapon, to be fired from a 280-mm cannon located seven miles from ground zero. Additional effects experiments would be conducted as part of the Upshot tests.[11]

Plans for Upshot-Knothole also called for an expanded program of troop maneuvers as part of Desert Rock V. As they had been prior to the Tumbler-Snapper series, military officials were unhappy with what they considered to be overly conservative restrictions on troop placement and movement. They wanted troops entrenched much closer than the 7,000-yard limit imposed in Tumbler-Snapper, and they wanted higher exposure

Operation Upshot-Knothole



Nevada Proving Ground showing ground zeros for Operation Upshot-Knothole. Source: Jeannie Massie, et al., *Shot Badger: A Test of the Upshot-Knothole Series, 18 April 1953*, DNA 6015F (Washington, DC: Defense Nuclear Agency, January 12, 1982), p. 11.

limits than the AEC's permitted weekly exposure allowance of 0.3 roentgen or 3.0 roentgens total over the entire series (or 3.9 roentgens over a thirteen-week quarter as anticipated for Upshot-Knothole). The Department of Defense informed the AEC that it would "assume full responsibility for the safety of Desert Rock participants." Defense officials promised that if safety standards were "less conservative" than the AEC's and "accident or criticism" resulted, the Department of Defense was "prepared to make a public announcement of these facts." The AEC agreed, but with the caveat that the agency deemed its "established safety limits . . . to be realistic, and . . . that when they are exceeded in any Operations, that Operation may become a hazardous one." The military, as a result, set its limits at 6.0 roentgens at any one test, with no individual receiving more than 6.0 roentgens in any six month period. Troops would be entrenched as close as 3,500 yards to a tower shot, but "selected volunteers" could be placed in "deep foxholes" as close as 1,500 yards to a 20 kiloton shot. These volunteers could be subject to 10 roentgens exposure.[12]

Volunteer military officers just after emerging from a trench located only 2,500 yards from ground zero following the Nancy shot, March 24, 1953. Source: DOE, NNSA-Nevada Site Office.

FCDA, Operation Doorstep, and the Press

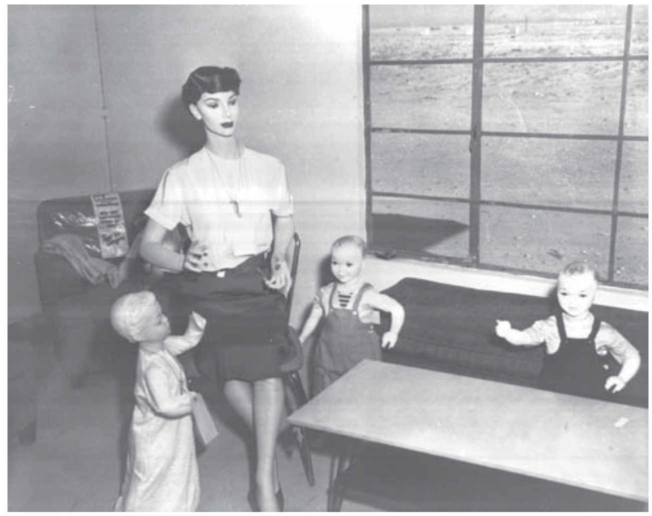
Upshot-Knothole also provided the Federal Civil Defense Administration (FCDA) with its long-awaited opportunity to participate in a "major test and demonstration program." As in the past, the prospect of an "open shot" at which 300 FCDA observers might be present gave the AEC pause because of the difficulty of excluding "representatives of the press and other persons." Public relations and administrative problems, AEC Chairman Dean noted, were far more difficult to handle than the security problems. The FCDA argued, however, that an open test with full press coverage would boost interest and participation in their nation-wide civil defense program. The Commission sympathized with this position and in late December 1952 informed FCDA of their approval provided that "no aliens," that is, foreign observers, be permitted to attend. The AEC scheduled the open shot for mid-March with the first test of the series, the estimated fifteen-kiloton Annie development test to be detonated on a 300-foot tower at Yucca Flat.[13]

The FCDA program, dubbed Operation Doorstep*, consisted of a full array of effects experiments. Since it was "impractical . . . to build complete office, skyscraper or big apartment buildings," explained Harold L. Goodwin, director of FCDA's operation staff, in a press briefing the day before the test, components such as wall panels and partitions were being tested in a series of concrete cells open at the front and back. "When we find out how they fail, and why they fail," Goodwin noted, "we will have taken a big step forward in determining what will happen to big buildings in attacked cities." Smaller structures

* "The name was appropriate," noted FCDA Administrator Val Peterson, "since the purpose of the program was to show the people of America what might be expected if an atomic burst took place over the doorsteps of our major cities." FCDA, *Operation Doorstep* (Washington: Government Printing Office, 1953), p. 2.

Operation Doorstep

One of the two frame houses built 3,500 and 7,500 feet from ground zero. Source: DOE, NNSA-Nevada Site Office.



Mannequin woman and three children in living room. Source: DOE, NNSA-Nevada Site Office.

Basement shelter with mannequins. Source: DOE, NNSA-Nevada Site Office.

Wooden house, truck, and car with two mannequins inside. Source: DOE, NNSA-Nevada Site Office.

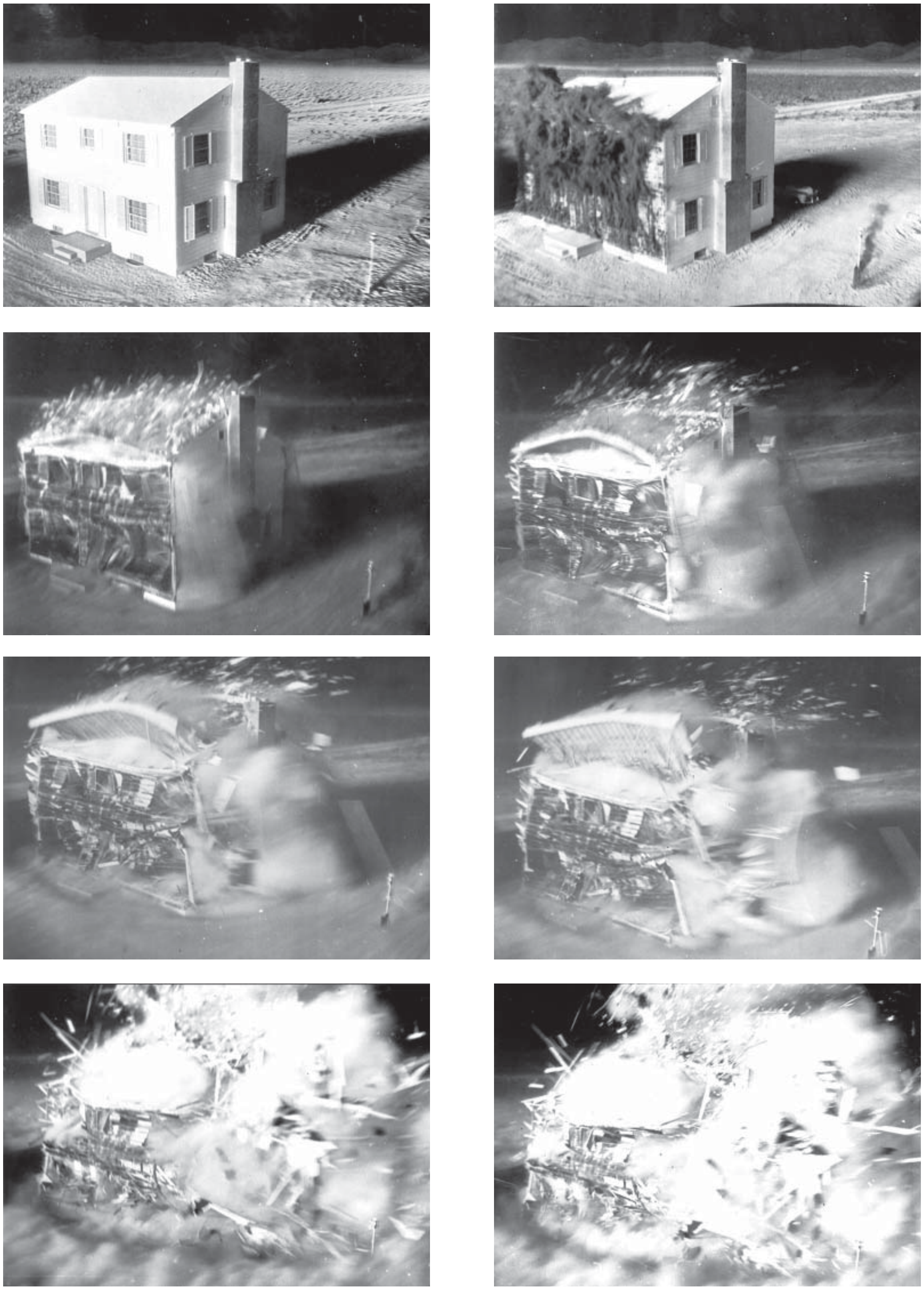
could be tested intact, such as two frame houses built 3,500 and 7,500 feet from ground zero. These center-hall, two-story dwellings were typical of thousands of American homes. Complete except for utilities and interior finish, the houses contained government-surplus furniture, household items, and fully-dressed department-store mannequins to measure and assess damage. Officials anticipated that the house closest to ground zero would be completely destroyed by the blast. Reflective whitewash on the exterior and Venetian blinds, they hoped, would keep the house from burning. Officials expected that the house at 7,500 feet would be damaged but not destroyed. Blast shelters, designed to protect occupants within a collapsing structure, were placed in the basements of both houses. Eight additional shelters designed for backyard use were constructed nearby. Fifty automobiles, some with mannequins, also were placed at varying distances from ground zero. Publicity from Operation Hot Rod, the initial effects experiment using passenger vehicles during the Ranger series, had prompted "some people" to come to the "dangerous conclusion," Goodwin told the reporters, "that an automobile is a sort of rolling foxhole for the atomic age." These experiments were therefore especially important because they would "provide definitive information on protection of persons in vehicles."[14]

The civil defense experiments were significant not only for the technical data that would be obtained but also for the sense the public would derive of the nature of a nuclear attack. The AEC and FCDA jointly prepared an elaborate public information plan involving 250 newsmen, 360 state governors and mayors, and scores of county and civil defense officials. This was twice the participation as in the previous shot open to the press, Tumbler-Snapper's Charlie, where access had been granted grudgingly by the AEC. The tenor of Annie was much different. The AEC and FCDA sought to "promote as extensive and as vivid coverage as possible by all media." They invited observers to visit the site and examine the layout of the experiments before the shot, view the test, and inspect the results after the blast. They encouraged photography, arranged for live, nationwide radio and television coverage, and allowed a select number of correspondents and civil defense personnel to accompany troops in forward positions during the test (an activity for which the AEC made sure the military took full responsibility).[15]

Annie detonated at 5:20 a.m. on March 17, 1953, with a yield of sixteen kilotons. The effects experiments went as expected. The house closest to ground zero collapsed, with a high-speed camera capturing the destruction in a dramatic eight-photograph sequence published widely in newspapers and magazines. Mannequins on the first floor were badly damaged, with some so trapped in debris that they could not be easily extricated. Mannequins in the basement shelters, by contrast, escaped harm. The dwelling at 7,500 feet suffered extensive damage but remained standing. Mannequins in the living areas of the house were thrown about considerably. Heads were generally pockmarked and clothing cut by flying glass. The mannequins later were displayed at the J.C. Penney store on Fremont Street in Las Vegas. The Las Vegas *Review-Journal* ran before and after photographs with the statement that "these mannequins could have been real people, in fact, they could have been you. Volunteer now for the

Mannequins in damaged living room. Source: DOE, NNSA-Nevada Site Office.

House Destroyed by Annie Shot



Time-sequence photos of the house 3,500 feet from ground zero during the March 17, 1953, weapon effects test at Yucca Flat. Shooting 24 frames per second, the time from the first to last picture was two-and-one-third seconds. The camera was completely enclosed in a two-inch lead sheath as a protection against radiation. The only source of light was that from the blast. In frame 1, the house is lighted by the blast. In frame 2, the house is on fire. In frame 3, the blast blows the fire out, and the building starts to disintegrate. Frames 4 through 8 show the complete disintegration of the house. Source: DOE, NNSA-Nevada Site Office.

Demolished wooden house and two vehicles. Source: DOE, NNSA-Nevada Site Office.

Civil Defense." As for the family automobile, it proved relatively safe beyond a ten-block radius if windows were left open to prevent the roof from caving in. Most cars not burned or radioactive could be driven away after the shot.[16]

The public relations portion of Annie proved equally successful, even if the event itself was somewhat anticlimactic after a big buildup. Prominent daily newspapers and weekly news magazines covered the shot with special reports and photographs. An estimated eight million television viewers watched live. On CBS, viewers saw images of pre-dawn darkness consisting of three pin-points of light on a black screen that Walter Cronkite, located seven miles away at News Nob, explained were the tower and the two effects houses. Viewers heard the countdown, which Cronkite described as "The Voice of Doom," and then the screen went dark as the camera had to be covered. As seen on NBC, Annie produced a series of "wobbly flashes" followed by a view of the mushroom cloud. More sobering than the images was the commentary by Chet Huntley, entrenched with the troops only two miles from ground zero, who immediately after the blast described it as "the most tremendous thing that ever happened to me." Other reporters and many of the troops up close were less impressed. United Press correspondent Robert Bennyhoff told his readers that what he experienced was "disappointing." He felt "none of the intense heat the scientists had predicted" and the shock of the blast "was nowhere near as violent as I expected." One officer expressed the opinion that it "was not worth coming out here for." An artillery-man compared the blast unfavorably with that produced by a standard artillery piece.[17]

Newly appointed FCDA Director Val Peterson, who also had been in the forward trenches, nonetheless accomplished what he had set out to do. The AEC and FCDA had captured the nation's

Val Peterson, Director, Federal Civil Defense Administration. Source: National Archives.

attention with the Annie shot and Operation Doorstep, and the following day Peterson announced that President Eisenhower was "gravely concerned" with the "inadequate progress" of civil defense throughout the country. "In the name of the President," Peterson declared, "I call upon every American . . . to speed Civil Defense progress in the immediate, urgent interest of our national security."[18]

Upshot-Knothole, Weapon Effects, and Desert Rock V

Annie was the first of eleven shots in Upshot-Knothole. Yields for the first seven shots, all weapon-development related and, with one exception, detonated on a tower at Yucca

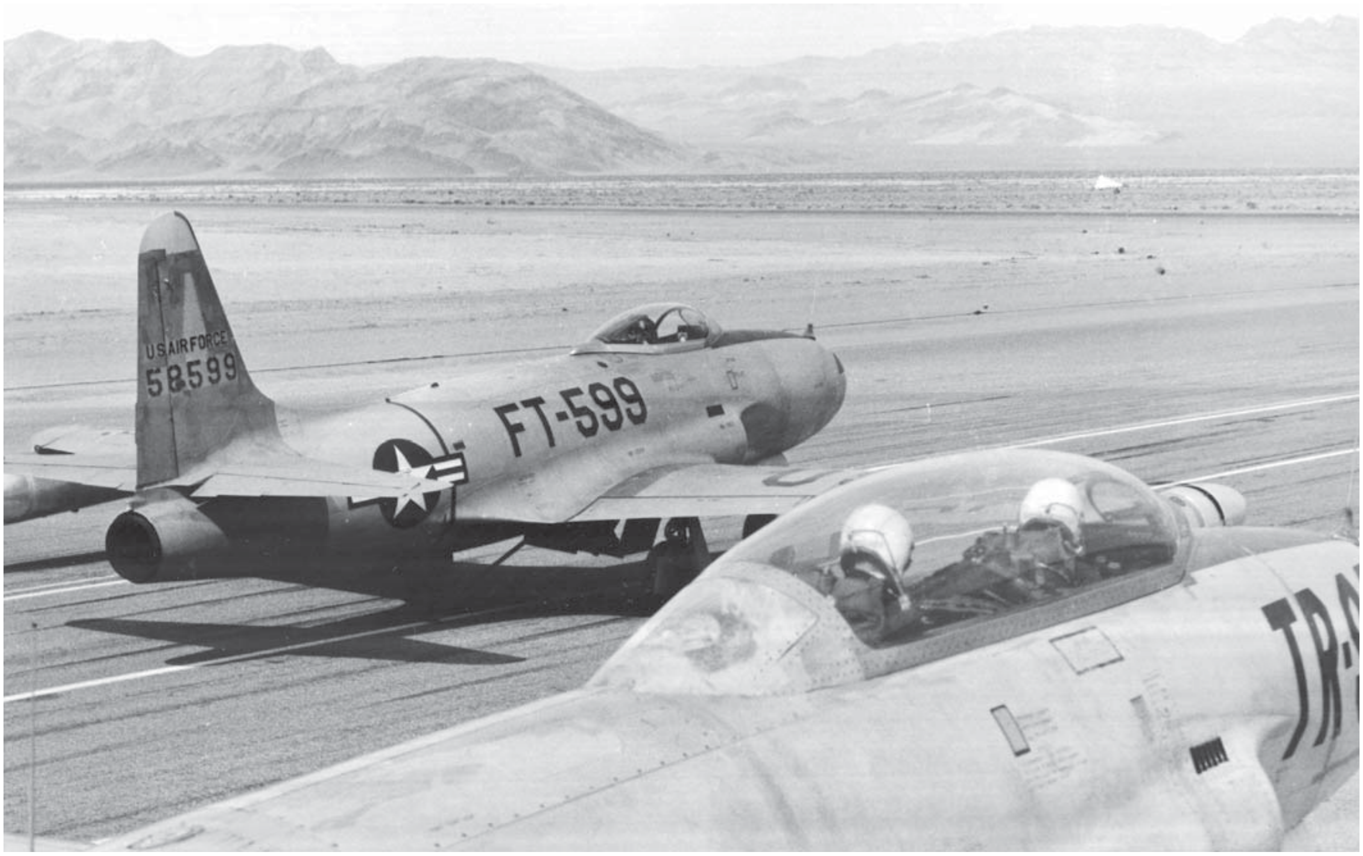
Observers at News Nob. Source: DOE, NNSA-Nevada Site Office.

Flat, ranged from 200 tons to 43 kilotons. Both of the tests conducted by the new Livermore laboratory, Ruth and Ray, came in at 200 tons, well under their anticipated yields. Both were derisively termed "fizzles," with Ruth vaporizing only the top 100 feet of its 300-foot tower. This was somewhat embarrassing because a test was expected to erase all evidence associated with it and thus automatically "declassify" the site. Ray was detonated eleven days after Ruth on a 100-foot tower. Herbert York, first director at Livermore, later noted that "considering the attacks on the quality of Los Alamos leadership that were part of the arguments supporting the establishment of a second laboratory, it is not surprising that some Los Alamos scientists filled the air with horse laughs" following Ruth and Ray.[19]

Remnant of the tower following the Ruth shot. Source: Lawrence Livermore National Laboratory.

Sandwiched between Ruth and Ray, the 11-kiloton Dixie, the fourth shot, was dropped on April 6 at 7:30 a.m. from a B-50 bomber flying at an altitude of over 33,000 feet and detonated at a height of 6,020 feet above Yucca Flat. This was significantly higher than any previous test and produced "one of the more spectacular bursts" of the series, with the cloud topping out at 43,000 feet. Radiation problems were nearly nonexistent, but all high-level air traffic was prohibited for six hours in a 100,000 square mile area, including most of Arizona and as far east as Albuquerque. Among Dixie's effects experiments was an evaluation of the radiation hazards for aircrews flying through the cloud. Two remote-controlled drone aircraft, each carrying 60 mice and two monkeys, flew through the cloud minutes after the detonation and landed at Yucca Flat airstrip. The animals were taken to Los Alamos for examination. In another experiment, four helicopters experienced the detonation while hovering 10 feet above Yucca Lake, some 11 miles south of ground zero. The helicopters then headed for ground zero, simulating the movement of airborne troops into the area. An additional 26 manned aircraft participated in Dixie. Ten of these, nine of which were F-84Gs, were involved in cloud sampling beginning an hour and 15 minutes after the detonation. After the samples were taken, the aircraft landed at Indian Springs Air Force Base where they parked in designated areas, with the engines off and canopies closed, while the

Dixie shot, detonated 6,020 feet above Yucca Flat. Source: DOE, NNSA-Nevada Site Office.



QF-80 jet drone (marked FT-599) in takeoff position at Indian Springs Air Force Base for a pilotless flight through Dixie's radioactive cloud. (Note the empty cockpit.) The mother ship, a DT-33, with two pilots aboard, is in the foreground. Navigation and control of the drone during the final approach and penetration of the cloud was directed from a ground-control station at Indian Springs AFB, while the mother ship circled the cloud formation. Control of the drone was returned to the mother ship as it reappeared out of the cloud. Landing at Indian Springs AFB was again directed from a ground-control station. Source: DOE, NNSA-Nevada Site Office.

samples were removed by ground personnel using long-handled tools. The samples were placed in shielded containers and sent by courier aircraft to AEC and Department of Defense laboratories for analysis. After the samples were removed from the sampling aircraft, the pilots opened their canopies and stepped out onto a platform held by a forklift, so that they would not have to touch the exterior of their contaminated aircraft.[20]

Conducted at Frenchman Flat with the same planned ground zero, Encore and Grable, the eighth and tenth shots of the series, were primarily effects tests. Encore, an air drop, detonated at 27 kilotons on May 8, 2,400 feet above the desert floor, missed the intended target by 837 feet. Several seconds before device release, a mechanical linkage failure in the bombing system caused the B-50 bomber to drift. The device released as the bombardier flipped the switch to abort the drop. The miss played havoc with many of the effects experiments requiring a more exact distance or angle from ground zero.[21]

Encore included more effects experiments than any other shot in Upshot-Knothole. Among the experiments:

- The Army set up three complete "hospital tent layouts" at 5,000, 9,000, and 15,000 feet from ground zero to determine the extent of destruction. At 5,000 feet, the layout burned with "all contents completely demolished." At the farthest site, the layout did not burn and was only partially damaged. After the shot, guards were placed at the site to protect the "medical material."

- The Army and the U.S. Forest Service, to assess the damage done to trees and the "amount of cover" provided by a forest, placed 145 ponderosa pines, with an average height of 51 feet, in a "grove" 6,500 feet from ground zero. Taken from forest reserves near the test site, the trees were cemented into concrete blocks eight days before the test. Encore broke off some of the trees at their cemented base and ignited others.

- The military and the Forest Service, to determine the vulnerability of urban structures to fire, built five miniature "demonstration houses" at two locations, 6,000 and 8,000 feet from ground zero. Three of the houses were two-by-two meters, and the other two three-by-three meters.

- The Army, to evaluate the protection against skin burns provided by service clothing, placed 55 shaved and anesthetized pigs dressed in army uniforms at varying distances from ground zero. Pigs were used because their flesh is similar to human flesh. "PIGS STAR IN ATOM TEST" headlined the Las Vegas *Review-Journal*.

- The military placed numerous tanks, trucks, and other equipment, including

Desert Rock military observers witnessing the Encore shot. Over 2,000 troops "attacked" through ground zero shortly after the detonation. Source: DOE, NNSA-Nevada Site Office.

145 ponderosa pines cemented into concrete blocks on Frenchman Flat prior to the Encore shot. Source: Defense Threat Reduction Agency.

four F-47 and one F-86 aircraft, at varying distances from ground zero. A display area of equipment and bunkers, trenches, and foxholes manned by sheep, designed to add realism to the Desert Rock troop maneuvers, was set up out to a distance of 10,000 feet southeast of ground zero. After the shot, a five-ton wrecker moved into the area to upright overturned vehicles.

Other experiments involved industrial-type structures, five separate center sections of an open-deck, single-track truss railroad bridge, 27 automobiles, and a "large variety of bio-med material."[22]

Grable, the first test of a nuclear artillery shell, detonated on May 25 with a yield of 15 kilotons at 524 feet above the same sweeping array of vehicles, buildings, and bomb shelters that had endured Encore. Fired by remote control from an 85-ton 280mm cannon located on high ground about ten kilometers south-southwest of ground zero, the shell was a Los Alamos designed Mark-9 gun weapon. This was the first detonation of a gun-type device since Hiroshima. Among the many observers at Grable were Secretary of Defense Charles E. Wilson, Secretary of the Army Robert T. Stevens, Army Chief of Staff Matthew Ridgway, and several congressmen.[23]

Soldiers in Desert Rock V conducted mock battles following six of the eleven Upshot-Knothole shots. In all, over 13,000 troops participated, with fresh units assigned for each test. Observers, mostly officers, constituted another 4,500, and an additional 2,000 men serviced Camp Desert Rock. Being positioned much closer to

Grable shot, with the 280mm cannon that fired the nuclear artillery shell in the foreground. Source: DOE, NNSA-Nevada Site Office.

ground zero than in previous exercises made for a more realistic and immediate battlefield experience for the troops but also made for overexposures. A joint AEC-Department of Defense press release described what two battalions entrenched 4,000 yards from ground zero experienced at the 23-kiloton April 18 Badger shot:

> As the roaring blast rolled over the trench, the troops were showered with dirt and stones. The entire desert seemed to erupt and when the men left their foxholes visibility was limited to fifty yards. The intense heat wave ignited hundreds of Joshua trees and as the strong winds carried the dust away the whole desert was aglow with these flaming torches.

Shifting winds soon exposed one of the battalions to an "unprecedented and unanticipated radiation fall-out," according to the brigade commander, and they were evacuated immediately. Average total exposure was 4.8 roentgens. Twelve volunteer officers positioned in a six-foot deep trench at 2,000 yards fared even worse. One marine colonel was "blinded by the absolute whiteness" from the flash and then "shaken back and forth very strongly a number of times" by earth movement. "The blast wave then hit with a high pitched crack," he reported, with "very heavy dust" blocking his view of the mushroom cloud. "During the light, earth shock and pressure phases," he observed, "I was rather overwhelmed by the magnitude of these effects, but immediately thereafter in a matter of 6 to 7 seconds I had complete control of all faculties and could have engaged in close combat." High radiation, with exposures as high as 9.6 roentgens, forced an early evacuation. Close-in volunteers at the April 25 Simon shot, which at 43 kilotons was 20 percent more than the predicted yield and the largest test to date at the Nevada Proving Ground, encountered readings of 100 roentgens per hour immediately after the blast. Evacuation began five minutes later. Film badge readings for the volunteers ranged from 11.7 to 16.3 roentgens.[24]

Troops crouching in their trench just prior to the Encore shot. The soldier with a handkerchief tied over his face is trying to protect himself from the large quantities of dust and dirt that will be thrown into the trench as the blast from the explosion passes overhead. Source: DOE, NNSA-Nevada Site Office.

Fallout: Simon, Harry, and Climax

Radioactive fallout became a central concern with Upshot-Knothole. During Tumbler-Snapper, fallout had been more or less a nuisance consideration, but in Upshot-Knothole off-site exposures began to call into question the very existence of the test site. The early shots of the series seemed, at the time, to present minimal problems. A slight wind shift following Nancy, the second shot of the series detonated on March 24, put the fallout cloud over Lincoln Mine, with a peak reading of 0.58 roentgen per hour, and AEC monitors asked residents to remain indoors over a two-hour period "as a routine precautionary measure." This "caused some anxiety" for test health and safety officials, admitted Tom D. Collison, head of the rad-safe unit, but the exposure dose did not exceed 3.4 roentgens, and with the population indoors this value was probably substantially reduced. Fallout from the other six initial shots fell largely on uninhabited areas.[25]

Simon, the seventh shot, produced significant contamination. On site, heavy fallout prompted officials to delay the next planned shot at Yucca Flat, Harry, until cleanup was completed. In the two days following the shot, 39 persons exceeded the 3.9 roentgens permissible dosage. Off site, the cloud from Simon moved eastward in a narrow but intense path. Good weather and planning resulted in "no significant fallout" in inhabited areas, but two major highways east of the proving ground, Highways 91 and 93 from Glendale, Nevada, extending north 20 to 30 miles, were hit with fallout, with ground readings as high as 0.46 roentgen per hour. Contaminated vehicles soon appeared, and Test Director Graves asked state and local police to assist in setting up roadblocks. Over a two hour period, monitors checked nearly 400 vehicles, of which 50 of these, with readings above seven milliroentgen per hour on their wheels and mudguards, were given free carwashes. "In general, the reaction of the public was most cooperative," noted one monitor. "No one questioned our authority for our actions." When told "they were in contaminated vehicles," drivers and passengers "appeared to be not overly concerned when informed that there was no danger of any great magnitude. They merely wanted to know what to do and how to go about it. Once this was explained, everything flowed very smoothly."[26]

Although public alarm had been avoided, ongoing concern prevailed within the AEC. On May 13, John C. Bugher, director of the Division of Biology and Medicine, told the Commission that potential integrated doses from Simon in some thinly populated areas had been as high as ten roentgens. He also reported that the day after Simon a "sharp rain-out" of fallout had occurred near Troy, New York, delivering a potential integrated dose of two roentgens. Adding to the Commission's woes, ranchers downwind from the test site were claiming livestock deaths due to fallout, and perplexed citizens across the country were beginning to attribute unusually volatile spring weather to atomic weapons testing.[27]

Radiological safety uniform worn by on-site monitor. Source: DOE, NNSA-Nevada Site Office.

As a further complication, Los Alamos sought to add an eleventh test, Climax, to the existing Upshot-Knothole schedule following the Grable shot. Unanticipated variations in yield in two earlier shots of the series raised concerns about similar problems occurring at the spring 1954 Castle series in the Pacific. Scheduled for Domino, the planned fall 1953 series at the Nevada Proving Ground, the Climax device had been completed sooner than expected and was ready to be tested. A successful

Radiological-Safety control room at the Control Point a few hours after the Nancy shot. A fallout map is being prepared by group in left foreground, recording reports from ground level monitoring teams within 200 miles of ground zero. Source: DOE, NNSA-Nevada Site Office.

test could not only "significantly improve" the "chances of gainful return from the more than $100 million which will be spent for Castle" but also eliminate the need for Domino. What gave the Commission pause was Climax's estimated yield of 70 kilotons, far larger than any previous shot in Nevada. Chairman Dean noted his concern that "so large a detonation might produce serious shock in nearby communities or . . . might cause severe fall-out or rain-out on more distant localities." Graves assured Dean and the other commissioners that severe shock damage and excessive fallout could be avoided. Climax would be an air drop with detonation planned for 1,000 feet or higher. As the last shot of the series, it also would be possible to "select the weather conditions with great care." The Commission approved the proposed test on May 18, with the shot, pending presidential approval, scheduled for the ten day period following Grable.[28]

In the meantime, Harry, the 32-kiloton ninth shot of the series, produced additional significant off-site fallout. Detonated on May 19 at 5:00 a.m. in weather judged "to be perfectly satisfactory for this shot," Harry deposited heavy fallout in a populated area centered approximately on St. George, Utah, when a slight change in wind direction shifted the pattern further to the north. In the early morning hours, roadblocks again appeared on Highways 91 and 93. Monitors asked residents of Mesquite and Bunkerville, Nevada, close to the Utah border, to remain indoors for a 45 minute period as the cloud passed. In St. George, a reported reading of 0.3 roentgen per hour prompted a monitor shortly after 9:00 a.m. to warn local officials that residents should take cover. By noon, the populace was back on the streets. Health and safety officials estimated that the potential "total lifetime dose" in St. George was as high as 6.0 roentgens, with lesser amounts in other communities. Ordered to remain in the

Air Force crew that tracked radioactive clouds during Upshot-Knothole. Source: DOE, NNSA-Nevada Site Office.

area for several more days due to the unease of residents, the monitor in St. George was concerned that radioactivity might get into the milk supply from cows eating contaminated vegetation. He considered collecting samples from local dairies but instead limited his sampling to several purchases from stores so as not to create alarm. Scientists later estimated that children in the area exposed to radioactive milk received thyroid doses from

Monitoring equipment being worked on, St. George, Utah, May 11, 1953. Source: Los Alamos National Laboratory.

iodine-131 that ranged from inconsequential to levels possibly causing thyroid abnormalities.[29]

Test officials thought the crisis had been handled well, but the Commission was not pleased. On May 21, the Commission grilled Bugher and Graves about the weather criteria for conducting tests. At a reconvened session the following day, Commissioner Eugene M. Zuckert stated that the AEC had a "serious psychological problem" on its hands that required consideration of possible alternatives to continental testing. In the present public frame of mind, Zuckert noted, it would take only a "single illogical and unforeseeable incident" to preclude holding any future tests in the United States. He also observed that the AEC was involving President Eisenhower in the matter by asking him to approve Climax, but it had not informed him of the magnitude of the shot or the possible dangers involved. At Zuckert's suggestion, Dean approached Lewis L. Strauss,

AEC Commissioner Eugene M. Zuckert. Source: Department of Energy.

former commissioner, now special assistant to the president on atomic energy. Strauss initially counseled Eisenhower to reject the added test because of the risk posed for continental testing, but Dean's argument that canceling Climax could delay the Castle series persuaded him to seek the President's approval. Eisenhower was not happy. "I don't like it," he told Strauss. "I don't like to have the time element argued in such a case. The proper officials should have brought the query up three months ago. However, in the circumstances, it's approved."[30]

Initially scheduled for May 31, test officials postponed Climax due to extensive cloud cover. The forecast for June 2 indicated a remote possibility of a radioactive fission debris rain-out over Salt Lake City, but officials decided to go ahead with the shot. With the B-36 bomber carrying the device already airborne in the early morning hours of June 2, however, increased likelihood of rain over Salt Lake City and the shift of winds more in the direction of the city prompted officials again to postpone Climax. Rescheduled for June 4, Climax detonated at a

Climax shot, June 4, 1953. Source: DOE, NNSA-Nevada Site Office.

height of 1,334 feet above Yucca Flat. The shot's somewhat-less-than-predicted 61 kilotons—still the largest atmospheric test conducted up to that date in Nevada—produced much less off-site fallout than Simon or Harry. In addition, the test provided the necessary information for the Castle series, and, as a result, AEC officials cancelled the fall 1953 Domino series planned for the proving ground.[31]

Rep. Douglas R. Stringfellow (R-UT). Used by permission, Utah State Historical Society, all rights reserved.

Atomic Weather and Dead Sheep

The success of Climax and the end of Upshot-Knothole helped ease the test site's public relations problems. Few newspapers outside the local area covered the fallout incidents, and these tended to stress reassurances provided by the AEC. Although the fallout issue continued to fester and the communities of southwest Utah had been somewhat unnerved by Harry, most people locally downwind from the Nevada Proving Ground did not complain about the roadblocks or having to remain indoors. The radioactive dusting, in general, had engendered neither public outcry nor open protest. After Harry, Utah Representative Douglas R. Stringfellow complained to Dean, in a letter made public, that he was "greatly disturbed" by the alarm, bitterness, and anxiety expressed by his constituents "as to the harmful effect which radiation from these blasts might have upon persons residing in the neighboring communities." The New York *Times* did a "check of communities" near the test site that "failed to disclose any widespread public apprehension of the sort cited by" Stringfellow, but Dean and his staff moved quickly to alleviate any concerns the congressman might have. Several staffers met with Stringfellow in his Washington office, and Kenneth E. Fields, director of the AEC's Division of Military Application, accompanied him out to the proving ground to witness the Grable shot. Afterwards, Fields told Dean that Stringfellow had "got what he wanted" and would be "very helpful to us." Two weeks later, Stringfellow informed Dean that he had "made several speeches and radio broadcasts in my district and also issued press releases in which I reassured the people of Utah that every precautionary measure was being taken to protect their health and welfare. I also attempted to allay their fears and reassure them that the degree of radiation from atomic fallout was so low that it could not have any adverse effect on their physical well-being."[32]

More nettlesome from a public relations standpoint were widespread concerns that the atomic tests in Nevada were affecting the weather and sparking a seemingly unusual number of severe tornadoes across the country. Newspaper and magazine articles speculated on some sort of connection. "The world's weather has taken a freakish turn lately," noted the *U.S. News & World Report*, "and many people wonder if all these recent atomic explosions had something to do with it." A Gallup poll indicated that 29 million Americans believed that there was a connection between

Beecher, Michigan, following the June 8, 1953, "monster tornado" that ripped through the region. The tornado killed 116 people and injured 844 along a 27-mile path. It was the last tornado in the United States to claim more than 100 fatalities. Source: National Oceanic and Atmospheric Administration.

testing and bad weather. During and after Upshot-Knothole, the AEC received an estimated 1,000 letters from the public, nearly all of them weather related. One correspondent asked the President, whom she assured she was "not a Democrat," to "extend the time of these tests to more lengthy intervals, giving the air a chance to clear completely, instead of collecting atoms in bunches thru the pressure wrought by forced explosions." Even Congressman Sterling Cole, chairman of the Joint Committee on Atomic Energy, asked Dean "to assure the Committee, once again, especially in the light of these noted weather anomalies, that every effort has been made by the Commission to obtain the judgment of expert scientists on the relationship between detonations of atomic weapons in the continental United States and the weather." Dean and the AEC's public relations staff did their best to provide these assurances to all concerned. The agency, Dean told Cole, was "continuously in touch" with Weather Bureau and military meteorologists. Their "unanimous judgment" was that there was "no relationship between atomic detonations in Nevada and weather conditions over the United States."[33]

Reports of livestock deaths due to fallout were a more serious—and real—issue. Initial complaints focused on horses with scabs and sores on their backs and several head of dead cattle. Radiation appeared to be at least partially involved, as AEC health and safety officials found "unmistakable signs of beta burns" on the horses but none on the cattle. Both horses and cattle still measured radioactivity in spots on their back or flanks. The AEC officials theorized that the horses had received fallout from the first Upshot-Knothole shot, Annie, which produced the beta burns, and the cattle had not. Both horses and cattle received fallout from Harry, accounting for the measured activity. The AEC eventually paid claims for twenty horses, but rejected any claims for the cattle since they showed no sign of radiation damage and, AEC officials believed, had died of malnutrition and related problems.[34]

Dead sheep posed the more difficult problem. On June 2, 1953, Utah officials informed the AEC that unusually large numbers of ewes and newborn lambs—several thousand of some 10,000 animals—had died that spring from flocks wintered in pastures north and east of the proving ground and lately returned to the Cedar City area. Previously unseen symptoms baffled local veterinarians and stockmen. Consultants brought in by the AEC examined surviving sheep, and initial indications were that radiation might be implicated in sheep deaths. On June 10, Gordon M. Dunning of the AEC's Division of Biology and Medicine briefed the Commission. Some of the sheep examined, he told the commissioners, "were determined to have beta burns in their nostrils and on their backs." The commissioners quickly focused on the "serious public relations problems" arising from "the fall-out incidents" and the "importance of presenting immediately to the public the full facts concerning the reported incidents." Evidence was growing, noted Dunning, that the "people in the vicinity of the Nevada Proving Ground no longer had faith in the AEC."[35]

Determining the exact cause or causes of death of the sheep, nonetheless, was not that simple. Environmental factors seemed to play a role. With the driest year in two decades, clear signs existed that the sheep were undernourished. On the other hand, radiation readings taken of the animals and the strange lesions on faces and backs suggested that the sheep had "picked up significant amounts of radiation or radioactive material." Health and safety officials were unsure. "In the opinion of the investigators," Division of Biology and Medicine Director Bugher told the Commission on June 17, the sheep deaths "had not been caused by radiation." Radiation injury, however, could have been a "contributing factor." Several of the AEC's consultants went a step further. "The Atomic Energy Commission," stated Robert Thompsett, a Los Alamos veterinarian, "has contributed to great losses." With answers awaiting further detailed studies and radiation experiments on sheep, plans for an early release of findings dissipated.[36]

Test Site in Jeopardy

Following Upshot-Knothole, the future of the Nevada Proving Ground remained uncertain. Even before "Dirty" Harry and the end of the series, DMA Director Fields asked Lt. Col. Raymond P. Campbell, Jr., a staff officer in his test branch, to evaluate the prospects of the site given the fallout problem. Campbell was not optimistic. "The level of radiation here is such that, if fallout occurred in a populated area immediately adjacent to the Proving Ground, beta burns might be experienced," he told Fields. "This would be a serious situation indeed since these burns cause hair to fall out and blisters or ulcers to form. This would probably arouse immediate public clamor for the closing of the Proving Ground." Not everyone agreed. Some senior officers in the military thought the AEC was "making a serious mistake in over-emphasizing the effects of fall-out . . . [and] the precautions taken by AEC were extreme and caused undue public concern." Indeed, prompt response, absence of any outward harm to anyone exposed, and AEC reassurances initially made Campbell's something of a minority position. After the first reports of radiation damage to livestock, however, this began to change. Beginning in early June 1953, concerns about public and congressional reactions to testing became front and center within the AEC. On June 9, Commissioner Zuckert recommended that a full-scale review be made of the "highly interrelated public relations and safety problems that we have created."[37]

The following month, the AEC reactivated the Committee on the Operational Future of the Nevada Proving Ground. Chaired by Carroll Tyler, head of Santa Fe Operations, and renamed the

Committee to Study Nevada Proving Ground, the group consisted of top officials such as Bugher, Graves, Los Alamos Director Bradbury, and the AEC's Director of Public Information Morse Salisbury, as well as specialists on weather and blast effects from other agencies. Fields's mandate to Tyler was to produce "at the earliest practicable date" a report on the proving ground's prospects in "light of developments during and after Upshot-Knothole." In the meantime, personnel at the proving ground were cut to a bare minimum, and the Commission refused to authorize any further activity pending the findings of the Tyler committee. Lacking specific instructions, Tyler decided the task was to produce a more detailed study than that submitted in May by the committee's predecessor. The committee needed to "support any conclusions," Tyler observed, with "supplemental reports or documentation." At the committee's initial meeting on August 6, Tyler parceled out report assignments, about half of which dealt with the value of continental testing and the other half with preserving the Nevada site.[38]

The committee met again—for a final time—on September 24 and 25. After reviewing the reports, which broke little new ground but served to summarize the issues involved, the committee concluded unanimously that a continental test site remained necessary and that the Nevada Proving Ground "meets the essential criteria of logistics and safety better than any other continental site known to the Committee." The committee also expressed confidence that "operational controls" at the site could be "strengthened to provide continuing assurance of public safety" and recommended that a "more extensive educational and informational program be activated nationally and in the region of Nevada and its adjoining states." The committee, nonetheless, had not finished its task, noting that supplemental studies, particularly in the area of operational controls, were needed. In the interim, the committee submitted a preliminary report "recognizing that various decisions and actions affecting continental tests may have been held in abeyance pending completion of its study." The Commission, for its part, decided to wait for the final report.[39]

Carroll L. Tyler, left, manager of Santa Fe Operations, and Norris E. Bradbury, director of Los Alamos Scientific Laboratory. Source: Los Alamos National Laboratory.

Meanwhile, the issue of sheep deaths was coming to a head. As the AEC awaited additional data, the southern Utah sheepmen were becoming impatient. On September 16, Congressman Stringfellow informed Lewis Strauss, recently appointed the new AEC chairman, that he was "anxiously awaiting information" and could not "understand the long delay in issuing your report and making repatriation [sic] to the injured parties concerned." Strauss responded that the evidence so far did not indicate that radiation exposure contributed to the sheep deaths and that experimental work was ongoing at AEC laboratories.[40]

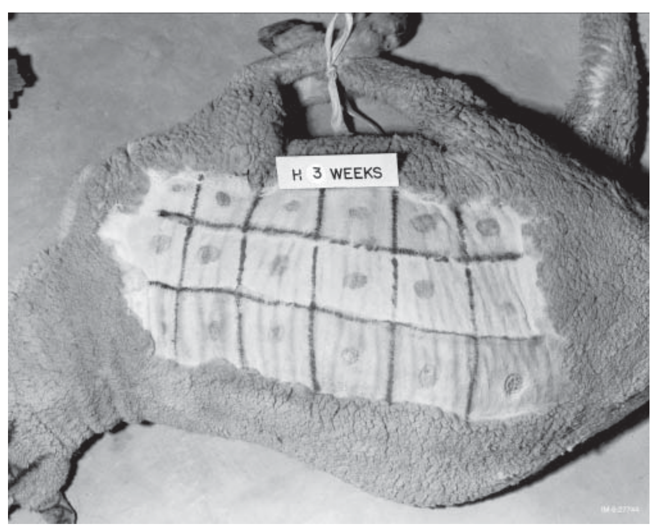
Two major studies were nearing completion. At the AEC's Hanford facilities, comparison of thyroid tissue of the Utah sheep with that of experimentally treated sheep suggested that no radiation damage had occurred. At Los Alamos and the University of Tennessee, researchers sought to compare the lesions of the Utah sheep with those produced by controlled beta irradiation of sheep

AEC Chairman Lewis Strauss. Source: Department of Energy.

in the laboratory. Early results were less conclusive than those at Hanford. At a meeting at Los Alamos on October 29, some participants expressed doubts that the data presented, as one put it, "throw much light on the Utah situation." Nonetheless, at the end of the session, AEC health physicist Gordon Dunning, in an effort to "summarize their many discussions," pushed through a statement—signed by nearly all present—that there was "a preponderance of evidence to support the conclusion that the lesions were not produced by radioactive fall-out." Back in Washington, AEC officials were delighted with the results, and attention turned to drafting a final report. Released in early January 1954, the long-awaited report exonerated the test program as a factor in sheep losses. "Considering all of the information and data available at this time," the report declared, "it is apparent that the peculiar lesions observed in the sheep around Cedar City in the spring of 1953 and the abnormal losses suffered by the several sheepmen cannot be accounted for by radiation or attributed to the atomic tests conducted at the Nevada Proving Grounds." The report, concurred in by the U.S. Public Health Service and the Department of Agriculture's Bureau of Animal Industry, but not by the State of Utah, made no mention of dissenting views.[41]

The sheepmen remained unconvinced. Within a year, sheep owners filed suit against the United States seeking damages totaling $176,959. In 1956, the federal district court in Salt Lake City rejected their claims on the basis of testimony by expert witnesses that there was no evidence that fallout was involved. In 1982, twenty-six years later, the same judge who had tried the original case vacated his decision, ruling that the government had perpetrated a fraud upon the court by withholding information. The following year, however, a three-judge panel of the Tenth circuit overturned this decision.[42]

Apparent resolution of the sheep issue in early 1954 coincided with the completion of the report by the Committee to Study Nevada Proving Ground. Consisting of sixty-two pages and backed up with twenty-five studies totaling more than 220 pages, the report reaffirmed the committee's September findings and made an



Sheep subject to controlled irradiation experiments at Los Alamos. Source: Los Alamos National Laboratory.

exceptionally strong defense of testing in Nevada. The committee did propose certain operations restrictions involving reducing fallout, prohibiting marginal shots, and imposing yield limitations. In addition, the committee advocated a "planning maximum" of ten to fifteen shots over a one year period. Finally, the committee recommended lowering the off-site exposure standard from 3.9 roentgens over thirteen weeks to the same amount over an entire year.[43]

Concurrently with the report's completion, Division of Military Application Director Fields asked the Commission to authorize the resumption of activities at the Nevada Proving Ground in preparation for the next planned test series, Teapot, in early 1955 or possibly in late fall 1954. Inclined to accept the recommendations of the Tyler committee, the Commission first wanted input from its advisory committees. Not to further delay activities at the test site, they also approved the initiation of planning for the next test series and the release of construction funds. Deliberations by the advisory committees focused on the planning maximum. The Advisory Committee on Biology and Medicine recommended a maximum of ten shots per year, with only three of these being high-yield tower shots. The General Advisory Committee, by contrast, favored no limitations in test numbers and proposed that numbers be "determined by the needs of the weapon laboratories and the Division of Military Application." Not until June 30, 1954, did the Commission finally approve the continued use of the Nevada Proving Ground, subject to the operating criteria submitted by the Tyler committee but with no limitations on the number of tests.[44]

Joe 4 and Castle Bravo

Upshot-Knothole was the prelude to Castle. In their July 1953 semiannual status report to President Eisenhower, the Commission reported that the tests held in Nevada had "helped Los Alamos greatly in moving toward design of deliverable thermonuclear weapons" and "provided increased assurance of the successful test of a deliverable thermonuclear weapon" during the Castle series scheduled for the Pacific in spring 1954. Ivy Mike had confirmed that a thermonuclear explosion was possible. Castle would prove an operational thermonuclear weapon based on information derived from Upshot-Knothole.[45]

Some urgency existed in the task. In June 1952, the Joint Chiefs of Staff told the Commission that military requirements made necessary the production by 1954 of a megaton-range thermonuclear weapon that would be compatible with current delivery systems. On August 8, 1953, Soviet Premier George M. Malenkov announced that the Soviet Union had developed a hydrogen bomb. Four days later, the Soviets conducted their fourth nuclear weapons test, dubbed Joe 4 by the Americans, and the Air Force long-range detection system confirmed that "a fission and thermonuclear reaction" had taken place. Although

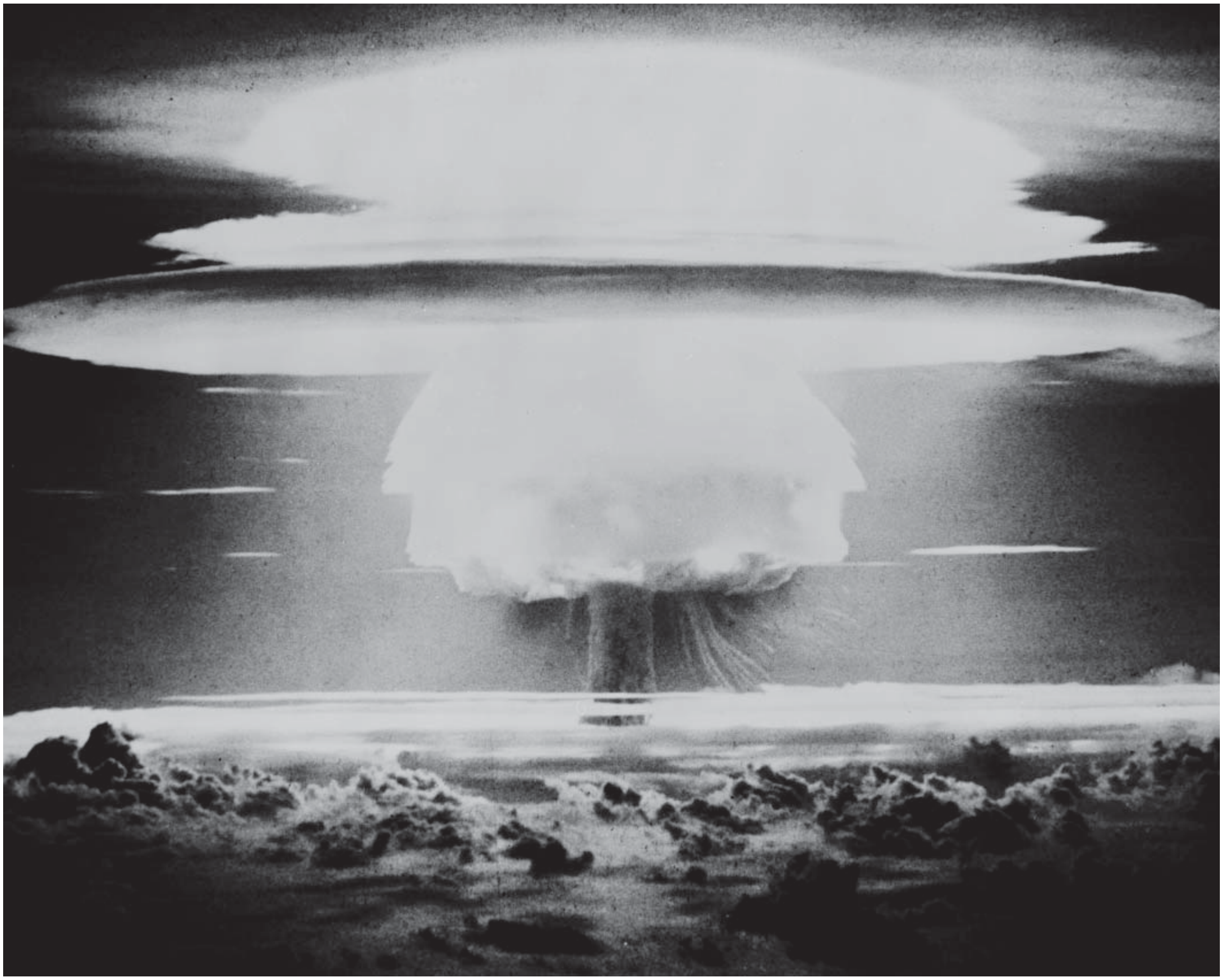
Joe 4, August 12, 1953. Source: Nuclear Weapon Archives.

Joe 4 was not a "true" thermonuclear device using staged radiation implosion and did not provide the Soviets with an operational airborne weapon, American officials and scientists at the time lacked sufficient evidence to determine the exact nature of the detonated device. AEC Chairman Strauss thought that the Soviets had bypassed the refinement of fission weapons and concentrated on developing thermonuclear designs. The Joint Chiefs feared that Joe 4 might negate the "substantial lead in destructive capability" that the United States possessed, and in December 1953 they proposed new and expanded stockpile requirements focusing on high-yield thermonuclear weapons and low-yield fission weapons for tactical uses. The Commission was somewhat taken aback. Stunned by the incredible destructive capability of the proposal, Zuckert estimated that by 1957 the stockpile would be the "equivalent of several billions of tons of TNT," which "could perhaps destroy the entire arable portion of the USSR." Strauss and Commissioner Henry D. Smyth expressed concern about possible hazards from radioactive fallout should the military ever use the thermonuclear weapons. The Commission agreed with Zuckert that the "highest civilian authority," aware of all the implications, should make the determination if proposed stockpile requirements were consistent not only with military requirements but also with national objectives. As a result, Strauss and Secretary of Defense Wilson presented the issue to Eisenhower who on February 6, 1954, signed a formal directive approving the new stockpile requirements.[46]

New requirements would be moot without success at Castle. Plans called for seven shots, all with projected megaton yield. All but one would be at Bikini Atoll, last used for Crossroads in 1946 and uninhabited, with the native Bikinians still in exile. Enewetak Atoll would host one shot. With a permanent base camp on its southern edge, Enewetak was not big enough to handle all of the thermonuclear testing on its own. Three high-yield shots were designed to provide an "emergency capability" weapon that could be carried in a B-36 bomber. A fourth, high-yield but relatively smaller in size and weight at 25,000 pounds, was intended for use in the new B-47 bomber. The three remaining shots, two of which were Livermore laboratory designs, would "point the way to the next generation of thermonuclear weapons" that were "smaller, lighter, more deliverable, and perhaps of higher yield." Fallout from all of the megaton blasts, partly because of the lack of significant problems with Ivy Mike, was considered a potential but unlikely hazard outside of the immediate area. The "danger zone" established for Castle thus included the two atolls but not the inhabited Rongelap Atoll less than one hundred miles to the east of Bikini.[47]

Bravo, the initial shot, was especially significant. As the first test of a dry thermonuclear system, quite unlike the ungainly Mike device with its liquid deuterium cooled by a cryogenics system, Bravo had the potential not only to affect the subsequent agenda of Castle but also to change the course of future thermonuclear weapon development. Detonated at dawn on March 1, 1954, Bravo greatly exceeded expectations. At fifteen megatons, Bravo was more than twice the predicted yield of six megatons and the highest yielding test ever conducted by the United States. "Highly successful," pronounced Major General Percy Clarkson, commander of the Joint Task Force, but with an unanticipated yield that "resulted in certain effects not foreseen."[48]

Bravo's unforeseen effects consisted of surprisingly high levels of radiation, deposited both on site and downwind. Test personnel experienced hazardous conditions almost immediately. The firing party, in a control bunker twenty miles from ground zero, reported rapidly rising radiation readings, not only outside the building but inside as well, and were soon evacuated. Fallout near the bunker totaled 800 roentgens. Task force ships, already thirty miles south of the atoll, recorded on-deck readings as high as five roentgens per



Castle Bravo, March 1, 1954. Source: DOE, NNSA-Nevada Site Office.

hour and were ordered out to a fifty mile range. As Bravo's fallout cloud drifted eastward, others were put into harm's way. At Rongerik Atoll, 133 nautical miles from ground zero, amphibious aircraft sent by the Air Force on March 2 evacuated 28 military personnel manning a weather station and other scientific equipment. Exposures, at the time, were estimated at 40 to 98 roentgens. Somewhat less fortunate were the 82 natives at Rongelap, with estimated doses of 100 to 125 roentgens, who were not evacuated until the next day. The islanders soon displayed symptoms of high exposure, including low blood counts, hair loss, and skin lesions. "From a blood picture standpoint," Clarkson noted, "the Rongelap natives corresponded very well with the Japanese who were 1.5 miles from ground zero at Hiroshima and Nagasaki." Several other Marshall Islands atolls also were evacuated, but the natives did not suffer exposures as significant.[49]

Other victims, exposed to even higher levels of radiation, turned up belatedly. Two weeks after Bravo, the Japanese fishing boat *Daigo Fukuryu Maru* (No. 5 Lucky, or Fortunate, Dragon) arrived home with all twenty-three crewmen suffering from radiation exposure. Trawling for tuna 100 miles east of Bikini, just outside the danger zone, in the early morning hours of March 1, the crew members

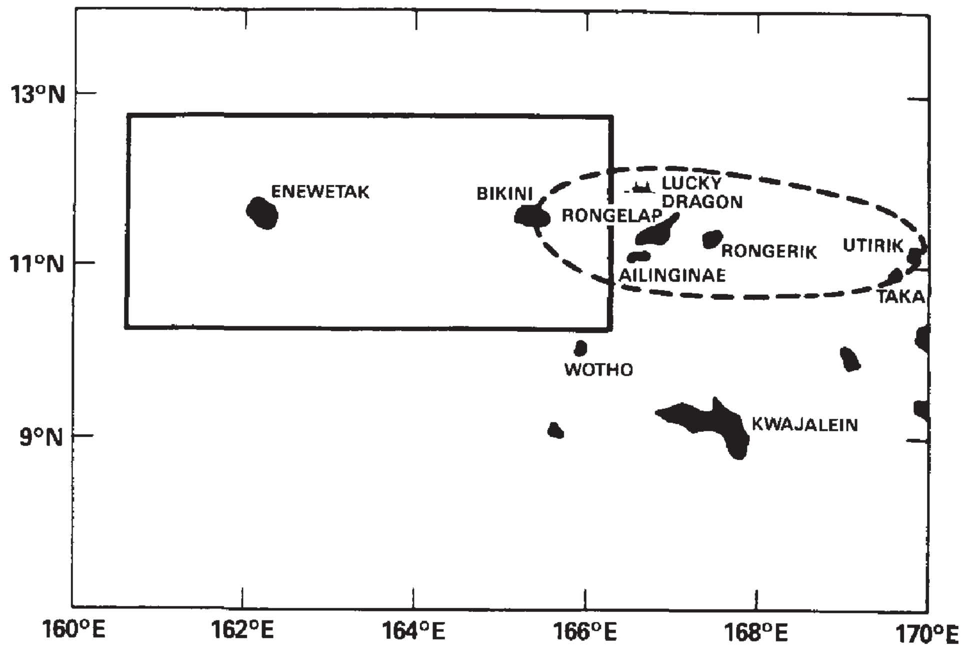
Radiation safety team member checking readings on outrigger canoe, Rongelap, March 8, 1954. Source: Defense Threat Reduction Agency.

had witnessed the bright flash of Bravo, followed within seven minutes by the shock wave. Three hours later, white flakes, later termed "ashes of death," began falling on the *Lucky Dragon*. Exposure symptoms soon appeared, including discolored and blistered skin, swollen hands, hair loss, and eyes and ears that oozed a thick yellow secretion. One crew member died of hepatitis several months later. Studies indicated that the crew of the *Lucky Dragon* had been exposed to external gamma radiation ranging from 130 to 450 roentgens. The incident became a major issue in Japanese politics and in Japanese-American relations.[50]

The New World after Castle Bravo

Bravo reshaped and redefined the Castle series. Subsequent shots were subject to much more stringent weather criteria. The second test, Romeo, scheduled for March 13, was delayed day to day by unfavorable weather for two weeks. Just as test officials were ready to move to Enewetak as an alternate firing site, the weather lifted, and Romeo was detonated on a barge in the Bravo crater with a yield of eleven megatons. Other shots were delayed by weather conditions as well. The results of Bravo also greatly expanded the danger zone. During the Ivy series, the danger area was 15,000 square miles. Castle, with the inclusion of Bikini, measured 67,000 square miles prior to Bravo. After Bravo, the danger area expanded to 570,000 square miles or roughly twice the size of Texas. The Nevada Proving Ground, in comparison, was only some 500 square miles. Finally, the success of Bravo altered the testing agenda for the series. In demonstrating the feasibility of a dry thermonuclear device, Bravo negated the need for an emergency capability weapon using liquid deuterium along the lines of Mike, and that shot was cancelled. Another dry thermonuclear shot was added. Castle, in the end, totaled six shots. The first of two planned Livermore shots, Koon, fizzled with a surprisingly low yield of 110 kilotons, resulting in the cancellation of the second Livermore shot.[51]

Despite the problems with Bravo and the fizzle of the Livermore test, the Castle series, from a technical perspective, far surpassed the expectations of scientists and officials. Thermonuclear weapons were now a reality, and the United States had a choice of weapons for emergency capability. So thoroughly were dry thermonuclear weapons demonstrated that the AEC could cancel contracts for cryogenics research for the "wet" device. Moreover, Castle design concepts prepared the way for a whole "family" of thermonuclear weapons, from small tactical to multi-megaton strategic weapons, which would render some stockpile weapons obsolete or of little utility. As Los Alamos Director Bradbury, at a meeting on July 14, 1954, asked the General Advisory Committee, "Is anyone going to care about using a B-47 to deliver kilotons when 3 MT bombs of the same weight are available?" Rather than a balanced distribution of yields in the stockpile, Bradbury proposed concentrating on "types" of which "a large number are needed." Isidor I. Rabi, who had replaced Oppenheimer as chairman of the committee, agreed that a "complete revolution . . . has occurred in atomic weapons." Commenting on the "maturity of the weapons art," Rabi stated that there would be "very little resemblance between the situation two years from now and that two years ago."[52]



The exclusion area established for the Castle Bravo shot did not contain the Marshall atolls east of Bikini. The dotted lines indicate the path of the fallout cloud. Also shown is the position of the Japanese fishing vessel, the *Lucky Dragon*, at the time of the detonation. Source: Richard G. Hewlett and Jack M. Holl, *Atoms for Peace and War, 1953-1961: Eisenhower and the Atomic Energy Commission*, Volume III of *A History of the United States Atomic Energy Commission* (Berkeley: University of California Press, 1989), p. 172.

Castle's long-term implications for politics, international relations, and, ultimately, humanity in general were even greater. The exposures suffered by the *Lucky Dragon* crew and the Marshallese islanders, in conjunction with the Upshot-Knothole dustings and sheep deaths, marked the beginnings of an international fallout controversy that would, ultimately, result in an atmospheric test ban treaty and radically reshape the test program. Public fear would be the driving force. Castle's "sweet taste of success," note the historians Richard Hewlett and Jack Holl, was tainted with a "sickening reality: mankind had succeeded in producing a weapon that could destroy large areas and threaten life over thousands of square miles." Precise, unclassified descriptions of a thermonuclear weapon's destructive power and range were as yet not possible, but the public could sense some of the magnitude when, at the conclusion of President Eisenhower's press conference on March 31, 1954, AEC Chairman Strauss made headlines when he stated that the bomb could be made big enough "to take out any city," even New York. What remained classified was even more sobering. At a fallout effects briefing before the Commission on May 24, DMA Director Fields superimposed Bravo's fallout pattern on a map of the northeast United States with Washington, D.C., as ground zero. The lifetime dose in the Washington-Baltimore area would have been 5,000 roentgens, more than 1,000 roentgens in Philadelphia, and more than 500 roentgens in New York City, enough to kill half the population if fully exposed. Fallout in the 100 roentgens range, comparable roughly to the Lucky Dragon exposures, spanned a wide swath northward through New England toward the Canadian border. Classified secret, Fields's map received little distribution even in official circles.[53]

Mooting a Test Moratorium

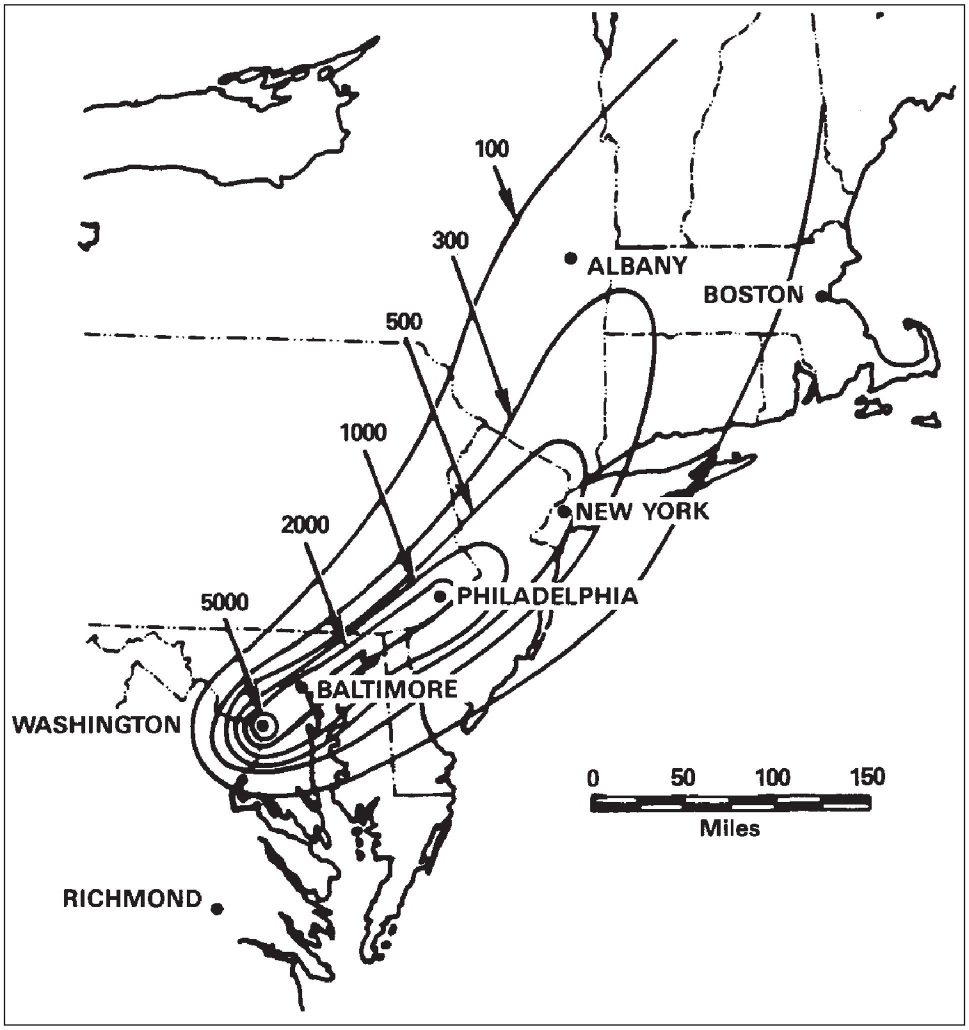
Eisenhower was not unaware of the dangers posed by nuclear energy in general and thermonuclear weapons in particular. Disturbed by the "awful arithmetic of the atomic bomb" and the "probability of civilization destroyed" in a full-scale exchange of thermonuclear weapons, he sought to transform the destructive power of nuclear energy into a unifying force for peace. In his groundbreaking Atoms for Peace speech before the United Nations on December 8, 1953, he proposed that the nuclear nations contribute fissionable material from their stockpiles to a new International Atomic Energy Agency. The diverted fissionable material would be used to "serve the peaceful pursuits of mankind." Scientists and engineers from around the world would "apply atomic energy to the needs of agriculture, medicine, and other peaceful activities," Eisenhower proclaimed. "A special purpose would be to provide abundant electrical energy in the power-starved areas of the world."[54]

The Atoms for Peace initiative soon gave rise to discussions within the Atomic Energy Commission of other means of curbing the arms race. On February 2, 1954, Commissioner Thomas Murray broached the possibility of a moratorium on large-scale testing. He noted that an international limitation of testing could lessen world tensions, which large-scale testing tended to increase, and slow up or halt the development of large-scale thermonuclear weapons. Such an agreement, Murray added, might be "self-policing." A violation of the agreement would be detectable using means that did not require direct inspection and infringement of a nation's sovereignty. Murray observed that the United States was well ahead of the Soviet Union in thermonuclear technology and a moratorium therefore would help maintain American superiority in nuclear weapons. A Soviet rejection of limitations on testing, he believed, would give the United States a stunning propaganda victory. Chairman Strauss thought the proposal merited further study, and he recommended that Murray bring it to the attention of the President. This Murray did, with no apparent immediate result.[55]

Castle Bravo gave the moratorium proposal momentum. The public debate sparked by the Bravo fallout focused in large part on stopping all tests permanently. By April, the White House

AEC Chairman Lewis Strauss briefing President Eisenhower on the Castle series, March 30, 1954. Source: Department of Energy.

AEC Commissioner Thomas Murray. Source: Department of Energy.



Fallout pattern from Castle Bravo detonation superimposed on the eastern United States. Source: Richard G. Hewlett and Jack M. Holl, *Atoms for Peace and War, 1953-1961: Eisenhower and the Atomic Energy Commission*, Volume III of *A History of the United States Atomic Energy Commission* (Berkeley: University of California Press, 1989), p. 181.

was receiving over 100 pieces of correspondence a day advocating an end to testing. In an April 2 statement denouncing all "weapons of mass destruction," Prime Minister Jawaharlal Nehru of India called for a moratorium on the testing of thermonuclear weapons. Four days later, Secretary of State Dulles, at a meeting of the National Security Council, handed Eisenhower a handwritten note, "I think we should consider whether we could advantageously agree to Nehru's proposal of no further experimental explosions." This, Dulles assured the President, "could be policed—or checked—." "Ask Strauss to study," Eisenhower replied.[56]

On April 12, United States Ambassador to the United Nations Henry Cabot Lodge, referring to Nehru's statement, asked Dulles if the United States might agree to a partial moratorium on tests over one megaton. The State Department, in turn, requested comments from the AEC. The proposed moratorium, the AEC replied, was not in the national interest. Cessation of testing, Fields noted, would have a serious effect on the AEC's fulfillment of existing military requirements. The limitation of testing to under a megaton would be difficult to verify, Fields observed, and there was "no reason to believe" that the Soviet Union would comply.[57]

Dulles and Eisenhower remained unconvinced. At a May 6 National Security Council meeting, Dulles stated that a moratorium was in the national interest because the Castle series had put the United States "a lap ahead" of the Soviet Union. If the moratorium could be policed, he added, "it would be to our advantage." Strauss and Secretary of Defense Wilson were skeptical that the United States could adequately police a test moratorium. Eisenhower disagreed. Enforcement, stated the President, was not a major issue. If the Soviets violated the moratorium, the United States would resume testing. It was wrong, Eisenhower reiterated at a follow-up meeting, for the United States to "take a negative view on this terrible problem." Observing that it would be a "bleak future" that held nothing but nuclear weapons, Eisenhower stressed that there would be no long-term answer to the problem of nuclear warfare without first establishing a test ban.[58]

Any expectations for a near-term moratorium, however, soon vanished. Soliciting advice from the two weapons laboratories, the Commission summoned Edward Teller and Norris Bradbury to Washington. Teller and Bradbury agreed that their "technical advice" was, in the main, negative. A total ban on testing, they agreed, would still enable the Soviets to conceal low-yield tests. In addition, any ban that extended beyond 1957, even if a moratorium were adequately policed, would seriously retard weapon development in the United States. On June 23, Dulles informed the National Security Council that the administration was "virtually unanimous" in opposing a nuclear test moratorium. This represented "the power of logic over the power of will," he noted, since the State and Defense Departments, the AEC, and the Central Intelligence Agency all "wished to reach a different conclusion." Eisenhower accepted this judgment but told his advisors that if there was any way to negotiate an effective moratorium or ban he would do it.[59]

The following afternoon, Eisenhower and Dulles met with British Prime Minister Winston

British Prime Minister Winston Churchill and President Eisenhower, June 29, 1954.
Source: National Archives.

Churchill in the Red Room at the White House. Churchill expounded at some length and with considerable feeling on his fears for the future of his country. Two or three hydrogen bombs, he had been informed, could deal a death blow to the British Isles. After seeing films of the Ivy Mike shot, he had ordered work on air-raid shelters abandoned because they would prove of little use in a thermonuclear attack. Reversing a position he had taken earlier, the Prime Minister then informed Eisenhower that the British would develop their own hydrogen bomb.[60]

Part IV

Atmospheric Testing in the Balance, 1955-1956

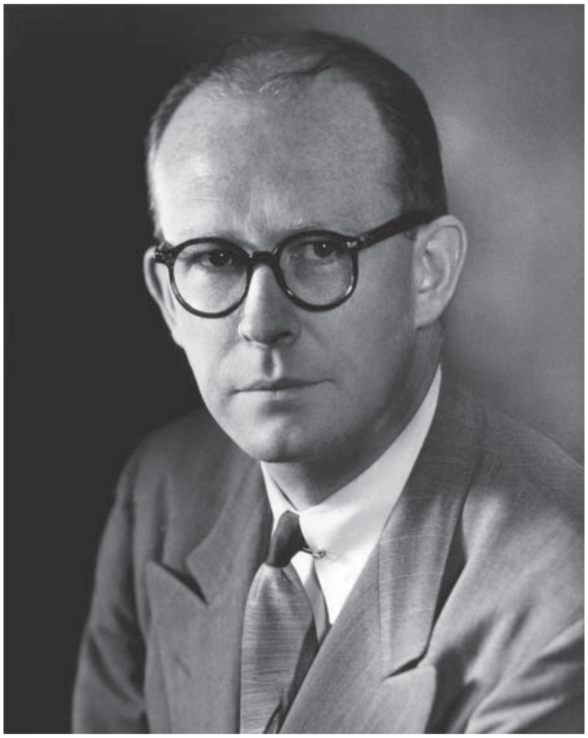
Focus on Fallout

Radioactive fallout set the context for nuclear weapons testing over the remainder of the decade. No respecter of national boundaries, fallout had spread worldwide and become a contentious international issue. Public fear of radioactivity, a potentially toxic and little understood phenomenon not apprehensible to the senses, moved politicians and leaders to press for an international ban on nuclear weapons testing. Seeking resolution to the problem, the Eisenhower administration attempted to reconcile national security, health and safety, and propaganda needs in ongoing negotiations with the Soviet Union. At the local level at the Nevada and Pacific test sites, fallout determined most of the testing parameters, including the potential yield of the device, how and where it would be detonated, and, perhaps most importantly, when and under what weather conditions.

Official interest in the biological effects of fallout on large human populations dated back to the late 1940s. Project Gabriel, a research effort sponsored by the Atomic Energy Commission (AEC), indicated that the explosion of 3,000 "nominal" atomic bombs the size of the Nagasaki device could cause serious worldwide contamination and that strontium-90, of all the radioactive bomb products, might be of greatest concern. Strontium-90, with a half-life of 28 years, behaved much like calcium and tended to concentrate in the bone where it could cause bone cancer. Following the Ranger and Greenhouse test series, revised Gabriel figures indicated that 100,000 bombs would be required to reach the "doomsday" level. The off-site fallout problems of the Upshot-Knothole series revived and stimulated Gabriel and other fallout research. Scientists from the University of California at Los Angeles studied soils, plants, and small animals collected within several hundred miles of the test site. Researchers at the Rand Corporation focused on predicting fallout from a single detonation under a wide range of conditions. Extensive data on fallout dispersal was available from the fallout monitoring network of the AEC's Health and Safety Laboratory, which, beginning with the Buster-Jangle series, collected and reported fallout readings throughout the country.

Gabriel also spawned Project Sunshine. Under the direction of Willard F. Libby, a scientist at the University of Chicago and a member of the AEC's General Advisory Committee, Project Sunshine analyzed the strontium-90 content of materials, including human bones, collected worldwide. Particular sensitivity was attached to the collection of infant bones, which were believed to provide the most accurate measures of strontium uptake. To avoid breaking "security specifications," Sunshine officials developed a cover story involving the survey of natural radium in human bones.[1]

Gabriel, Sunshine, and other fallout information remained highly classified. Despite the publicity and uproar following Castle Bravo, the general public, as well as civil defense officials and other interested parties, knew little about the nature and dispersal of fallout. By fall 1954, AEC Chairman Lewis L. Strauss and General Manager



AEC Commissioner Willard F. Libby. Source: Department of Energy.

Secretary of Defense Charles E. Wilson. Source: National Archives.

Kenneth D. Nichols became convinced that a public statement on fallout was necessary. There would be leaks to the press, warned Nichols's assistant, Paul F. Foster, by someone taking "it upon himself to do something to alert the public to the gravity of this, as yet unknown, danger." Foster identified the fallout issue as "one of the gravest problems facing the Administration," and he urged that "our citizens must be made to look at the stark facts of life" so that support could be generated for effective civil defense and dispersal of key industries. The State and Defense departments, however, disagreed on the need for a fallout statement. State Department officials expressed concern that publication of fallout information could have a "bad effect" on "our foreign policy objectives." Secretary of Defense Charles E. Wilson stressed the importance of "not arousing public anxiety" about the dangers of atomic warfare and fallout, noting that "too much had already been said publicly about fallout."[2]

Public debate, nonetheless, could not be stifled. Press accounts of the fallout hazard—some more, some less accurate—kept appearing, and Strauss remained concerned that the Commission would be accused of "concealing facts of vital importance" at the same time they were trying to "reassure the public" that they were not endangering their health and safety by continued weapons tests in Nevada and the Pacific. Encouraged by Eisenhower's comment at a December 10, 1954, cabinet meeting about, as Strauss put it, the "virtue of laying all the facts on the line before there is an inquisition," the Commission in January 1955 revised and reworked at least five different drafts of their statement on "The Effects of High Yield Nuclear Detonations." On February 2, Eisenhower personally reviewed and annotated the draft and, the following day, formally approved its release. On February 15, three days prior to the start of the Teapot test series in Nevada, the Commission released the report. In a statement accompanying the report, Strauss provided assurances that testing in Nevada produced no off-site safety and health hazards. He stated, without qualification, that the "hazard has been successfully confined to the controlled area of the Test Site." The highest actual radiation dose at an off-site community, he noted, was estimated to be less than one-third that allowed yearly for atomic energy workers under the AEC's "conservative safety standards."[3]

Reaction to the fallout report was mixed. Although the foreign response was surprisingly mild, the Commission, domestically, had the misfortune of having Ralph Lapp, a nuclear physicist who had worked at Los Alamos during World War II, publish an alarming article on "Radioactive Fall-out" in the *Bulletin of the Atomic Scientists* only four days before the release of the report. Asserting that a single "superbomb" could "contaminate a state the size of Maryland with lethal radioactivity," Lapp criticized the government for maintaining tight secrecy on the fallout issue. As a result of the article, the AEC not only received little credit for its candor in releasing the report, but the report itself appeared to be a reluctant response to Lapp. In any event, the report produced much excitement in the press. The Las Vegas *Review-Journal*, in a big-type headline, announced that the "H-Bomb Fall-Out Terror Is Told." The Los Angeles *Examiner* superimposed a fallout map on the Los Angeles area with chilling results. *Life* magazine ran a three-page spread on "Facing the Fallout Problem" that included graphics of fallout shelters.[4]

Planning for Teapot

Nuclear weapons testing in Nevada nonetheless proceeded apace. Planning for Operation Teapot began in fall 1953, but actual construction and preparation at the Nevada Proving Ground did not start until February of the following year when the Commission released funding for test site activities. Staffed by a skeleton crew of 102, primarily engaged in security and maintenance, the workforce rapidly expanded. By the end of 1954, Mercury housed some 2,000 workers, with many more making a daily commute from Las Vegas, which was 65 miles away, and other local communities. Consisting of a group of hutments in 1951, Mercury now had numerous permanent buildings, including administrative offices, dormitories, a theater, warehouses, two mess halls, a recreation hall, and a post exchange. Outside Mercury, construction focused on preparing the sites for the individual tests. With the move increasingly toward tower shots, assembly and erection of steel towers became paramount. The AEC estimated that a standard 300-foot tower cost $101,000 and a 500-foot tower $154,000 ($69,000 for fabrication and $85,000 for the foundation and erection). The towers, the tops of which were accessed by exposed ladder, generally took four months to build. In an extreme rush, they could be set up in four weeks.[5]

Mercury cafeteria. Source: DOE, NNSA-Nevada Site Office.

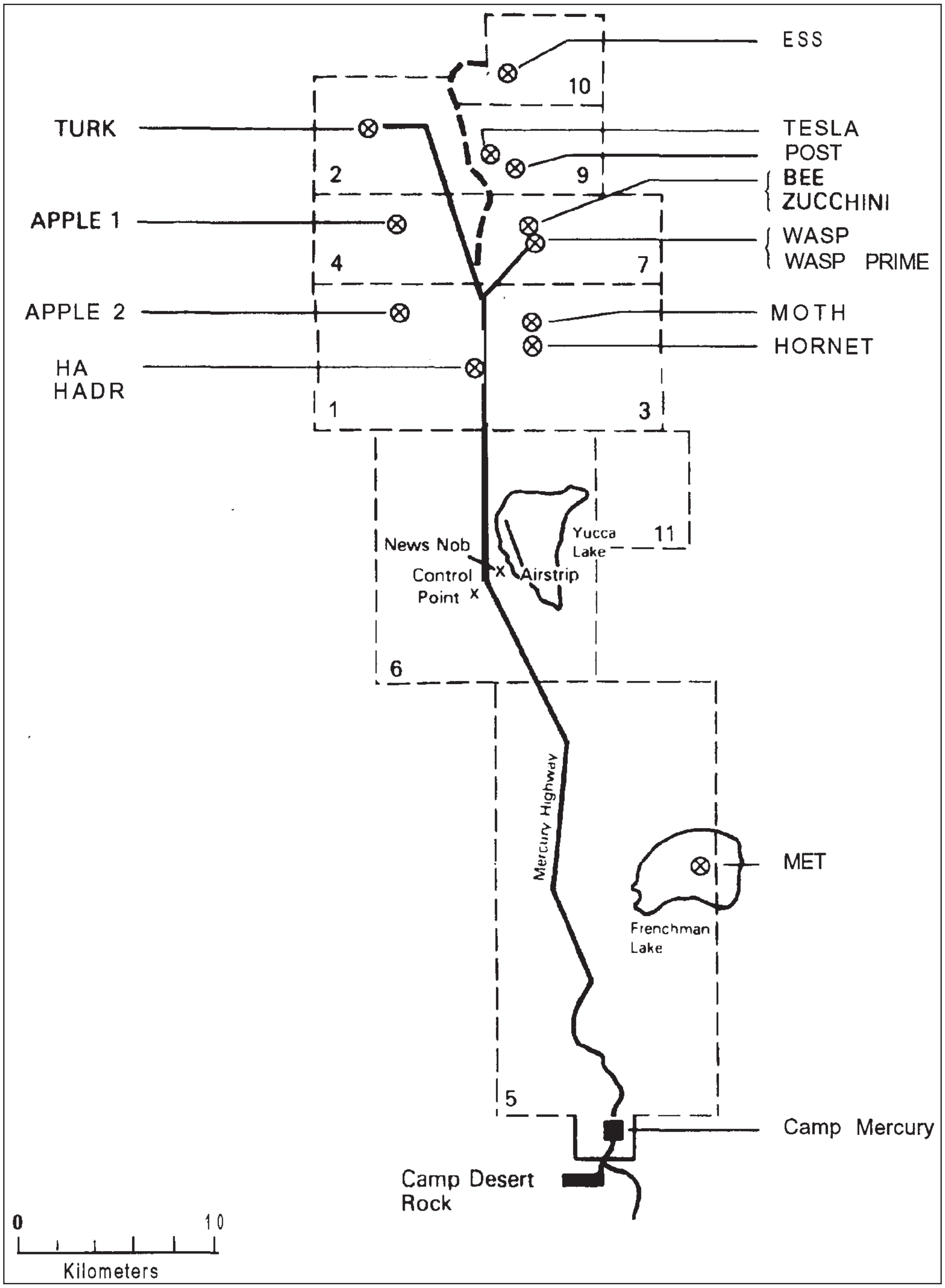
The AEC contracted for the work. Various construction contractors built the towers, while the Reynolds Electrical and Engineering Company (more commonly known as REECo) was the overall site contractor. Organized labor took an active role in monitoring working conditions. In late December 1954, workers in the Teamsters and several other unions walked off their jobs in a dispute with REECo over an interpretation of contract provisions for subsistence. The contract provided for $5 a day to workers commuting to the site and $3.50 a day for workers who chose to live at Mercury. Workers staying on site were given bunk beds for 50 cents a night and paid $1 per meal. Extras, such as milk and pie, were not included in the subsistence allowance. The unions wanted a uniform $5 allowance for both commuters and those living at Mercury. After two days of negotiations, workers returned to their jobs on December 31.[6]

On that same day, the AEC announced that the Nevada Proving Ground had reverted to its original name, the Nevada Test Site. The official explanation was that the acronym NPG was frequently confused with the Naval Proving Grounds. Los Alamos weapons scientists, even so, had long chafed at the name "proving ground" because it connoted activities not related to weapon development. The scientists saw the test site as a "backyard workshop," with the Ranger series as the operative model, where tests could be conceived and implemented in a matter of weeks. Proving ground implied proof testing, military and civil effects, troop maneuvers, and open, public displays, all of which interfered with development testing.[7]

The name change did not, however, affect the testing agenda for Teapot. The series included the entire mix of testing activities with, as in previous series, an emphasis on development testing. In the almost two years since the Upshot-Knothole series, the Los Alamos and Livermore laboratories had accumulated a large backlog of tests. As the testing agenda took shape in early January 1955, Teapot would consist of twelve tests, including six Los Alamos, three Livermore, one joint Los Alamos and Department of Defense, and two military effects shots. A number of shots focused on the military requirement for smaller weapons that would be "needed in very large numbers" for tactical applications. Several shots supported the development of warheads that would be of "utmost importance if delivery by guided missiles becomes the most feasible delivery system." The maximum yield anticipated from these tests was about thirty-five to forty kilotons. The Los Alamos Zucchini shot doubled as a development test and a civil effects test for the one "open shot" of the series. The Los Alamos/DOD Met (Military Effects Test) shot used a new design with a projected yield of twenty-eight kilotons.[8]

The two Department of Defense effects shots evolved from a proposal first broached in November 1953, which, as Carroll Tyler, manager of the AEC's Santa Fe Operations office, noted, included "a high altitude (40,000 ft.) air burst on the order of one to eight kilotons, and a surface burst with a yield *greater than ten kilotons*." In the high altitude shot, the military sought to determine the effects of a nuclear detonation in a rarefied atmosphere for use in developing an air-defense program. The surface shot involved determining maximum crater size for potential use against enemy aircraft take-off and landing runways. The high altitude shot provoked little concern with AEC officials other than creating "some unusual problems to assure safety to air crews," but the surface burst was an "entirely different situation." The shot, Tyler noted, would "result in serious contamination and health problems, both on and off-site, which in addition to the immediate health aspects, could conceivably result in the abandonment of the continental test site." Despite AEC efforts to derail the surface shot, Defense persisted. Finally, on July 1, 1954, the day after the Commission approved stricter testing guidelines recommended by the ad hoc Committee to Study Nevada Proving Ground, Strauss officially denied the request. Quoting the guidelines, he informed the Department of Defense that "these

Operation Teapot



Nevada Test Site showing locations of shot ground zeros for Teapot series. Source: Jean Ponton, et al., *Operation Teapot, 1955*, DNA 6009F (Washington, DC: Defense Nuclear Agency, November 23, 1981), p. 10.

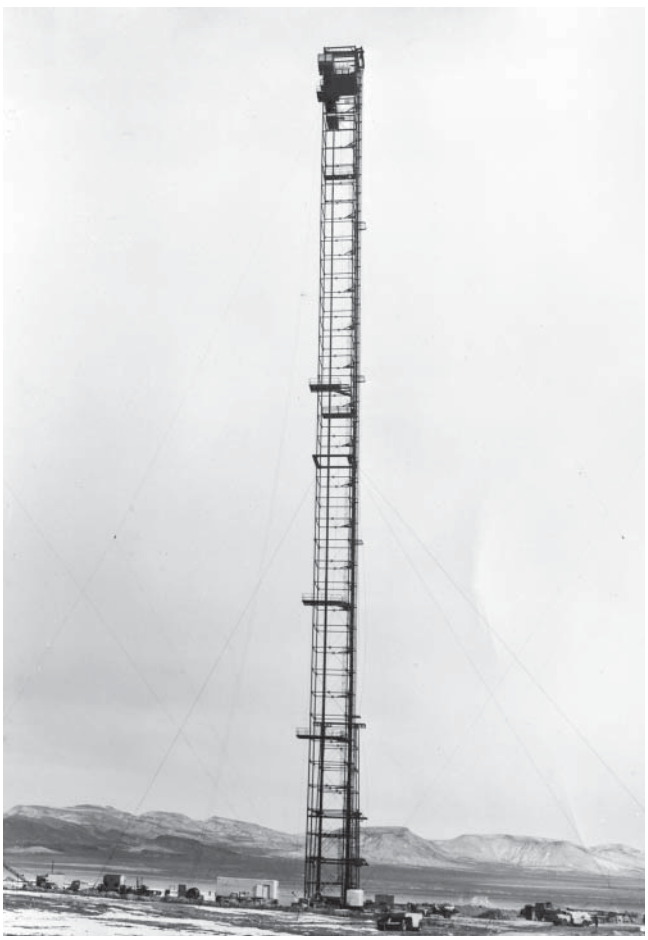
Camp Desert Rock, looking north. The 100 semi-permanent buildings and more than 500 tents accommodated 6,000 troops. Source: DOE, NNSA-Nevada Site Office.

criteria are incompatible with either a surface or an underground detonation of devices of a yield of 10 KT." The military eventually relented, and the program that emerged consisted of the high altitude shot, dubbed HA, with a projected yield of two kilotons, and the Ess (Effects sub-surface) shot of a one-kiloton device buried 67 feet deep. Military and AEC testing officials concluded that under the proper conditions no significant fallout from Ess would occur at distances greater than fifty miles. In addition to the effects tests, the Department of Defense again requested troop maneuvers in what would become Desert Rock VI. Participation would not be as extensive as in previous test series, and maneuvers were to be conducted only in conjunction with the higher-yield shots.[9]

Teapot and the Fallout Problem

Fear of fallout was the controlling factor for all of the Teapot shots. Test officials believed that while fallout could not be eliminated it could be managed to the degree that it was not an off-site hazard. Several strategies were employed. The ad hoc committee's guidelines set limits with regard to yield and burst altitude. Size mattered, as did the fireball touching the ground and increasing fallout intensity. The largest shots were placed on 500-foot towers, 200 feet taller than any tower used in previous test series. Even the smaller shots in Teapot, including those with projected yields as low as one kiloton, used 300-foot towers. In addition, officials planned to experiment with the use of water, oil, or some other binder on the soil around the towers. Finally, tests would be geared to optimal or near-optimal weather conditions, depending on the size of the shot. Officials divided the tests into two groups. Group A, those shots with the largest yields, required "more exacting weather conditions because of fall-out potential beyond the borders of the test site." These shots would be fired as ready, but only under strictly defined wind conditions. Much less stringent requirements applied to the smaller Group B shots. These could be inserted into the test schedule as needed. As a result, the Teapot schedule listed "ready" dates as opposed to projected "firing" dates.[10]

Strict weather requirements demanded accurate forecasts and expert judgment. In past series, weather forecasts were made eight to twelve hours before a shot on the basis of data taken up to twelve hours earlier. Anticipating a "very considerable improvement" for Teapot, test officials would now receive a final weather briefing one hour prior to detonation using up-to-date information on wind directions and velocities. Teapot Test Manager James E. Reeves also established an advisory panel, chaired by his science advisor, Alvin Graves, to help determine if a shot should be postponed due to adverse weather conditions. Reeves and Graves considered weather-caused delays likely, noting that the anticipated length of the series could be extended by as much as a factor of two. The complications of such an "elastic schedule," they observed, for civil defense, Desert Rock, and other participants and observers were considerable.[11]



One of the 500-foot towers used in the Teapot series. The cost of fabricating and erecting each of the towers was estimated at $154,000. Source: DOE, NNSA-Nevada Site Office.

James E. Reeves, left, test manger at the Nevada Test Site, discusses Teapot Turk shot with Alvin C. Graves, scientific advisor, March 7, 1955. Source: DOE, NNSA-Nevada Site Office.

The AEC also assigned public relations a major role in ameliorating the fallout problem. Although public education could not control fallout, officials hoped that it would help manage the fears and concerns caused by fallout in off-site communities. Division of Military Application officials in Washington initially proposed a less "defensive" approach that included interpreting small-yield tests as "completely controlled experiments" that would "have as their purpose the development of atomic warheads which would be used over our own cities to protect against enemy air attack." These shots, because of their size, would "not affect the public residing in the areas beyond the test range" and could be "sold as 'friendly blasts' offering comforting protection." Field officials objected, however, that there was a long-standing policy against any public statement about the "specific purpose" of tests, and the idea was dropped.[12]

Test Manager's Advisory Panel at the weather evaluation on the evening of February 15, 1955, which resulted in a second 24-hour postponement of the Turk shot, the first scheduled test of the Teapot series at the Nevada Test Site. The forecast was for high winds, reaching 100 knots at higher altitudes, toward the southeast. The forecast fallout pattern is shown on the map to which Major O. W. Stopinski, Air Force Weather Service, is pointing. At far right is Alvin C. Graves, Los Alamos Scientific Laboratory (LASL), who is the test manager's scientific advisor and chairman of the advisory panel. Seated, left to right, are Lt. Col Clifford A. Spoh, Air Force Weather Service; Thomas N. White, LASL; Lester A. Machta, U. S. Weather Bureau; Duane Sewell, University of California Radiation Laboratory, Livermore; John C. Bugher, director, AEC Division of Biology and Medicine; Everett F. Cox, Sandia Laboratory; and Test Manager James R. Reeves, AEC Santa Fe Operations. Source: DOE, NNSA-Nevada Site Office.

An elaborate public education campaign, nonetheless, preceded Teapot. Unlike with previous test series, early announcement of Teapot, on September 25, 1954, alerted "public officials, stockmen, miners, and others in southwestern Utah and southern Nevada" who might need advance planning to prepare for the upcoming tests. In the weeks before the first shot, test officials visited local communities, explaining the program and handing out a basic fact sheet on testing and a small popular booklet synopsizing the fact sheet. The fact sheet contained a wealth of background information intended for "professional men and public officials," and officials distributed thousands of copies of the booklet to the general public. In addition, 20,000 copies of the booklet "A-B-Cs of Radiation," compiled by the Brookhaven National Laboratory, were distributed to school children in Nevada and adjacent states. An AEC motion picture, *Atomic Tests in Nevada*, focusing almost entirely on fallout and safeguards, was widely shown, opening in mid-January 1955 in St. George, Utah, where, as the AEC's director of information services, Morse Salisbury, noted, "residents were asked to stay under roof after one shot two years ago."[13]

Finally, the AEC signed an agreement with the U.S. Public Health Service assigning that agency responsibility for most off-site radiation monitoring. During Upshot-Knothole, about a dozen Public Health Service officers had assisted in the collection of fallout data. For Teapot, sixty-six regular and reserve officers rotated in and out of thirty-three positions, manning mobile monitoring teams and fixed stations at twelve towns in Nevada and Utah. During the series, the officers were allowed to discuss their readings with the local populace and provide information concerning the tests. This helped assure off-site residents that potential fallout hazards were not being covered up.[14]

Teapot

With plans and preparations covering, in the words of the historian Barton Hacker, "everything human foresight could conceive," Teapot began, in mid-February 1955, somewhat inauspiciously. Unfavorable winds delayed the anticipated first

At a pre-dawn briefing at Indian Springs Air Force Base, Nevada, fighter pilots of the 4926th Test Squadron (Sampling) leave the briefing room after being notified of a last-minute postponement of the Turk shot. Lt. Col. James A. Watkins, right, has just broken the news to his pilots. Each postponement of a shot meant hours of additional work for maintenance men and pilots. The 4926th was assigned the mission of penetrating the atomic cloud to gather radioactive air samples. Source: DOE, NNSA-Nevada Site Office.

shot, Turk, one of the larger shots with a projected yield of thirty-three kilotons, for almost three weeks. The chairman of the Joint Committee on Atomic Energy, Senator Clinton P. Anderson of New Mexico, had flown from Washington to observe the test only to return when it was first postponed. Anderson promptly wrote Strauss, asking for an evaluation of "whether the Nevada Test Site can be utilized effectively and economically under the present criteria for anything other than very small yield devices." Anderson quickly pointed out that he was not advocating "taking any real risk" and assumed the present criteria were "necessary for public safety." Rather, he questioned the practicality of testing in Nevada when, as one "weather scientist" informed him, "the probability of finding weather conditions that meet all the present criteria is about one day in twenty-five."[15]

The Commission was stunned. This was a "big change" in attitude, Strauss told his fellow commissioners, with General Manager Nichols noting that Anderson had always counseled that "nobody has ever been hurt" and the AEC should not "worry about all these things." Willard Libby, now a commissioner, stated that he was "pretty disturbed by this," adding that it would "set the weapons program back a lot to go to the Pacific." Strauss, however, admitted to having second thoughts of his own. His "coolness" toward testing in Nevada dated back to the Upshot-Knothole series in spring 1953, he said, and if it were left to his "sole decision" he would take the two largest

Teapot shots and "load them on a ship and go out to Eniwetok and put them on a raft and set them off." Strauss pointed out that off-site fallout at Nevada was permissible in a "very narrow corridor" where if the winds shift ten degrees the fallout goes over an inhabited area such as St. George, Utah, which "they apparently always plaster." Then "they are in trouble again," but, "of course, they really never paid much attention to that before." "I have always been frightened," Strauss concluded, "that something would happen which would set us back with the public for a long period of time."

Putting his personal predilections aside, Strauss recommended responding promptly to Anderson and downplaying the scheduling difficulties. He noted that the two Las Vegas newspapers, which "seldom agree on anything," both continued to support testing because it furthered national defense and brought a lot of prosperity to the state. "That is a sensible view," interjected Libby. "People have got to learn to live with the facts of life, and part of the facts of life are fallout." That was "certainly all right," Strauss responded, "if you don't live next door to it." "Or live under it," Nichols added. "We must not," Commissioner Thomas Murray broke in, "let anything interfere with this series of tests—nothing."[16]

Quickly drafting a response to Anderson, Strauss provided background on the development of the criteria and told the Senator that it was "still too early in the series to make any conclusive determination of the efficacy of our current operating criteria." Strauss also started sending Anderson brief progress reports on Teapot explaining significant delays.[17]

Delays there were, but Teapot hobbled on. Before Turk finally was detonated on March 7, three of the smaller shots—Wasp, Moth, and Tesla—took place, albeit not without delays of their own. Tesla would have been fired on February 15 had not "technical difficulties" pushed it back to March 1. Wasp was delayed for over four hours on February 18 because of an engine fire on the drop aircraft immediately prior to take off, requiring transfer of the device to a standby plane, and a broken cloud cover that led to two "negative runs" prior to the successful drop. Taking advantage of favorable weather, test officials on March 29 detonated Apple-1 shortly before 5:00 a.m. and Wasp Prime five hours later. This was the first time two devices were detonated on the same day. Wasp Prime had been added to the Teapot series after the results of the Wasp test had been analyzed. Possibly the most embarrassing delay involved the open shot, which, after being postponed on a daily basis for over a week, lost a fourth of its audience.[18]

Teapot nonetheless proved to be a striking success. Development tests proceeded largely according to plan even if not according to schedule, and fallout results tended to vindicate the rigid standards. Monitors detected no significant off-site fallout, and the AEC avoided much of the bad publicity that so concerned Strauss and his fellow commissioners. "We have had no heavy fall out anywhere in this series," John Bugher, director of the Division of Biology and Medicine, told the AEC's Advisory Committee on Biology and Medicine. "Partly by careful work and partly by good luck, the fall out has all taken place in areas uninhabited and away from towns."[19]

Weapon Effects

The Department of Defense and the Federal Civil Defense Administration (FCDA) also emerged relatively satisfied from Teapot. The three major weapon effects tests, although not without their problems and with the possible exception of Met, performed as anticipated. The sub-surface shot, Ess, detonated on March 23 with a yield of 1.2 kilotons, produced a crater some 320 feet in diameter and 100 feet in depth. Radioactive contamination considerably delayed exploratory

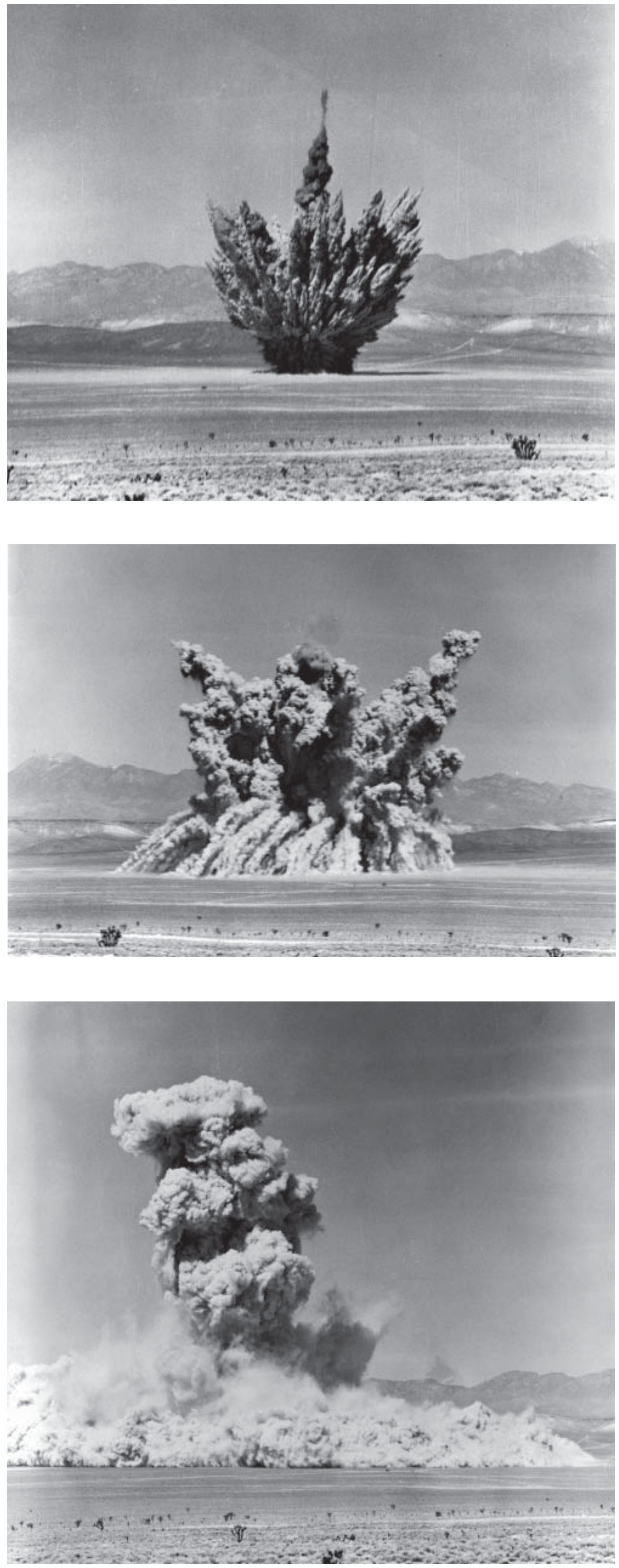
Operation Teapot Weapons Tests

The first test of the Teapot series, Wasp, top left, was fired at noon, February 18, 1955. Shortly after detonation, the nuclear cloud began forming from the fireball while the stem was sucked up toward the cloud. Camera crew, top right, records the detonation of Wasp Prime. The fireball from the predawn Moth shot, bottom right, is beginning the transformation into a nuclear cloud. Shear in the cloud from the Tesla shot, bottom left, is caused by varying wind directions and speeds at various altitudes. Source: DOE, NNSA-Nevada Site Office.

excavation of the crater. On April 6, several minutes prior to the high altitude shot, HA, F-86 Sabre aircraft laid down a grillwork of drifting smoke lines to measure the shock wave. The HA device was dropped from a B-36 bomber flying at an altitude of 46,000 feet. This was 2,000 feet less than the intended altitude due to an engine failure on the drop aircraft. Using a parachute to slow down the drop speed and allow the aircraft to safely get away (the only parachute drop ever conducted at the test site), HA detonated at 36,400 feet with a yield of three kilotons. Following a fireball that formed a perfect sphere almost a half mile in diameter, a giant smoke ring formed in the sky. Cloud samples were taken by an impressive array of aircraft that included two B-36s, two B-57s, and four F-84Gs.[20]

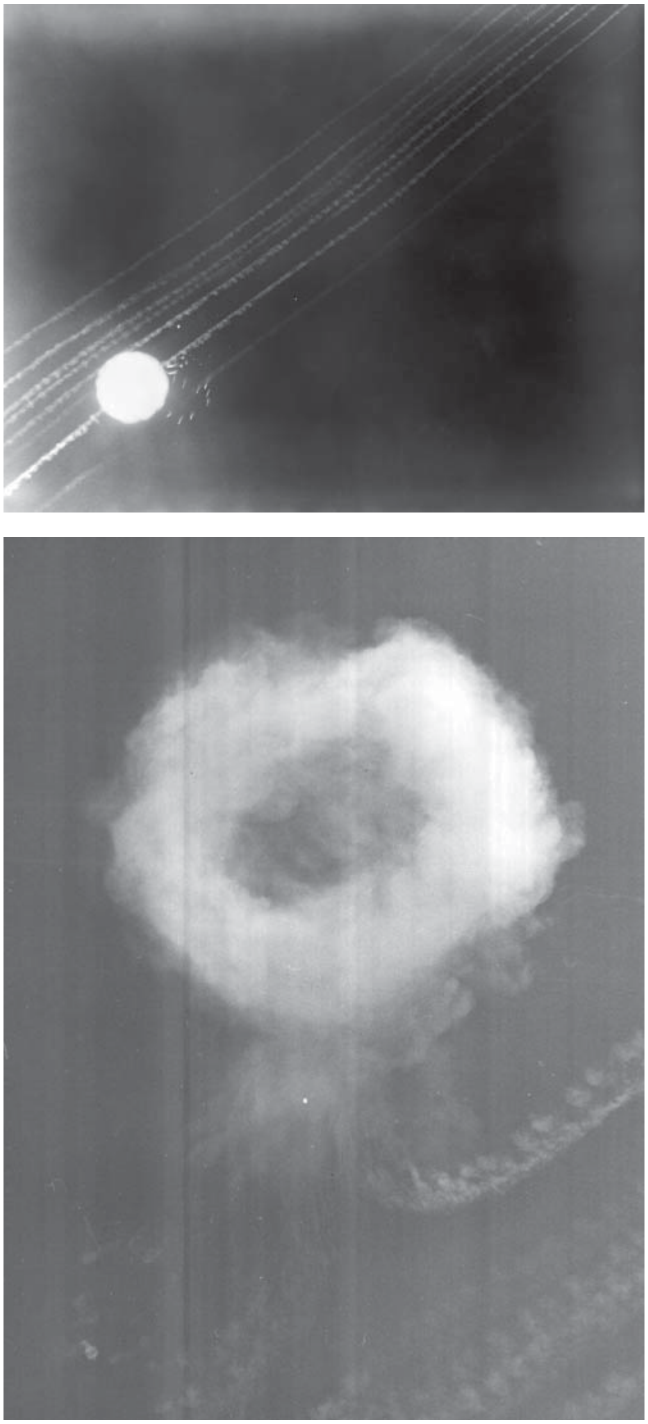
The Met shot, fired from a 400-foot tower on Frenchman Flat, had two effects purposes. The military sought, first, to measure how in-flight jet aircraft responded to destructive blast forces and, second, to assess the behavior of shock waves along the ground surface. For the former, the military used three highly instrumented drone QF-80A jet fighters based at the nearby Indian Springs air strip. Although one of the drone fighters was lost on takeoff in a "spectacular crash" at the end of the runway, a backup drone was available. The three drones were positioned at various heights directly above the blast. For the ground surface assessment, the military set up three blast lines extending roughly 3,000 feet out from the foot of the tower in three different directions. One blast line was over the natural dirt of Frenchman Flat. Asphalt was laid for the second line, and ground water was pumped from beneath Frenchman Flat, stored, and released to a depth of about a foot prior to the shot for the third line.[21]

Detonated at 11:15 a.m. on April 15, Met produced a yield of twenty-two kilotons, somewhat below the projected yield of twenty-eight kilotons. The three drone aircraft survived the blast effects but crash landed. Although data collected by the



Time-sequence photos of the sub-surface Ess shot, March 23, 1955. Source: DOE, NNSA-Nevada Site Office.

apparently unbeknownst to the military, the AEC used a device with a new design rather than a previously tested device with a reliable yield. The shortfall in yield, as a result, compromised much of the effects data.[22]



Fireball, top, and atomic cloud, bottom, of the HA shot, April 6, 1955. Source: DOE, NNSA-Nevada Site Office.

aircraft was retrieved, the military was not entirely satisfied with the Met results. For calibration purposes, the military had wanted a shot yield within ten percent of the thirty-one kiloton Buster Easy test. Despite assurances from Strauss, and

Doom Town

Teapot's open shot proved to be the biggest and most elaborate, as well as for many the most disappointing, event of its kind ever hosted at the test site. Unlike the two previous open shots, the Federal Civil Defense Administration conducted a full-fledged field exercise, Operation Cue, similar in concept to the Desert Rock maneuvers. Central to Operation Cue was a small FCDA-constructed community alternatively dubbed Doom Town, Terror Town, and Survival City by the press. Doom Town consisted of eight houses and six industrial buildings. At 4,700 feet from ground zero, FCDA built four houses, two on each side of a clearway bisecting the effects area like a broad, unpaved road leading out from the tower. Not intended to compare types of construction, the effects test on the houses—a one-story, precast concrete structure, a reinforced house of masonry block, a one-story rambler frame house with a reinforced-concrete bathroom shelter, and a two-story house of brick and cinder blocks with basement shelters—was to determine ways to measure expected damage and strengthen each type. A two-story frame house was built at 5,500 feet, with three additional houses at 10,500 feet. Three types of industrial buildings were set up at 6,800 feet from ground zero, with a similar trio at 15,000 feet. Linked with the houses were electric and gas systems, including a 3,000 kilowatt power transformer substation capable of supplying a town of 5,000 inhabitants. At distances of 10,500 feet and 15,000 feet, FCDA placed groups of house trailers, fire engines, ambulances, and utility repair trucks. Doom Town was populated by an assortment of seventy mannequins representing men, women, children, and infants arranged in realistic poses to gauge blast disruption

Drone Aircraft

Pilotless QF-80 jet fighter, top, of the Air Proving Ground Command's 3205th Drone Group used to fly through atomic clouds during Operation Teapot. Instrumentation pods slung under the wings, inboard of the fuel tanks, record effects on the aircraft. The drone aircraft, bottom, is being guided in for a landing by its ground controller. Source: DOE, NNSA-Nevada Site Office.

and effects on clothing. Fifteen tons of assorted standard foods would be exposed and then, over a period of many months, fed to dogs, monkeys, and assorted volunteers, including nine Mennonite conscientious objectors.[23]

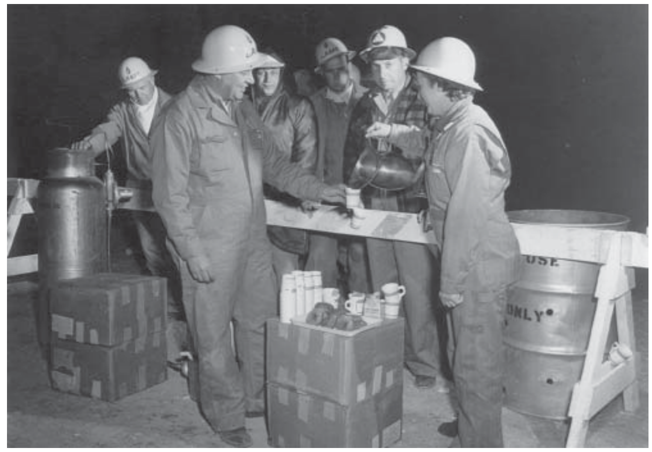
FCDA officials proposed bringing in 600 civil defense observers and 300 media representatives. An additional 300 civil defense workers would participate in the field exercise. Intended to "demonstrate to the public that preparedness for the civil defense worker is considered as important as for the soldier," the exercise would be "as realistic as possible," using a post-shot Doom Town as a backdrop. Focusing on what could be done to rehabilitate the town after the bomb had been dropped, the exercise would involve feeding mass groups of survivors, "rescuing" trapped mannequins, and demonstrating proper sanitation techniques. Civil Air Patrol aircraft would fly on and off the desert floor carrying messages, evacuating the "wounded," and rushing in plasma and other emergency supplies.[24]


Troops rehearse moving into trenches in preparation for "D-Day." Trenches are six feet deep, approximately 4,000 yards from Ground Zero. Source: DOE, NNSA-Nevada Site Office.

Not to be outdone, the military put on its own Desert Rock extravaganza for the open shot. The Army brought in from Camp Irwin, California, in a long, cross-country desert march, Task Force Razor, a reinforced armored battalion of some 800 soldiers. Fifty-five fully-manned Patton tanks from the battalion were located 3,100 yards from ground zero. During the shot, they would be "buttoned up" completely, with hatches locked against the shock wave, heat, and radioactivity. Behind the tanks were twenty-four armored personnel carriers, four self-propelled 105-mm. howitzers, and 6,000 feet of sand-bagged trenches, the closest at about 3,500 yards. Over 2,300 soldiers would wait out the shot in the trenches. Immediately following the blast, the tank force was to move toward ground zero in a "breakthrough" maneuver.[25]

In addition to the troops that would stay at Camp Desert Rock, officials anticipated that some 2,500 military and civil defense observers and workers would descend on Las Vegas for the open shot. The expected influx in conjunction with the Tournament of Champions golf meet and a major prize fight made city officials so nervous that they, in what must have been a first, actively discouraged tourists from coming to town. With the open shot scheduled for Tuesday, April 26, 1955, activities were already in full swing by the prior weekend. On Saturday, FCDA, AEC, and DOD officials briefed the official visitors in the Las Vegas High School auditorium. On Sunday, some thirty-five buses took the visitors out to the test site where they toured Doom Town. Monday brought more briefings and the "registration of VIPs." FCDA Director Val Peterson "created a daily sensation," arriving at the auditorium briefings "from the grounds of the plush Sands Hotel" in one of two of his white, two-seat helicopters. One reporter described the scene as a three-ring "atomic circus," with FCDA officials "so jealous" that they barred newsmen assigned to Desert Rock from visiting Doom Town, the Army that "bluntly admitted it was horning in on the civil defense show," and the AEC shying "away from the publicity spotlight."[26]

With the stage fully set, the "big show" began to come apart. Originally scheduled for the Zucchini test, the open shot would now be held using the Apple-2 device, a late addition to the test series when the yield of Apple-1 failed to meet expectations. Apple-2, with a projected yield of forty kilotons, demanded exacting weather conditions. Nature, however, refused to cooperate. On Monday night, less than twelve hours before the shot, a major gale with winds of fifty miles per hour and gusts of eighty hit the test site, knocking over 115 tents at Camp Desert Rock, forcing homeless troops into alternate housing, and postponing Apple-2 for twenty-four hours. Early Wednesday morning, hundreds of observers and participants gathered at the test site for the scheduled 5:15 a.m. shot only to have it called off "30 minutes before H-hour." "Vegans Miss Bath of Radiation," headlined the Las Vegas *Review-Journal*, noting that the winds at the time would have "bathed" the Las Vegas valley "in a

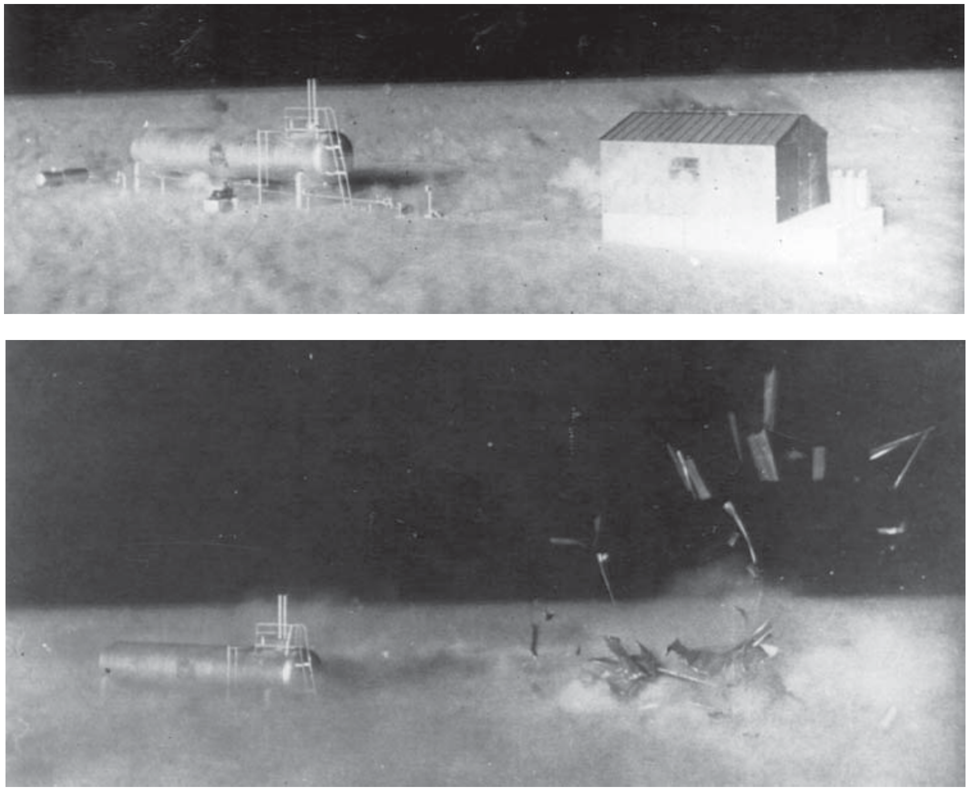


Coffee and doughnuts for FCDA staff personnel while awaiting the early morning Apple-2 shot. Source: National Archives.

20 roentgen dose of atomic radiation." Successive days each brought further postponements. By the weekend, a "mass exodus" of observers and participants was underway, and many state and local civil defense officials, some of whom were running out of money, headed for home. On late Saturday night, the convoy of buses, now reduced to sixteen in number, was met with chilling rain mixed with some snow and another shot delay. The California Civil Defense unit, tapped as one of the "main cogs" of the field exercise, rounded up their "$175,000 convoy of emergency equipment" and departed.[27]

FCDA Administrator Val Peterson, right, Paul Warner, head of FCDA Education Services, and an unidentified "friend" prepare to adjust dark glasses to observe Apple-2 shot. Source: National Archives.

Those with the wherewithal to stay ultimately were not disappointed. Apple-2 finally was fired on Thursday, May 5. The yield of twenty-nine kilotons was less than expected, but Apple-2's explosive display and destructive force were nonetheless considerable. Television viewers across the country received a "grandstand view" of the shot, although the blast knocked out cameras in a forward trench. Plans had called for split-screen coverage, with close-ups of civil defense workers on one side and the view from News Nob on the other. Doom Town suffered significant damage. The blast destroyed two of the houses—one brick, the other wood—at 4,700 feet from ground zero and wrecked two of the industrial buildings. Several



Liquefied petroleum tank and shed, top, smoldering from the heat of Apple-2 flash and, bottom, shed disintegrating as blast wave hits. Source: National Archives.

structures, however, survived with little more than broken windows. Downed utility poles resulted in electric power outages, although the power substation came through intact. Gas and telephone service remained in effect. The mannequin inhabitants of Doom Town also suffered mixed fortunes. Those in shelters, except in the collapsed houses, escaped alive if not unhurt. Those without protection "lay dead and dying in basements, living rooms, kitchens and bedrooms."[28]

Press interpretations of the Doom Town event differed markedly. "Survival Town Buildings Stand Up Well in Test," the Los Angeles *Times* headline read, while various Las Vegas *Review-Journal* articles proclaimed "'Death' and Destruction in Atom-Blasted Town," "A-Age Survival Odds Not Good: Real Folks Find Test Tribe Dead," and "Everyone Mile From Blast Hit." One *Review-Journal* reporter counseled "John Q. Public" to "live a bucolic life in the country, far from a potential target of atomic blasts. For destruction is everywhere. Houses destroyed, mannequins, representing humans, torn apart, and lacerated by flying glass."[29]

Testing in the Pacific: Wigwam

On May 14, 1955, the day before the last shot of the Teapot series, the Department of Defense and Atomic Energy Commission conducted an underwater weapon effects test, Wigwam, in the open waters of the Pacific some 500 miles southwest of San Diego. The Navy was keenly interested in determining the range at which the shock of a thirty-kiloton explosion at 2,000 feet below the surface would provide "lethal hull-splitting damage" to a submerged submarine. The Navy also wanted to learn the "surface effects" of the explosion, particularly with regards to radioactivity, to determine if a surface vessel could

Civil defense observers watch as Apple-2 cloud begins to disperse. Source: National Archives.

use a nuclear depth charge without endangering itself. Little interested in the effects aspects, AEC officials held grave misgivings about the test itself. They feared that adverse public reaction could, as Division of Biology and Medicine Director Bugher noted, "create an unfavorable public disposition toward the AEC's regular test program." Initially refusing to concur in the military's plans for Wigwam, AEC officials relented when they determined that no one on the west coast of the United States or Mexico would be endangered and that the test area was "essentially free of fish" of commercial importance.[30]

Testing in open water required a substantial task force and proved somewhat more difficult than expected. Some 6,500 personnel and thirty ships took part in Wigwam. The device was suspended by cable from a towed, unmanned barge in water that was 16,000 feet deep. Most ships and personnel conducting the test were positioned five miles upwind from the surface detonation point. Two ships with special radiological shielding were five miles downwind. Unanticipated wind and sea conditions played havoc with task force activities. Instead of the expected ten-knot winds and three-foot swells, the task force faced fifteen to thirty-knot winds and swells ten to fifteen feet high. Rough seas damaged equipment, but the shot proceeded as scheduled despite a significant loss of test data.[31]

Wigwam, according to one AEC official, was "a very impressive detonation to observe." Approximately ten seconds after the detonation, the initial gas bubble formed by the interaction of thermal energy and water burst through the surface forming "spikes and plumes" that reached a height

Operation Teapot Apple-2

Mannequins in thermal radiation experiment 7,000 feet from ground zero following the Apple-2 shot. Tilted askew, mannequins were for the most part not seared by the blast. Note, however, the shadow of the mannequin's hand scorched into the slacks in photo at right. Source: National Archives.

Plume forming following the Wigwam detonation as water falls back into the ocean, May 14, 1955. Source: Defense Threat Reduction Agency.

of 1,500 feet over an area roughly 3,100 feet in diameter. As the plumes fell back to the surface, a large cloud of mist formed. The blast shock wave hit the ships five miles distant in "three successive impulses of several seconds' duration each." A "base surge" was apparent close to the zero point, but by the time the wave reached the ships its effects could not be observed.[32]

One-Point Detonation Safety Tests

For a follow-up to Teapot in Nevada, AEC officials initially proposed a fall 1955 series, Dixie, consisting of Los Alamos and Livermore development tests. Los Alamos officials complained, however, that the short length of time between Teapot and Dixie would not allow for the "assimilation of the results" of Teapot and their "translation into practical experiments" for Dixie. They urged that Dixie be postponed until early 1956, which also would push back the spring 1956 Pacific test series, Redwing, to late fall 1956 or even 1957. Instead, AEC officials decided to cancel Dixie and fold the planned Dixie tests into the Redwing series. This meant there would be no full-scale tests in Nevada until 1957. The test site, nonetheless, did not lay dormant. Over 500 construction, maintenance, and service contractors remained after Teapot. In addition, both the Livermore and Sandia laboratories conducted low-level, non-nuclear experiments on the site.[33]

At the request of the Department of Defense, the AEC also initiated a series of one-point detonation tests designed to confirm that the accidental discharge of a weapon's high explosives would not produce a nuclear detonation. Concern over an accidental nuclear disaster had grown as nuclear weapons had become more sophisticated and specialized. Earlier bombs were assembled just before firing, with the fissile material being inserted before takeoff or even in-flight. Newer "sealed pit" weapons came with their fissile material installed. As DOD stepped up plans to deploy large numbers of air defense and antisubmarine weapons "in a constant state of readiness, often in close proximity to densely populated areas and aboard ship," Military Liaison Committee Chairman Herbert B. Loper told AEC Chairman Strauss, "we face the problem associated with erratic flight and possible accidents involving warheads and/or weapons in storage or during launching." Hence, the perceived need for safety testing, with the requirement that a device be "one-point safe." This meant that the ignition of the high explosives at any one point, as opposed to simultaneous ignition at all points in an actual detonation, would not result in significant nuclear yield.[34]

The Commission approved the safety test series, dubbed 56-Project NTS, in late August 1955. On October 19, the AEC announced that Los Alamos would conduct on the test site "a series of experiments to determine the safety of various weapons and experimental devices in the event of accidents, such as fires, during handling or storage." Los Alamos, with a team of thirty "scientific personnel," would carry out the tests since the devices in question were designed by the laboratory. Four tests, to be conducted in a small valley east of Yucca Lake, were scheduled in quick succession from November 1 to 5. Los Alamos considered the probability of a nuclear explosion to be "very small," but an off-site radiological safety organization was mobilized and available if needed. The first two shots were uneventful. The third shot, however, raised questions about inherent design safety. Testing was then suspended for technical reasons, and the fourth test did not take place until January 18, 1956. In order to determine the design problem, Los Alamos testers altered the fourth device so that it would produce a slight yield equivalent to over four pounds of TNT.[35]

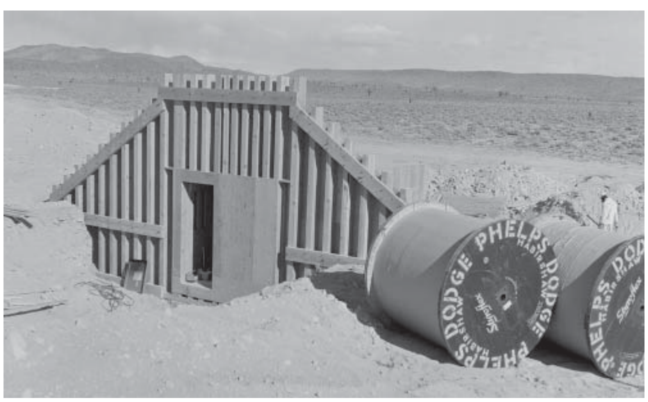
The yield of the fourth shot, though slight, proved higher than expected. Not everyone had been informed about the altered device, unfortunately, and the four-member recovery team went in too soon after the shot, recording gamma exposures ranging from 4.3 to 28 roentgens. Eleven days later, one of the four suffered a fatal cerebral thrombosis. Although radiation was "hardly likely" to have caused the stroke, adverse publicity forced the AEC to issue a statement denying any link.[36]

The extent of contamination from plutonium scattered from the four tests proved to be a surprise as well. Two areas a mile wide and ten miles long stretching out from ground zero contained measurable amounts of plutonium on the ground. Much of the eastern portion of the test site became contaminated. Plutonium, albeit in minute quantities, was also detected in off-site air samplers. This caused some consternation, but subsequent studies indicated that plutonium concentrations off site nowhere approached dangerous levels. On the positive side, dispersal and cleanup, near ground zero, of the plutonium provided valuable information and experience in the event of an actual accidental detonation.[37]

Safety tests soon became a major part of the testing regimen. "In 1956, we had our first really good clues that all was not well with our stockpile," Robert Brownlee, a Los Alamos physicist, later recalled. "We had managed to make everything just work perfectly, and we discovered, to our horror, that they were not safe. They could be set off quite accidentally." The results of the fourth shot sent "shockwaves" through the nuclear weapons program. Warheads had to be retrofitted to make them safe and then retested. Brownlee notes that subsequent to the fourth shot more than half of the money and effort spent on the program went toward making nuclear weapons safe.[38]

56-Project NTS

Using a theodolite to survey the test site. Source: Los Alamos National Laboratory.



Blockhouse several hundred yards from ground zero. Source: Los Alamos National Laboratory.

“Zero shack” at ground zero. Source: Los Alamos National Laboratory.

Putting detonators in place at zero shack. Source: Los Alamos National Laboratory.

Project 56, No. 4 test, January 18, 1956. Source: Los Alamos National Laboratory.

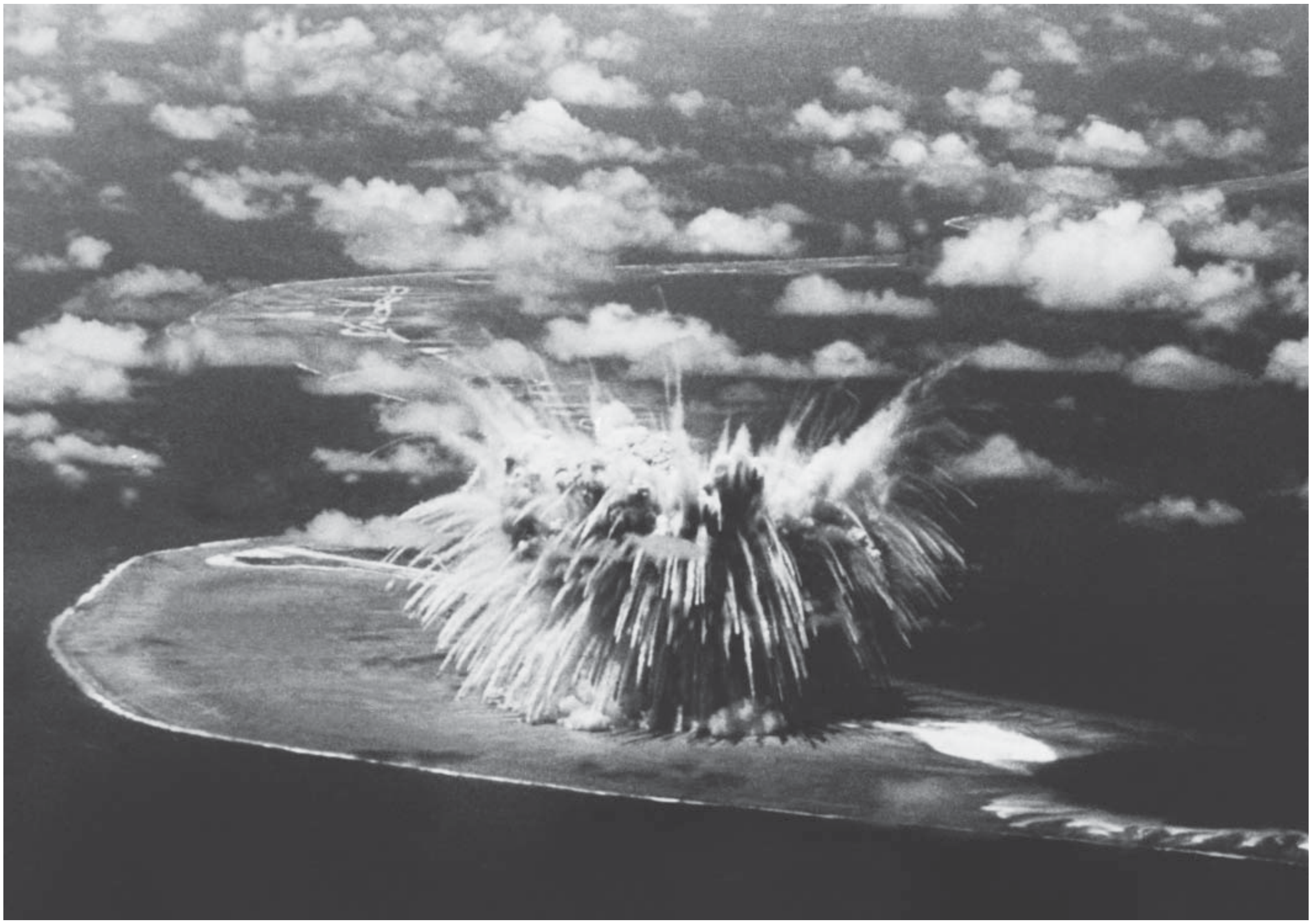
Testing in the Pacific: Redwing

In spring 1956, the United States returned to full-scale development testing in the Marshall Islands with Operation Redwing. The most ambitious series to date to be held in the Pacific, Redwing, incorporating the tests from the defunct Dixie series that had been planned for Nevada, consisted of seventeen shots. This equaled the combined total of tests in the five previous Pacific series. The Livermore laboratory, with ownership of seven of the shots, including the largest, the five megaton Tewa test, finally achieved relative parity with Los Alamos. Both Bikini and Enewetak atolls were used for the series. Bikini played host to five of the six blasts in the megaton range and the 365-kiloton Flathead test. Aside from Flathead, the kiloton-sized tests were done at Enewetak, as was the 1.85-megaton Apache shot, which was fired from a barge sitting in the Ivy-Mike crater. As at Teapot, test officials scheduled ready rather than firing dates. They conducted the smaller-yield tests while waiting for the right conditions to fire the high-yield shots, which had far more stringent limits on weather and wind.[39]

As Strauss informed Eisenhower, the four objectives of the Redwing series were to proof test stockpile or near stockpile weapons, continue developmental research on promising weapons, advance long-range research on new techniques and designs, and further the Department of Defense's weapon effects program. The Cherokee test involved the first airdrop of a multimegaton thermonuclear bomb, which, as a small group of reporters was allowed to view the shot, had the added advantage of demonstrating to the world that the United States, seven months after the Soviets had dropped a thermonuclear bomb from a strategic bomber, had a real weapon. Development tests focused on both strategic and tactical weapons.[40]

The military spent an estimated $15.5 million on weapon effects experiments. These included structure and equipment tests, thermal radiation effects experiments on panels of differing materials at varying distances from ground zero, and a bio-medical program measuring flash blindness and thermal effects using animals such as rabbits, monkeys, and pigs. The Air Force also flew drone aircraft, some flying as fast as the speed of sound, close to the fireball to determine blast, gust, and thermal effects.[41]

In several respects, Redwing differed significantly from earlier Pacific test series. Redwing, first of all, was more open. During previous series, the United States sharply restricted information outside official circles. After Castle, however, officials were keenly aware of the real public danger of high-yield testing, and they feared that attempted secrecy might revive public outcries and widespread international criticism. As a prelude to Redwing, the Department of Defense and Atomic Energy Commission issued a series of public statements culminating with a detailed description of measures taken to ensure public health and safety. These measures were considerably more enhanced and sophisticated than in previous series, with improved weather forecasts heading the list. A staff of over 500 gathered data from 50 weather stations and through the use of new techniques that included high-altitude balloons and missiles. Forecasters trained in advance tropical meteorology used the data to provide more accurate weather forecasts and, with the assistance of a special fallout prediction team, more reliable fallout predictions. New techniques were also used, although with questionable efficacy, in an effort to retard the amount of radioactivity going into the upper atmosphere. At the direction of Commissioner Libby, testers placed large amounts of silica sand in the shot barges hoping that it would increase local fallout and decrease long-range fallout. Finally, aware that "Castle showed us how tremendous the lethal fallout patterns of megaton weapons can be," test officials firmly vowed that



Seminole shot of Operation Redwing detonated on the surface at Enewetak Atoll on June 6, 1956, with a yield of 13.7 kilotons. Source: DOE, NNSA-Nevada Site Office.

"*we will not fire under conditions that are, in any way, marginal*."[42]

Redwing, as a result, proceeded without disaster and with few major problems. On the Cherokee shot, the drop, somewhat embarrassingly, missed the target by about four miles when the pilot mistook an observation facility for the target beacon. Exploding over the open ocean, the near miss, for a multimegaton weapon, resulted in the loss of some effects data but not in any safety or health problems. The second-to-last shot, Tewa, fired at Bikini, experienced a sudden wind shift immediately after detonation. Unexpectedly, the fallout cloud began heading in the general direction of the main base on Enewetak. Detectable fallout began at Enewetak nine hours after the shot. Fortunately, the fringe and not the main body of the cloud passed over the atoll, and no evacuation was deemed necessary when only "very light fallout occurred." The total yield for all seventeen Redwing shots of a little more than twenty-one megatons compared favorably to the forty-eight megatons of yield for the six Castle shots. The fission yield and the total fallout also were substantially less.[43]

Fallout and the Nuclear Test Ban

The linkage between radioactive fallout and the world-wide demand for a nuclear test ban—between health and safety and political issues—

would lead inexorably to a testing moratorium in 1958. Convinced that fallout was a public relations issue and not a health and safety problem, the Atomic Energy Commission, under the leadership of Lewis Strauss, fought a spirited if ultimately unsuccessful rearguard action within a divided administration to break the linkage and prevent a ban on nuclear weapons testing. "I am concerned," Strauss told Andrew J. Goodpaster, White House staff secretary, in December 1955, "by the intensification of the propaganda . . . that the testing of atomic weapons should be banned, and by the fact that a number of our own people are falling for this bait. We have successfully resisted it for a period of years."[44]

The Commission, nonetheless, did not mindlessly oppose a test ban. Strauss argued that a test ban should be implemented only as the "*final* phase of a comprehensive program for the limitations of armaments." The Soviet campaign for a testing moratorium, he argued, was a "coldly calculated maneuver to overcome our nuclear weapons superiority," which was the principal deterrent to aggressions "aimed at our subjugation and their domination of the world." The United States currently had the edge in nuclear weapons technology, Strauss conceded, but the Soviets, in the event of a testing moratorium, would overtake the United States through espionage, all-out research and development, and clandestine testing. At the same time, the "momentum and virility" of the American testing program would be lost. If a test ban was the first phase of a disarmament agreement, Strauss contended, the Soviets would deliberately stall subsequent negotiations while "they were surreptitiously increasing their own war potential." Even if the United States detected a violation of the test ban, Strauss concluded, it would be "politically difficult, if not impossible, to convince the world – in the face of Soviet denials – that such a violation had in fact occurred."[45]

Regarding Strauss's logic, President Eisenhower himself was the primary skeptic. He wryly noted that his own government might be the hardest to convince on the limitations of tests. Discouraged by the lack of progress toward disarmament, Eisenhower saw few alternatives to a gradual drift toward war. He nevertheless felt a moral obligation to find some alternative to the arms race, or, as he told his National Security Council, this "awful problem" could have only one result. If the H-bomb could be banned, he observed to his advisors, the world would be better off. Strategic planning, Eisenhower feared, was overlooking the "transcendent consideration" that "nobody can win a thermonuclear war." What, he asked rhetorically, was left of either country after the first seventy-two hours? We have to move on this, he concluded, "or we are doomed."[46]

Although Eisenhower's ruminations were for his inner circle only, the stark realities of what a full-scale thermonuclear exchange would entail continued to filter out to the general public. Several days after the Redwing-Cherokee test, General James M. Gavin, Army chief of research and development, appearing before a subcommittee of the Senate Armed Services Committee, estimated that a nuclear attack on the Soviet Union would result in "several hundred million deaths . . .

AEC Chairman Lewis L. Strauss and President Dwight D. Eisenhower in the White House Rose Garden. Source: Department of Energy.

depending upon which way the wind blew." If the wind blew from the northwest, casualties would extend throughout the Soviet Union and into Japan and perhaps the Philippines. If the wind blew from the other way, casualties would extend "well back up into Western Europe." Another Pentagon spokesman later commented that with "unfavorable" winds, the death toll could be 500 million and include possibly half the population of the British Isles.[47]

Made public on June 28, 1956, Gavin's remarks sparked considerable controversy. Administration officials decided to try to counter the "disastrous effects" of the testimony by minimizing the danger of fallout and emphasizing the development of "clean" weapons of reduced radioactivity. Most of the yield from a clean weapon would result from fusion, rather than fission, with a corresponding reduction in the amount of radioactive contamination. Although Eisenhower at an April 25 press conference had alluded to making weapons with reduced fallout and the Commission was reluctant to go further lest weapon design information be revealed, pressure from Dulles and the White House forced Strauss to issue a statement reassuring the public that "mass hazard from fallout" was "not a necessary complement to the use of large nuclear weapons." The Redwing series, Strauss concluded, "produced much of importance not only from a military point of view but from a humanitarian aspect."[48]

An attempt to dampen the flames produced by Gavin's comments, Strauss's "clean bomb statement" only added fuel to the fire. Press criticism was scathing, none more so than in the *Bulletin of the Atomic Scientists* where Ralph Lapp declared that Strauss had single-handedly invented "humanitarian H-bombs." Cleanliness or dirtiness, Lapp asserted, was a relative thing. Superbombs could be designed to be either relatively clean or very dirty. Clean bombs would be used for testing, Lapp assumed. Dirty bombs would be used as strategic weapons. "War is a dirty business," Lapp concluded, and "science has not succeeded in making it any cleaner. Part of the madness of our time is that adult men can use a word like humanitarian to describe an H-bomb."[49]

Strauss and the Commission could take some comfort in scientific studies confirming, to a certain degree, the AEC's assertion that atmospheric testing posed minimal health risks. The National Academy of Sciences' "The Biological Effects of Atomic Radiation," released on June 12, 1956, identified the genetic consequences of radiation as a primary consideration. The report compared the 30-year dose to the gonads received by the average person from natural background, 4.3 roentgens, and from X-rays and fluoroscopy, 3 roentgens, with the dose from the current level of weapons tests, .1 roentgen. Fallout from tests was apparently much less dangerous than radiation from medical uses, and, although the academy did not say that nuclear testing was safe, it did imply that the risks were minor. Similarly, Libby and Merril Eisenbud, manager of the AEC's New York Operations office, concluded that strontium-90, acknowledged as the most hazardous of the nuclides formed in the fission process, was largely an insignificant problem. Using data from the North Dakota milkshed, where the greatest concentrations had occurred, Eisenbud, in a November 1956 speech, stated that over a seventy year period estimated skeletal accumulation from background radiation and weapons tests to date was only seven percent above that received from background radiation alone. Libby's and Eisenbud's research, nonetheless, gave the AEC's Advisory Committee on Biology and Medicine pause. Both men had only analyzed past testing and not considered continued and future testing. Additional testing, the committee noted, might exceed permissible limits. As one geneticist put it, if testing continued at the same rate as it had for the past four years, limits would be exceeded in twenty-eight years.[50]

Testing and the 1956 Presidential Election

Despite the AEC's best efforts to derail any talk of a nuclear weapons test ban, the issue took center stage in the 1956 presidential elections. During the summer of 1956, few expected nuclear testing to become a campaign issue. On August 24, however, the Soviet Union, after a lull of five months, unexpectedly resumed nuclear testing. Strauss and the White House decided to publicize the test in order to discredit Soviet advocacy of a test ban. Two more Soviet tests were announced by the United States on August 31 and September 3. On September 5, Adlai Stevenson, the Democratic challenger, called for a halt to "further testing of large nuclear devices conditional upon adherence by the other atomic powers to a similar policy." Stevenson did not elaborate but noted that other nations had indicated "their willingness to limit such tests." Vice President Richard M. Nixon the next day labeled Stevenson's proposal "not only naïve but dangerous to our national security." The issue remained dormant until Eisenhower, two weeks later in his first major campaign speech, refused to endorse any "theatrical national gesture" to end testing that lacked reliable inspection provisions. "We cannot salute the future with bold words," the President exclaimed, "while we surrender it with feeble deeds." Angered by Eisenhower's remarks, Stevenson responded that his "gesture" to "spare humanity the incalculable effects of unlimited hydrogen bomb testing" aligned him with many "sincere and thoughtful persons," including Pope Pius XII, representatives of the Baptist, Unitarian, Quaker, and Methodist churches, and Commissioner Murray.[51]

Adlai Stevenson. Source: National Archives.

Against the counsel of his advisors who warned that national security was Eisenhower's strong suit, Stevenson made nuclear testing a central theme of his campaign. With a firm moral commitment, not all that dissimilar from Eisenhower's, Stevenson felt that he had to speak out on an issue at the very center of the Cold War. On September 29, he called for a test ban as the best way to "get off dead center of disarmament," which was "the first order of business in the world today." For the first time, he also mentioned "the danger of poisoning the atmosphere" as an additional reason for stopping tests. With the "actual survival of the human race itself" in question, Stevenson declared, scientists believed that "radioactive fallout may do genetic damage with effects on unborn children which they are unable to estimate."[52]

Republicans launched a scathing counterattack. Eisenhower, for the moment, maintained his silence while Nixon and other surrogates lead the charge. Nixon accused Stevenson of advocating "catastrophic nonsense" that raised "grave doubts" about his foreign policy abilities. The Vice President compared a test ban lacking inspections to "playing Russian roulette but with only the Russians knowing which chamber had the fatal bullet in it." Regretting the partisan attacks, Eisenhower spoke out on October 5. Noting that it took "months and months" to prepare for tests, he observed that the Soviets could use a test moratorium to make secret preparations to test and, even though their violations were discovered, "they could make tremendous advances where we would be standing still." The next day, Eisenhower, in a White House statement, declared that public discussion of a test ban could "lead only to confusion at home and misunderstanding abroad" at a time when "this specific matter is manifestly not a subject for detailed public discussion—for obvious security reasons." At this point, the press began to suspect—rightly—that the administration was considering disarmament proposals that included a test ban. When asked directly about the matter at a press conference on October 11, Eisenhower sidestepped the question and declared, "Now, I tell you frankly I have said my last words on these subjects."[53]

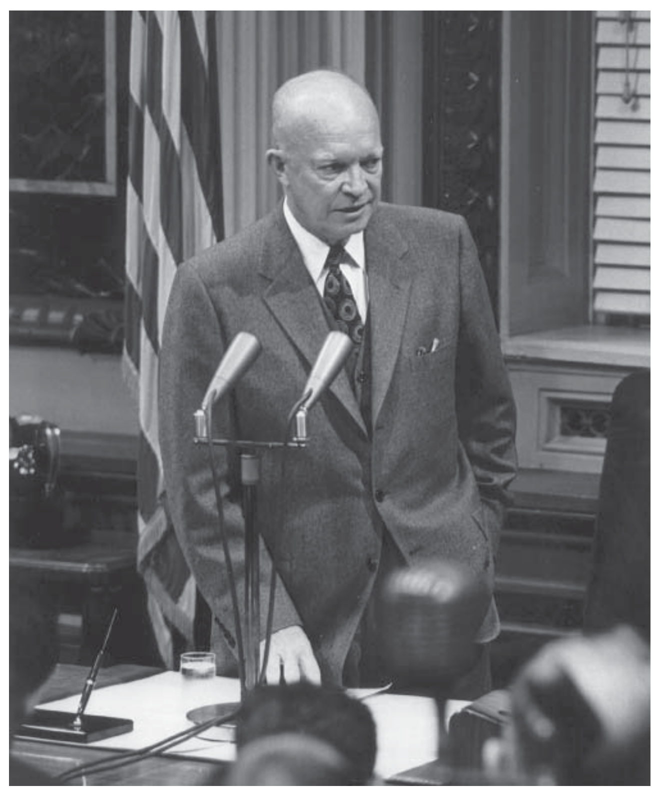
The test ban issue, meanwhile, energized Stevenson's run for the presidency. Stumping on the west coast and highlighting testing, Stevenson elicited, as the New York *Times* noted, "the biggest and longest spontaneous demonstration he has had at any time on any issue since the start of the campaign." On October 15, in a major televised address entitled "The Greatest Menace the World Has Ever Known," he spoke entirely on nuclear testing and presidential leadership. The arms race "threatens mankind with stark, merciless, bleak catastrophe," he observed, and a single 20-megaton bomb, enough to destroy the largest city, was equivalent to "every man, woman and child on earth each carrying a 16-pound bundle of dynamite—enough to blow him to smithereens and then some." Halting nuclear weapons testing, Stevenson asserted, could help break the "deadly deadlock" that prevented a move toward effective disarmament. Violations of a test ban could be "quickly detected," he noted, with explosions of large weapons incapable of being hidden "any more than you can hide an earthquake." Stevenson also stressed the potential health risks of strontium-90, "the most dreadful poison in the world," although he admitted that scientists "do not know exactly how dangerous the threat is." What was certain was that the "threat will increase if we go on testing." In addition, Stevenson claimed that a test ban would inhibit proliferation and help prevent "a maniac, another Hitler," from developing thermonuclear weapons. Finally, he called on "mighty, magnanimous America" to rescue "man from this elemental fire which we have kindled" and "regain the moral respect we once had and which our stubborn, self-righteous rigidity has nearly lost."[54]

With Stevenson's campaign gathering momentum, Democratic leaders, parts of the press, prominent scientists, including former AEC Commissioner Henry Smyth, and prominent groups of scientists, such as the Federation of American Scientists, rallied behind the test ban proposal. Stevenson received thousands of letters of encouragement on the testing issue, mostly from professional people in the affluent suburbs of the north. The President's mail, as well, reflected overwhelming support for a test ban. Not surprisingly, there was also opposition to Stevenson's proposal. Influential columnists and major newspapers, including the New York *Times*, came out against a test ban without adequate safeguards and supervision. Prominent scientists of an anti-test ban bent refuted the pro-test ban scientists, with Ernest O. Lawrence and Edward Teller, founders of the Livermore laboratory, describing the danger from fallout as "insignificant" and disputing the claim that a test ban would be self-enforcing. "Not all atmospheric tests," they argued, "can be detected with instruments." Nor was Stevenson helped by his own running mate, Estes Kefauver, who predicted that hydrogen bombs could "right now blow the earth off its axis by 16 degrees, which could affect the seasons." These claims were quickly discredited by Ralph Lapp and other reputable scientists.[55]

Edward Teller and Ernest O. Lawrence. Source: Lawrence Livermore National Laboratory.

Stevenson was undone, however, from an unlikely quarter. On October 19, the Soviets released a letter from Premier Nikolai Bulganin to Eisenhower criticizing the administration for its position on testing and endorsing a test ban as a first step in accord with "the opinion recently expressed by certain prominent public figures in the United States" which "we fully share." Eisenhower was livid at this not-so-veiled reference to Stevenson and what he, as well as the press, interpreted as blatant meddling in the American political process. In his response, also made public, he castigated Bulganin for his departure from "accepted international practice," insisted that disarmament measures required "systems of inspection and control, both of which your Government has steadfastly refused to accept," and denounced the reference to Stevenson as "interference by a foreign nation in our internal affairs." The results for Stevenson were disastrous. When a reporter asked White House Press Secretary James Hagerty if this meant that the Soviets had endorsed Stevenson, Hagerty smiled and responded, "no comment." Stevenson sought to distance himself from the Soviet faux pas, but to little political avail. "Though the Democratic nominee had been looking everywhere for support for his H-bomb proposals," New York *Times* correspondent James Reston commented, "Moscow was the one place he wanted to keep quiet." The test ban issue, *Newsweek* observed, had become "a political kiss of death."[56]

In the end, the Bulganin letter probably had little impact on the election. A Gallup poll at the end of October found that only 24 percent of the public favored a cessation of testing by the United States, with 56 percent opposed. Eisenhower swept the election, winning 41 states and nearly 58 percent of the popular vote. Nor was Eisenhower's position on the test ban greatly influenced by Stevenson's elevation of the test ban into a major campaign issue. For months, Eisenhower had been championing a test moratorium or at least some kind of brake on the arms race, albeit within the administration and unbeknownst to the press or the public. This did not change. Stevenson's contribution to the ongoing debate over the test ban, nonetheless, was not insignificant. For better or worse, Stevenson, as the historian Robert Divine notes, "brought the test ban out of obscurity and into the forefront of public discussion."[57]



President Eisenhower holds a press conference at the Executive Office Building, 1956. Source: National Archives.

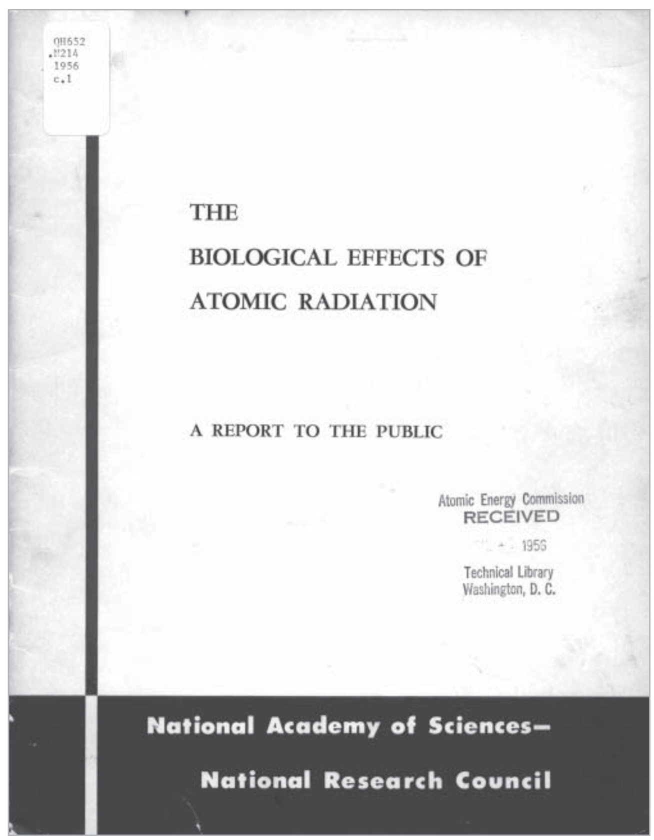
Part V

Atmospheric Testing Comes to a Close, 1957-1958

Prelude to Plumbbob

Following Teapot, officials of the Atomic Energy Commission (AEC) scheduled the next Nevada nuclear weapons test series, Pilgrim, later renamed Plumbbob, for spring 1957. Fallout remained the determining issue, not so much in terms of the growing world-wide fallout debate—the relatively small yields of the Nevada shots did not add appreciably to the overall fallout totals—but in the localized fallout that might descend on the communities around the Nevada Test Site. Analyzing the results after Teapot, officials viewed the size of the shot as the primary constraining factor. An upper limit of fifty kilotons had restricted Teapot tests, but planners began considering alternate modes of testing, including tethered balloons, even taller towers, and underground containment, that might justify higher yield limits.[1]

Long-term exposure limits to off-site populations also posed a potential problem. Although generally confirming the AEC's assessment that testing had placed the overall population at minimum risk, the June 1956 National Academy of Sciences (NAS) report on the biological effects of radiation recommended far more stringent limits on off-site exposure than the AEC had in place for Teapot, which were 3.9 roentgens during any twelve month period. The NAS concluded that "humanly controllable sources of radiation," including weapons testing, should be restricted to the extent that the general population should not receive on average more than 10 roentgens, in addition to background, from conception to age thirty. Population exposure limits "roughly equivalent to a limitation to about three Teapots in ten years," noted Alvin Graves of the Los Alamos Test Division, could sharply curtail "the amount of necessary work that can be done in Nevada."[2]



The June 1956 National Academy of Sciences report called for stringent limits on off-site exposures.

AEC officials were in something of a quandary. Past experience at the test site indicated that limiting exposures to 10 roentgens in 30 years would not be, according to Division of Biology and Medicine (DBM) Director Charles L. Dunham, "operationally feasible." On the other hand, the NAS report also stated that "individual persons" should not receive a total accumulated dose of 50 roentgens up to age 30. It "probably would be difficult" to categorize the many thousands of people living near the test site as "individual persons," Dunham observed, but they "might not constitute a 'general population'" either. In mid-November 1956, with Pilgrim/Plumbbob only six months away, Dunham, with input from the National Committee on Radiation Protection and concurrence from the AEC's Advisory Committee on Biology and Medicine and other relevant AEC offices, presented a set of recommendations to the Commission. Noting the necessity of "facing the problem frankly and in the interests of National Defense defining the degree of risk, as the Commission has done in the past," Dunham stated that a "reasonable figure" seemed to "lie somewhat between the 10 and 50 roentgens per 30 years." Dunham recommended that the "*operational guide*," as opposed to the "maximum limit," be "arbitrarily established at 10 roentgens in a period of 10 years with the first of the successive ten year periods starting in the spring of 1951." The criterion of 3.9 roentgens for any given twelve month period would remain in effect. Defending the "operational feasibility" of 10 roentgens in 10 years, Dunham cited the past 5 years of testing in Nevada in which "the highest total accumulated exposure to any *community* has been about four and one-half roentgens (about 15 people living in a motor court received about seven to eight roentgens)." This might suggest a "degree of ease in meeting the criteria that does not in fact exist," Dunham cautioned. "The relatively low exposures are the result of the most exacting plans and procedures for conducting the tests including many long delays until weather conditions were favorable."[3]

The Commission hesitated. In a meeting held on November 14, 1956, the Commission first considered Pilgrim, which would be a two-phase series, conducted in the spring and fall 1957, consisting of twenty-six shots and a number of one-point detonation safety tests. Despite Chairman Lewis L. Strauss's concern with the ever increasing number of shots included in each new test series, the Commission approved, in principle, going ahead with Pilgrim. Turning to Dunham's recommendations on exposure criteria, Commissioner Thomas E. Murray suggested establishing a second or third test organization for testing in the Pacific so that "arbitrary determinations" on exposures to fallout could be avoided. Strauss reminded his fellow commissioners that prior to Teapot he had recommended that all tests be moved to the Pacific, and he stated that if this were done the Commission would "not be faced with many problems such as a determination of radiological safety criteria." Strauss expressed particular concern about the proposed underground shots for Pilgrim. Defending the proposed criteria, Gordon M. Dunning of the Division of Biology and Medicine staff noted that the National Academy of Sciences "had also arrived at its figures of 10 roentgens and a 30-year period in an arbitrary manner." Commissioner Willard F. Libby raised the possibility of establishing the 10-year limit at 5 roentgens and transferring some but not all of the Pilgrim shots to the Pacific. After lengthy discussion, the Commission decided to approve the proposed exposure criteria, but with the understanding that Libby would review the fallout data and establish, if possible, the 10-year limit at a lower level than 10 roentgens. Strauss also asked that the AEC staff study the various factors involved in the transfer of all tests to the Pacific.[4]

Three weeks later, on December 5, the Commission reconvened to discuss recommendations on the Pilgrim series provided by General Alfred D. Starbird, director of the Division of Military Application (DMA), and concurred

The 700-foot tower, top, at the north end of Yucca Flat for the Smoky shot. The top of the tower, bottom, viewed from its base. About half way up is the elevator featuring an electro-magnetic system of control that eliminates the need for trailing cable below the elevator. Source: DOE, NNSA-Nevada Site Office.

in by the other interested AEC offices. Starbird presented three alternative plans to "reduce the expected fallout." Plan I envisioned moving Pilgrim, minus the underground and one-point safety tests, to the Pacific for a fall 1957 series. This would "eliminate the problem of further contaminating the Nevada area" but have a "very unfavorable impact" on weapon development schedules and morale of personnel and engender possible international criticism. Plan II involved transferring the "six difficult shots" from Pilgrim to Operation Hardtack, the next Pacific series scheduled for spring 1958. This would limit off-site fallout in Nevada but have "some undesirable effect" on weapon development schedules. Plan III, the recommended alternative, kept all of Pilgrim at the Nevada Test Site in a single-phase series but with redesigned "test device and/or suspension systems" for the "difficult shots" to reduce fallout. This meant the elimination of two shots, addition of a smaller-yield shot, substitution of a smaller-yield device for a larger one, higher towers up to 700 feet, and suspension of some devices from balloons—all of which would have "little effect" on weapons schedules. Starbird pointed out that implementation of Plan III changes would reduce the projected fallout for Pilgrim from 6,600 to 4,000 megacuries. With twice the amount of projected total yield in comparison to Teapot, Pilgrim would produce a similar amount of off-site fallout.[5]

The Commission approved Plan III but, in the absence of Strauss, reserved him the right to reopen the issue. Murray, as well, wanted to re-review the testing options in light of Libby's contention that the ten roentgens in ten years was a "conservative figure," especially since the actual doses received by individuals in the vicinity of the tests were, in Libby's estimation, "probably less by a factor of two than the measured values." Murray subsequently asked Dunham if Libby was correct, and Dunham responded that the estimated doses were high but not by a factor of two. With the full Commission meeting on December 10, Strauss expressed concern about the underground shot "occurring simultaneously with an earthquake." Libby thought the likelihood of this was "extremely remote." Murray then informed the Commission that, given Dunham's response on estimated doses,

View from the cab of the 700-foot Smoky tower looking south. The tower, momentarily the tallest structure in Nevada, was equivalent in height to a 70-story building. In left foreground are shelters to be tested for the French and German governments. On right side of the photo are military vehicles, part of a blast effects experiment, at varying distances from the tower. The trench area from which military observers will view the test is 4,500 yards from the tower. The troop assembly area is 9,800 yards away, and News Nob is approximately 17 miles distant. Source: DOE, NNSA-Nevada Site Office.

he favored moving the large Pilgrim shots to the Pacific in accord with Plan II. Adjourning without reaching a decision, the commissioners reconvened on December 12 and agreed that even with "some reservations about the specific plans" they "did favor the conduct of some type of test series in Nevada." Detailed plans, they noted, would be considered later.[6]

Moving Toward a Test Ban

President Eisenhower also harbored doubts about Pilgrim/Plumbbob. Once the commissioners finally agreed to move ahead with the test series, they forwarded to the White House a request for presidential approval of the tests scheduled to begin on or about May 1, 1957. Recently reelected in a campaign in which nuclear weapons testing had been a major issue and with his administration about to launch a major disarmament initiative, Eisenhower questioned the "advisability" of the test series. Secretary of State John Foster Dulles reassured the President that there should be "no difficulty" with the series because recent tests by the Soviet Union had provoked little comment.[7]

Unveiled at the United Nations on January 14, 1957, Eisenhower's disarmament proposals included controls on the production of fissionable materials that might lead to the limitation and eventual elimination of all nuclear tests. This was contingent on the establishment of acceptable inspection and verification provisions. Pending negotiation of an overall agreement, the United States suggested that testing nations announce tests in advance and provide for limited international observation of the tests. At the same time, Harold Stassen, Eisenhower's special assistant on disarmament, asked for the Commission's comments on both a test moratorium and a limitation, of some form, on tests. Unenthusiastic about any testing proposal, Strauss reiterated that the Commission, with the exception of Murray, was not in favor of a moratorium. On testing limitations, however, the Commission seemed somewhat more flexible and willing to consider various options.[8]

As the United Nations disarmament subcommittee convened in London on March 18, 1957, prospects for any sort of agreement did not appear bright. All three nuclear "have" nations were busy testing or preparing to test. The Soviet Union conducted six tests in March on the eve of the conference. The British had announced in January plans to test their first megaton thermonuclear devices at Christmas Island in the Pacific. Also in January, the AEC announced Operation Plumbbob, a "series of low-yield nuclear tests" to be conducted in late spring in Nevada.[9]

Harold Stassen, President Eisenhower's special assistant on disarmament. Source: National Archives.

Stassen, head of the United States negotiating team, nonetheless, was eager to make progress. Less than two weeks into the conference, the Soviets called for an "immediate and unconditional halt to tests, without any inspection" as a first—not the last—step toward disarmament, an offer that Stassen did not necessarily preclude. An irate Strauss complained bitterly to Dulles, who agreed to recall Stassen from London "to find out what is going on." At an April 20 meeting of the major figures, not including Eisenhower, Stassen explained that a limited twelve-month test ban prior to implementation of an inspection system was "only a limited risk" because it would not significantly alter the nuclear weapon capability of either the United States or the Soviet Union. More important, Stassen noted, was the "fourth" or "n-th" country problem. Without a test ban, France would test its first nuclear weapon in 1959. Other nations, Stassen observed, were certain to follow. Strauss argued that a moratorium, once in place, would be near-impossible to lift, with or without inspections. Dulles suggested that successful steps toward eliminating the proliferation problem would justify taking some risks, but he also rebuked Stassen for putting forth "personal" proposals that could prove highly dangerous if the Soviets accepted a position that the President could not endorse.[10]

Soviet leader Nikita Khrushchev. Source: National Archives.

World-wide pressure to end testing, meanwhile, continued to mount. In April, the Soviets exploded five devices within a two-week period, creating extensive fallout that circled the globe. Heavily hit by radioactive rain and snow, Japan sent loud-speaker trucks into the streets to warn citizens. Far from showing remorse, Soviet leader Nikita Khrushchev bragged that Soviet scientists had perfected an H-bomb, too powerful to test, that "could melt the Arctic icecap and send oceans spilling all over the world." The Japanese government vigorously protested the British tests and the Plumbbob series, as well as the Soviet tests, but to no avail. On April 24, the world-famous musician, doctor, and theologian Albert Schweitzer, at the urging of Norman Cousins, editor of the *Saturday Review*, issued an appeal for the end of testing. Libby attempted an open rebuttal of Schweitzer on scientific and national security grounds, but almost 2,000 American scientists signed a petition, initiated by Linus Pauling and Barry Commoner, that called for a stop to tests. With the British set to explode the first of three devices on May 15, "near hysteria" erupted in the British Isles. Parades and demonstrations attracted mass support. The philosopher Bertrand Russell stated that he did "not wish to be an accomplice in a vast atrocity which threatens the world with overwhelming disaster." Even in the United States the tide was turning against continued testing. Although in fall 1956 only one in four Americans opposed the testing of thermonuclear weapons, a Gallup poll in April 1957 found that almost two-thirds of the respondents favored ceasing testing if all other nations did so.[11]

In mid-May, Stassen again returned from London in an effort to reformulate the administration's disarmament policy. Claiming that the Soviets were genuinely interested in reaching an agreement, Stassen, in a bold departure from previous policy, called for a one-year suspension of all nuclear tests without prior agreement to an effective verification system. AEC officials, once more, were unhappy. A moratorium would imperil weapons programs and laboratory budgets, Division of Military Application Director Starbird noted, and, once accepted, strong public opinion would prevent the resumption of testing without some overt provocation by another country.[12]

Eisenhower met with his disarmament advisors on May 23 and 25. The President stressed that it was "absolutely necessary" to find some way to end the arms race, not only for moral but also for fiscal reasons. Risks with the Soviets were great, Eisenhower conceded, but so were risks to the economy if defense spending went unchecked. Saving the test ban issue for last, Dulles suggested that testing be suspended for twelve months, after which tests would be resumed if no inspection agreement had been reached. Strauss was stunned. This was his fall-back proposal, to be used "if all else failed," which apparently had gotten to Dulles in a roundabout way through Libby and Deputy Secretary of Defense Donald Quarles. Eisenhower, in any event, endorsed the proposal, telling Strauss that he was convinced that Strauss could hold the weapons laboratories together.[13]

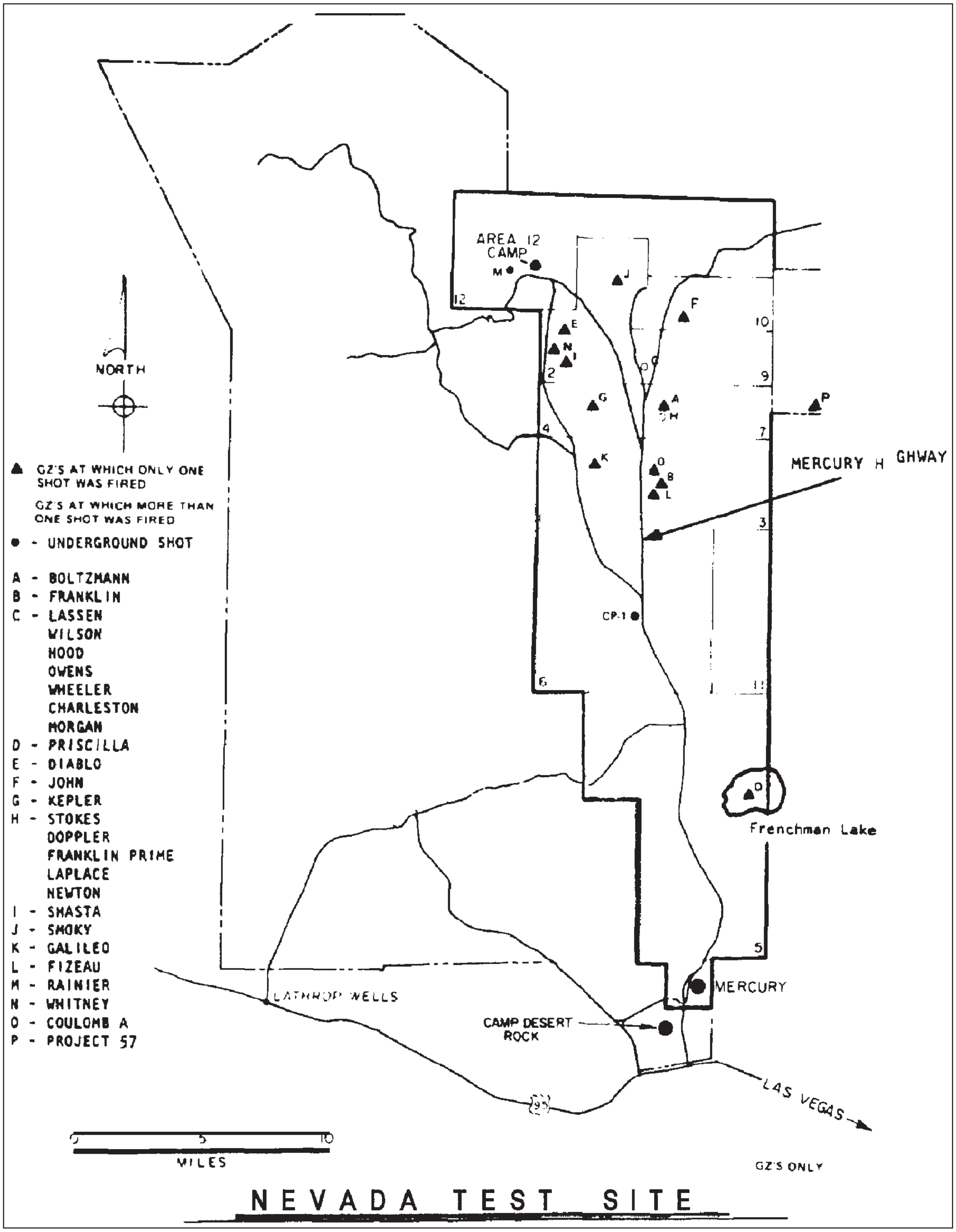
Once the disarmament conference resumed in London, the Soviets, on June 14, surprised everyone by announcing their willingness to accept a test ban with international control and supervision. Duration of the test ban would be for at least two or three years because, the Soviets noted, any shorter period "would have no practical significance and would do nothing effective to stop the atomic armaments race." The Soviets proposed establishing an international inspection commission to supervise the agreement and establish control posts in the United States, the United Kingdom, the Soviet Union, and the Pacific test area. American and British officials recognized this as a significant concession. For the first time, the Soviets had expressed a readiness to allow inspection posts within the Soviet Union itself. At a press conference on June 19, Eisenhower stated that he "would be perfectly delighted to make some satisfactory arrangement for temporary suspension of tests while we could determine whether we couldn't make some agreements that would allow it to be a permanent arrangement."[14]

Plumbbob

As prospects for a test ban brightened somewhat, the Atomic Energy Commission proceeded with Operation Plumbbob, the most extensive test series held to date at the Nevada Test Site. Among the twenty-four planned shots were the proof-firing of air defense and anti-submarine warheads scheduled for early production. These included a warhead for the Talos-W surface-to-air missile, two warheads for the Nike-B surface-to-air missile, and an atomic depth charge. Also planned were development tests of components and mockups for thermonuclear devices to be tested in the next Pacific series. These included an Intercontinental Ballistic Missile (ICBM) warhead and devices directed toward a higher yield-to-weight ratio. As in previous test series, exploratory and development tests would seek to achieve more efficient use of "active material" and warheads of smaller size and weight. New to Plumbbob was a "deep underground test," which, if successful, would produce no off-site fallout and furnish information for several new possible applications of atomic weapons. Finally, two tests solely designed for weapon effects purposes were planned. One involved an air-burst of the nuclear warhead in the Air Force's new air-to-air missile following its launching from an interceptor aircraft.[15]

Preparations for Plumbbob began well before the AEC officially announced the test series on January 25, 1957. Engineers from the AEC's Sandia Laboratory at Albuquerque, New Mexico, had been experimenting with balloon suspension for more than a year and now, in early 1957, were at the test site proof-testing the system. Tethered to the ground by four steel cables controlled by sheltered

Operation Plumbbob



Nevada Test Site showing locations of shot ground zeros for Plumbbob series. Source: P. S. Harris, et al., *Plumbbob Series, 1957*, DNA 6005F (Washington, DC: Defense Nuclear Agency, September 15, 1981), p. 8.

winches, the 50 to 75-foot diameter, helium-filled plastic balloons were flown at heights from several hundred to 2,000 feet. Each balloon carried a "basket," similar to a tower cab, which would carry the device as well as diagnostic instrumentation. To guard against a bomb-laden balloon "soaring over the countryside," an emergency deflation device controlled from the ground could deflate the balloon rapidly. Significantly cheaper than towers, balloons were used for 13 of the 24 Plumbbob shots. Those tests requiring more extensive instrumentation, and a steadier platform, used towers. For the first time, a 700-foot tower was built. Based on a modular design with upright members fabricated in twenty-five-foot lengths, all parts were identical and interchangeable, thus cutting erection time by as much as half. Test site officials also boasted about new diagnostic tools and instrumentation. These included electronic "streak" cameras capable of recording images in one billionth of a second, a camera for measuring shock waves reflecting off objects and people, a new oscilloscope capable of recording impulses from the very center of the fireball only one ten-billionth of a second after their origin, and "electronic fallout computers" designed to provide rapid forecasts of radioactive fallout on and near the test site.[16]

Public relations were a major component of Plumbbob. Fearing adverse public reaction in the communities surrounding the test site, AEC officials and Public Health Service officers monitoring the tests, as with Teapot, distributed materials, showed AEC-made films, appeared at local venues, and briefed local and state officials. Unlike Teapot, AEC officials sought to downplay the role of fallout in the tests and provide a more low-key setting for media and other observers. Avoiding the near-circus-like atmosphere preceding the Teapot Apple-2 open shot, and the disappointments after the repeated postponements of the test, officials decided not to have a Plumbbob open shot "with large scale public information media attendance." Rather, a smaller,

Sandia Laboratory personnel, top, begin a series of experiments on January 30, 1957, at the firing area in Yucca Flat to determine if anchored balloons may be used as detonation platforms for full-scale nuclear tests. The tube-like extension of the balloon (lower right) is used to inflate it with helium. Shot balloon, bottom, with dummy cab suspended and supporting cable in view, at the beginning of altitude run during experimental handling. Source: DOE, NNSA-Nevada Site Office.

Arthur Morse, right, of the CBS television program, "See It Now," interviewing Dale Nielsen, general manager in Nevada of the Livermore laboratory, in the Rainier shot tunnel diagnostics room. Source: DOE, NNSA-Nevada Site Office.

more manageable "supervised group" of American and, for the first time, foreign media representatives would be permitted to view nine selected Plumbbob shots. Reviewing the AEC's public information plan, the Operations Coordinating Board, set up by Eisenhower to follow up on all national security decisions, commented that the presence of foreign observers and media would not only "increase overseas attention" to Nevada Test Site activities but also "augment information channels to foreign audiences." This would result in a "decided net propaganda gain" due to "U.S. 'openness' as contrasted to Soviet secrecy," the "impressiveness" of test site safety requirements, and the "minimal nature" of fallout from smaller nuclear weapons. In another first, the AEC allowed "Q-cleared" Albuquerque and San Francisco operations office employees and contractors "connected with the weapons program" to observe a test "entirely at their own expense."[17]

Plumbbob: Downwinders, Blooming Atoms, and Protesters

Public relations efforts to quell public fears were initially of little avail. After over three years of an ever-growing fallout debate, the AEC's test manager later noted, an "almost panic fear of fallout" gripped the local populace. The local press, as well, for the first time, began to question the safety of testing in Nevada. On May 24, four days before the first Plumbbob shot, the Tonopah *Times-Bonanza*, which described itself as "the nation's closest weekly newspaper to the atomic tests with a vigorous editorial policy on the subject," complained that Tonopah appeared to be a much more likely target for fallout than Las Vegas. "Is this just another way of saying," the newspaper asked, "that the fallout is dangerous when the cloud hovers over a highly populated area but harmless when it traverses sparsely populated places?" Go ahead with the tests, the newspaper told the AEC, "but if you must shoot craps with destiny, first throw away the loaded dice!" Unfortunately, fallout from Boltzmann, the first shot of the series, headed northwest instead of eastward as predicted, and lightly dusted Tonopah with 25 milliroentgens of radiation. The irate editor of the *Times-Bonanza* accused the AEC of "talking out of both sides of its mouth when it says the fallout will hurt Las Vegans but not Tonopahans. Do they think we have some kind of magical radiation shield—like lead in our head?"[18]

Even the Las Vegas press was becoming somewhat more skeptical of AEC assurances. In early June, the Las Vegas *Sun*, long a stalwart supporter of testing, did a feature article on ranchers in the Twin Springs area north of the test site "losing faith" in the AEC. The article described fallout clouds that passed

> directly overhead, blotting out the sun and covering the valley with a dense fog.
>
> This passes over, but something unseen is left behind that makes their Geiger counters go crazy. Their eyes burn and sometimes the air has a chemical taste. Their cattle are afflicted with a horrible cancerous eye infection; one of their dogs went stone blind and another developed an ugly malignant sore. A woman went completely bald and a young boy died of leukemia.[19]

Sun Publisher Hank Greenspun, who would become something of a local institution in Las Vegas, noted that it was the "little fellow who always gets the brunt of all tests, whether scientific, economic or religious. These people are honestly afraid." By mid-July, however, local public concern had decreased considerably, the fruits of AEC public relations efforts and, perhaps more importantly, a largely trouble-free test series in terms of off-site fallout.[20]

Not that all was forgotten. In August, Nevada Senator Alan Bible told the members of the Senate that the time was "long overdue" for Nevada to receive some sort of "recognition" for hosting nuclear weapons tests. "I do not want Nevada," he declared, "to become the dumping grounds of an experimental atomic testing program." Aware of

Nevada Senator Alan Bible. Source: Special Collections, University of Nevada-Reno Library.

the importance of testing to the national security, Bible noted, Nevadans had "at all times held their objections to a minimum." This was not because they were "necessarily secure from all danger" but because they were patriots and supported their country. The senator suggested that the AEC establish in Nevada "experimental laboratories to be used in advancing the peaceful applications of atomic energy, or for the construction of a nuclear reactor for the production of power."[21]

Bible was being somewhat disingenuous. Nevada, and Las Vegas in particular, had reaped considerable economic benefits from construction and maintenance at the test site and the hosting of test participants. In 1952, President Truman designated the Las Vegas valley a "critical defense area," making it eligible for federal housing and infrastructure benefits. Nuclear weapons testing, in short, played a major role in the city's prosperity and population growth. Nevada politicians generally recognized this fact and fully supported activities at the test site. "It's exciting to think that the sub-marginal land of the proving ground is furthering science and helping national defense," observed Governor Charles Russell in 1952. "We had long ago written off that terrain as wasteland, and today it's blooming with atoms."[22]

Nevada Governor Charles Russell. Source: Nevada Historical Society.

When protest against nuclear weapons testing finally arrived in southern Nevada, not surprisingly it was largely a non-Nevadan affair. National concern over nuclear weapons and world-wide fallout remained high, and, during the Plumbbob series, outside protesters made their initial appearance in the state. On June 17, a lone picketer, an associate editor for the New York-based *Catholic Worker*, appeared at the AEC offices at 1235 S. Main Street in Las Vegas. The picketer, who also was engaging in a thirteen-day fast, carried a large sign headed "Stop Atomic Tests!" and containing quotations from Pope Pius XII. A larger, more coordinated protest effort took place when, in late July, the National Committee for Non-Violent Action against Nuclear Weapons, a group, also New York-based, composed primarily of Quakers, university students, and peace workers, opened offices in Las Vegas and announced plans to deliberately violate the law by trespassing on the test site. Describing as a "hollow mockery" the AEC's decision to schedule a test between August 6 and 9, the anniversary dates for Hiroshima and Nagasaki, the committee declared that its act of civil disobedience would be "undertaken in a spirit of prayer and from leadings of conscience." On August 6, some thirty members of the group gathered outside the Mercury gate to protest "the senseless folly" of atomic tests. Eleven members crossed over onto the test site and quickly were arrested, charged, convicted, and given one-year suspended sentences, with the understanding that there would be no more attempted entries. "Core of Protest Is Broken" headlined the Las Vegas

Franklin shot cloud, with blimp in foreground illuminated by flare, June 2, 1957. Source: DOE, NNSA-Nevada Site Office.

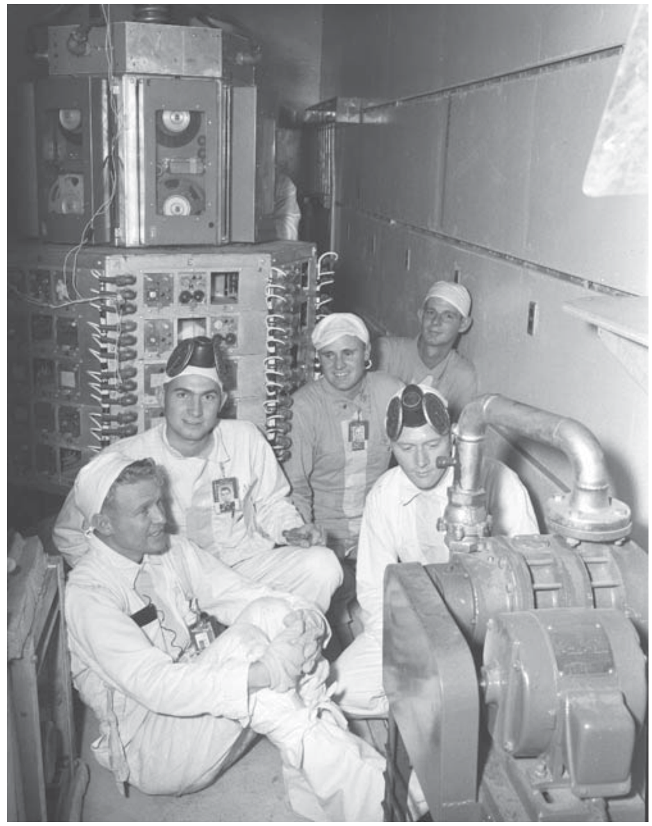
Review-Journal, complaining that the "worldwide publicity" from the affair would give the Soviets the opportunity to "unleash a new barrage of propaganda against the United States as a nation where the less wealthy persons are persecuted." Less strident and more uncertain, Greenspun observed that "these people" were "willing to walk upon the testing grounds while the bombs are being detonated" in order to "avert an atomic arms race." "They are ready to give up their lives for their beliefs," he noted. "How many of us have the same courage?"[23]

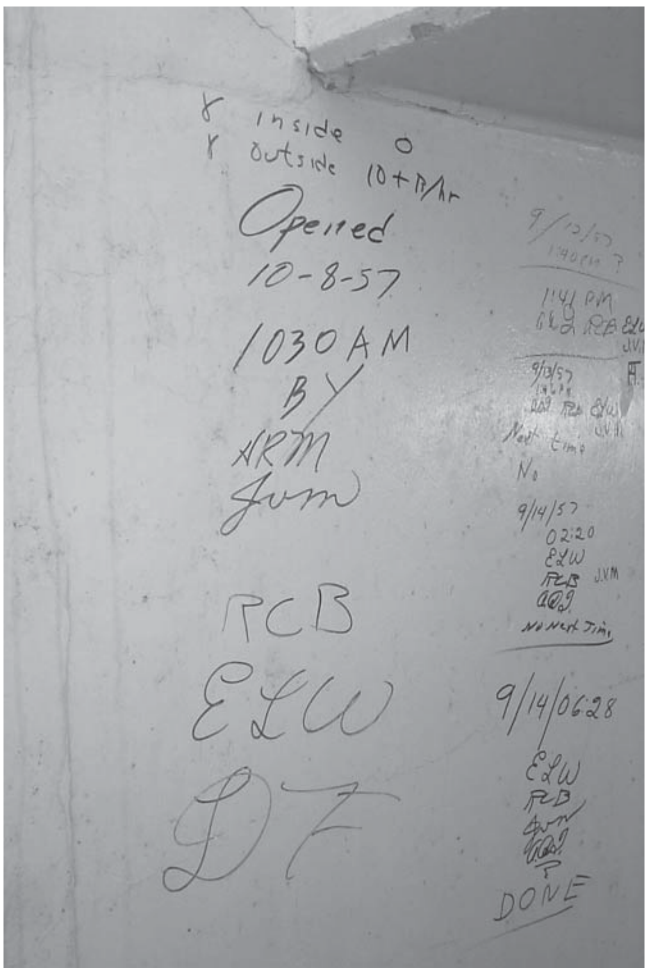
Other uninvited Plumbbob visitors were bent simply on site-seeing. Largely unaffected by the fallout controversy, "atomic-bomb watching" tourism actually flourished. In a lengthy article describing the ins and outs of finding the best vantage points for what "generally is a breath-taking experience," the New York *Times* noted that the AEC for the first time had released a partial schedule so that tourists could "adjust itineraries accordingly." There was, the newspaper assured its readers, "virtually no danger from radioactive fall-out."[24]

Plumbbob: Fizzles, Evacuations, Misfires, and Hood

Operation Plumbbob proceeded, as the historian Barton Hacker has noted, "with scarcely

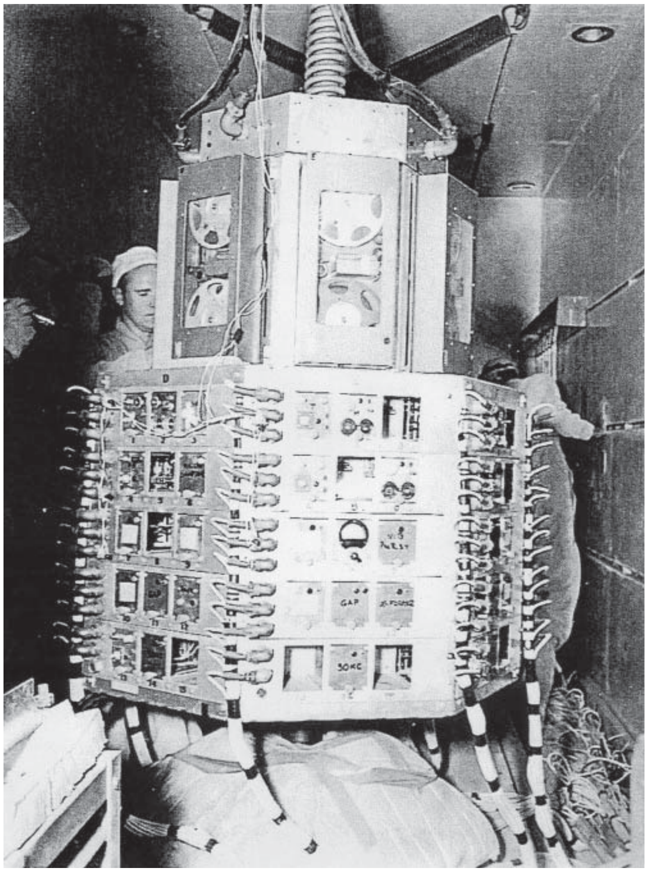
Fizeau Test Bunker



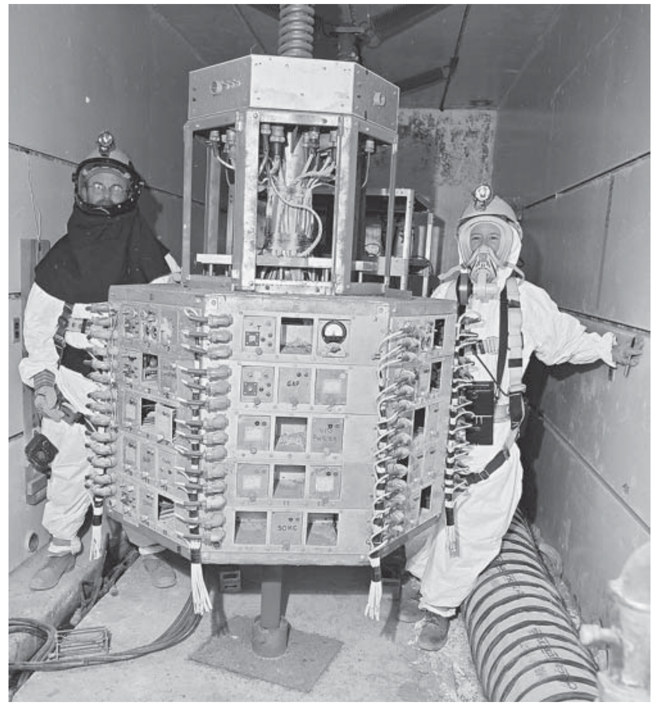


For the Fizeau test, a bunker was located directly beneath the 500-foot tower. The bunker served as the foundation for the tower and the "first vacuum line-of-sight experiments" conducted at the test site involving the vulnerability of various components to radiation and blast effects. Although the outside dimensions of the bunker were 72-1/2 feet long, 30 feet wide, and 26-1/2 feet high, the inside space was drastically reduced by the 10-foot-thick concrete walls and ceiling and 7-foot-thick concrete floor. Original crew, above, is shown with diagnostic equipment in the bunker. The approximately 5-ton steel bell hatch, top left, was set over the entrance prior to the event, and the bunker was backfilled and covered with 5 feet of soil. On September 14, 1957, the tremendous pressure unleashed by the 11-kiloton Fizeau detonation pressed the entire bunker 2 feet deeper into the ground. Graffiti on the bunker wall, bottom left, indicates that when the bunker was re-entered on October 8 considerable radioactivity remained outside the bunker but none within. Source: William Gray Johnson, *A Historical Evaluation of the T-3b Fizeau Bunker, Area 3, Nevada Test Site, Nye County, Nevada*, SR082201-1, Desert Research Institute, February 2002, and Atomic Testing Museum.

Preserving America's Nuclear Testing Heritage



The Fizeau test bunker housed instrumentation—oscilloscopes, oscillographs, and a host of other data-gathering equipment—that measured yield and performance. In November 2000, a team of contractors working for the U.S. Department of Energy surveyed the bunker to determine its present contents. Among other artifacts, they found a largely intact spring-loaded instrument package, known as a "pogostick," designed to bounce up and down to absorb the shock of an overhead explosion and thereby survive the impact while recording information. Above, the pogostick in the bunker in 1957. Top right, November 2000 survey team members, Desert Research Institute Archaeologist Bill Johnson, left, and Bechtel Nevada Industrial Hygienist Angela Ray, dressed in anti-contamination gear, which was required as a precaution but proved unnecessary, examine the pogostick. Following the survey, the pogostick was removed from the bunker and placed on display, bottom right, at the Atomic Testing Museum in Las Vegas, Nevada. Source: John Doherty, "Preserving Pogosticks & Tales of a Triggerman: Adventures in Cold War Archaeology," *DRI News* (Spring 2002) at http://newsletter.dri.edu/2002/spring/pogostick.htm, and Atomic Testing Museum.



a mishap." This does not mean that the series was uneventful or trouble free. The second shot, Franklin, designed by Los Alamos with a predicted yield of 2 kilotons, was a fizzle, yielding only 140 tons and producing, as the press noted, a "brief, non spectacular flash and a small, round, fluffy cloud." After Los Alamos made adjustments to the device, it was successfully re-fired as Franklin Prime, yielding 4.7 kilotons.[25]

Wilson, the fourth shot, forced the evacuation of the Control Point. Suspended from a balloon and detonated on June 18 at a height of 500 feet above Yucca Flat, Wilson produced a yield of ten kilotons and a fallout cloud, carried by light winds out of the north, which headed toward the Control Point, some twelve miles south of ground zero. Five minutes after the blast, the evacuation order was given. Eighty-two military observers and a similar number of scientists, in the words of the Albuquerque *Tribune*, "hopped into buses and cars and retreated to their headquarters at Camp Mercury." Affected areas of the test site were cleared within thirty minutes. According to AEC officials, the evacuation was more of a drill than a necessity. North winds had been predicted prior to the test, and, since the scientific crew was in need of an evacuation drill and the fallout, they believed, would not be a health hazard, officials went ahead with the test. The evacuation, in any event, was unnecessary, noted an AEC spokesperson, because the fallout was far below the level that constituted a health hazard.[26]

Diablo, the planned fifth shot, proved to be a misfire. When the countdown on the tower shot at Yucca Flat reached zero in the early morning hours of June 28, nothing happened. Even more embarrassing and potentially dangerous, Diablo was one of the nine open shots with several hundred observers in attendance, including a dozen foreigners from Britain, Canada, Norway, Italy, Spain, and Nationalist China. In addition, as part of a Desert Rock event, 2,000 marines huddled in trenches two miles from ground zero.

Representatives of five European nations watch the cloud formed by the Kepler shot at Yucca Flat, July 24, 1957. Source: DOE, NNSA-Nevada Site Office.

Cloud from the Lassen shot five seconds after detonation of the first device to be fired from a captive balloon. The test was fired from a height of 500 feet at Yucca Flat. Fallout from the test, announced as well below nominal in yield, was recorded only in the immediate test area. Helium-filled balloon was 67 feet in diameter, held in place by four steel cables, winches for which were remotely controlled. Source: DOE, NNSA-Nevada Site Office.

Brush fires burn on hillsides to the left of the Smoky shot, August 31, 1957. The cloud is shown as it begins to separate from the stem. Source: DOE, NNSA-Nevada Site Office.

With the failure of the device to detonate, a Las Vegas *Review-Journal* reporter at News Nob noted, "an awesome silence fell over the whole of Yucca Flat." After a few seconds, voices cried out, "Leave the goggles on, don't take them off yet." Then the loudspeaker broke in, announcing, "There has been a misfire. Hold your positions." There was no panic, observed the reporter, only the occasional "wisecrack"—"Man, that sure was a clean bomb, no fallout from that one"—as they waited for "twenty tense minutes" while officials determined that the chance of an accidental explosion was negligible. The site was then hastily cleared, and three volunteers climbed the 500-foot tower, the elevator having been removed by a crane prior to the planned detonation, to disarm the device. Forty-five minutes after reaching the tower cab, they tersely reported, "Device disarmed," which was "the signal for the tense scientists in the control point to relax." Officials determined that the misfire was attributable to a power failure, apparently from a severed connection caused by the crane removing the elevator. Diablo successfully detonated on July 15.[27]

Hood is noteworthy in that it was the largest atmospheric test, with a yield of 74 kilotons, ever conducted at the Nevada Test Site. Suspended from a balloon, Hood was detonated at 4:40 a.m. on July 5 at a height of 1,500 feet above the desert floor in the northeastern part of Yucca Flat. "LARGEST A-BOMB TOUCHES OFF SPECTACULAR DISPLAY," headlined the *Review-Journal*. Hood, noted the R-J's reporter, caused even "veteran observers 13 miles from ground zero to gasp with awe at its terrible immensity." Observers at News Nob were "bathed by a wave of heat" from the initial flash and then, a minute later, "felt ears pop with the crack of the pressure waves." The fireball, the reporter related, "fulminated for nearly a half minute as it shot upward and then developed into the traditional atomic cloud whose ultimate height hit 49,000 feet at the top and 30,000 feet at the base." Several square miles of desert brush ignited around ground zero. The light from the blast was visible from the Canadian to the Mexican border and far out into the Pacific Ocean. Twenty-five minutes after the detonation, two "jarring shocks," about ten seconds apart, rattled windows and shook structures in Los Angeles. Closer by, Groom mine, some twenty miles to the northeast, suffered broken windows and door frames and "bulges" in metal buildings. Off-site fallout from Hood was reported as being light.[28]

Plumbbob: Desert Rock and Weapon Effects

Although unbeknownst at the time, Desert Rock VII and VIII during the Plumbbob series proved to be the last Desert Rock exercises at the Nevada Test Site. Involved to varying degrees in all twenty-four of the Plumbbob tests, the armed forces shuttled in and out more than 20,000 troops at Camp Desert Rock. Personnel from all the services participated, as well as over three hundred Canadian observers and a unit of the Calgary-based Queen's Own Rifles.[29]

Military maneuvers were conducted after the Hood and Smoky shots. Officials shifted maneuvers originally scheduled for the Diablo shot to Hood when Diablo failed to fire. The largest military exercise ever performed at the test site, Hood involved over 2,000 marines, most of whom were entrenched nearly five kilometers from ground zero at the time of the shot. The blast collapsed some of the trenches, burying at least one soldier who had to be dug out. After a fifteen minute wait, some of the marines headed in the direction of ground zero. Others waited for helicopters, delayed for an hour because dust and smoke limited visibility, to take them to a landing zone located away from ground zero. Once there, the marines launched a mock attack. The Smoky maneuvers, conducted on August 31 with over a thousand troops including the Queen's Own Rifles, also involved helicopter-lift to a combat area. Due to heavy predicted fallout, the troops were not entrenched, as planned, 4,400 yards from ground zero. As a result, tests by a team of psychologists of the reactions of troops before and after witnessing the shot at close range were cancelled and rescheduled for the Galileo shot. Smoky later gained some notoriety when, in 1980, the Center for Disease Control (CDC) reported a cluster of nine leukemia cases among the then-identified 3,224 participants at the shot, five more than the expected rate of four. Measured doses for the Smoky participants as a group, however, were too low to explain the overage. For Plumbbob as a whole, more than 8,400 military personnel recorded exposures but only 16 apparently exceeded the military's five-roentgens limit.[30]

Two of the twenty-four Plumbbob shots, Priscilla and John, were Department of Defense weapon effects tests. The Priscilla shot used a

View from Mercury looking north one half hour after 6:30 a.m. June 24, 1957, Priscilla shot, at Frenchman Flat. The mushroom cloud is being blown off to almost due east and is rapidly dispersing into an air mass. Source: DOE, NNSA-Nevada Site Office.

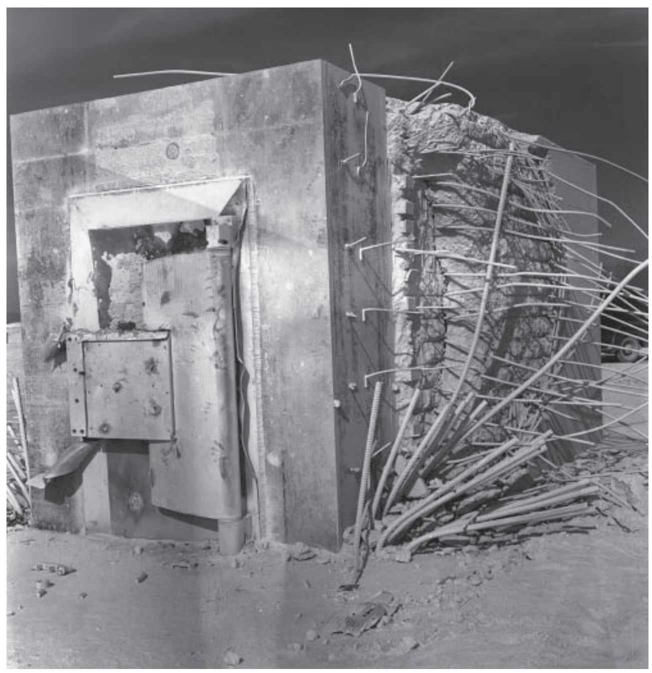
stockpile weapon with predictable yield in order to measure effects primarily on military and civilian equipment, material, and structures. Suspended from a balloon, the device was fired at 6:30 a.m. on June 24, yielding thirty-seven kilotons at a height of 700 feet above Frenchman Flat. The military, the Los Alamos and Livermore laboratories, and the Federal Civil Defense Administration conducted a total of eighty-two "scientific projects" at Priscilla, making it one of the most extensive weapon effects

Plumbbob Effects Experiments

Reinforced concrete blast door for the dual-purpose garage and mass shelter is at left. The view, looking outward, shows the front part of the door, which is four feet thick and weighs about 100 tons. Air-tight closure of the door is accomplished using an inflated rubber gasket that fits in a metal groove running around the inside of the door frame. Source: DOE, NNSA-Nevada Site Office.

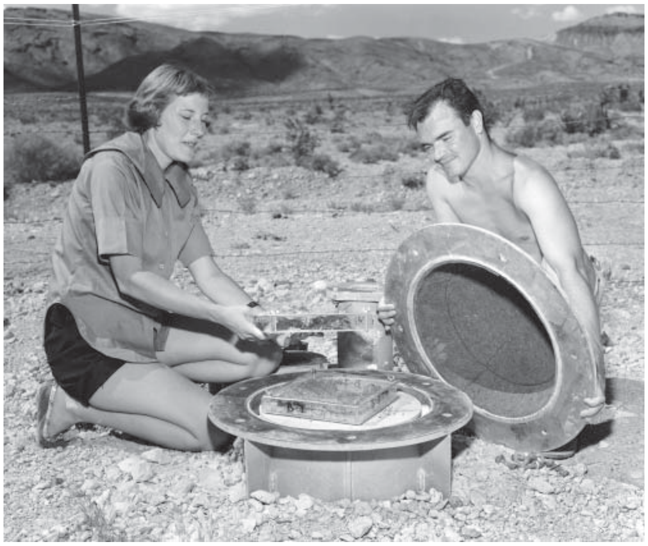
Four of five doors formed of standard commercial materials satisfactorily withstood the Priscilla blast at a high pressure range. One door was ripped out of its frame, and the surface of all of them was scorched and blackened by the thermal wave. From left to right, the doors are: 1) a solid plywood door, 2) a wood plank door made of a single layer of horizontal 2-inch x 4-inch lumber, 3) a cellular steel door formed of commercial sheet steel Q-panels set in and welded to a rolled steel channel frame, 4) a hollow plywood door that was blown out of its frame into the test shell, and 5) a steel plate door fabricated by welding an outer panel of one-quarter-inch thick steel plate and an inner cover of 20-gauge steel to a steel angle frame stiffened with horizontal steel T-bars. Source: DOE, NNSA-Nevada Site Office.

Automobile ramp leading down to entrance of the underground dual-purpose garage and mass shelter. Source: DOE, NNSA-Nevada Site Office.



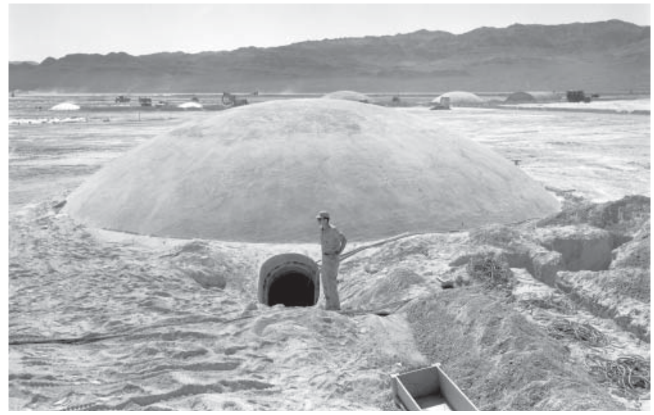
Mosler Safe Company's standard safe door and reinforced concrete vault assures that "vital records and valuables" are protected during Priscilla blast. Trim on the steel door, facing ground zero, was loosened by the blast, but the operation of the massive steel closure was not impaired. Slabs of reinforced concrete, added to the sides of the steel-lined vault after the latter had been constructed, were ripped off. Source: DOE, NNSA-Nevada Site Office.

Plumbbob Effects Experiments

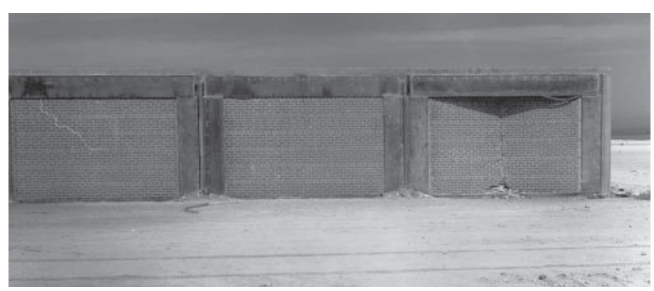


Mice, in special aluminum and plastic cages, are placed in an aluminum blast shield box. The blast resistant device is ventilated by a fan in the pipe (in background). Batteries (out of view to the left) operate the fan. The mice, protected against blast, heat, and shock, were placed at various distances from ground zero during the Franklin shot to test exposure to radiation. Source: DOE, NNSA-Nevada Site Office.

A twenty-five pound pig is removed from an aluminum barrel used during the Franklin shot's medical effects test. The pig containers were positioned at various distances from ground zero to measure radiation doses. Source: DOE, NNSA-Nevada Site Office.



Dome-type structures, 150 feet in diameter, were proposed by the Federal Civil Defense Administration as an effective and economical means of providing mass shelter. Down-sized dome shelters, 50 feet in diameter, one of which is shown above, were built at Frenchman Flat and subject to nuclear blast at approximate overpressure ranges of from 20 to 70 pounds per square inch. The reinforced concrete domes, of six-inch constant shell thickness, were exposed to the Priscilla shot without the aid of earth cover. The dome structure shown post-shot in the bottom photo was "expected to fail" under the stress of the high overpressures. Source: DOE, NNSA-Nevada Site Office.



Three wall panels of brick and other clay products following the Priscilla shot. The panel on the left is a twelve-inch thick solid brick wall without reinforcement. The center panel is twelve-inch thick solid brick reinforced with one-quarter inch steel rods. The panel on the right is four-inch thick brick backed by eight-inch thick tile. Source: DOE, NNSA-Nevada Site Office.

tests ever attempted at the test site. Among the structures tested were an underground, 90-foot square dual-purpose parking garage and mass shelter, ten concrete dome shelters 50 feet in diameter, two aluminum dome shelters 20 feet in diameter, a brick masonry above-ground shelter, and a reinforced concrete bank vault. Biological experiments included the placement of 719 pigs at eleven locations at varying distances from ground zero in an attempt to define more specifically effects on humans.[31]

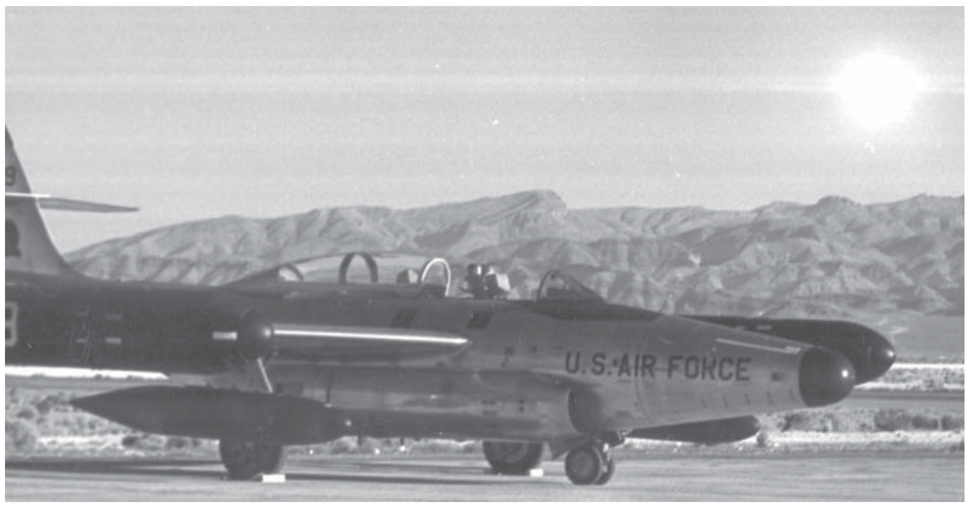
The John shot involved an airburst detonation of a nuclear warhead delivered by an air-to-air MB-1 Genie rocket launched from a F-89J interceptor aircraft. As an effects test, the Department of Defense wanted information on the dosage that would be received by the pilot, aircraft response to the blast, and delivery maneuvers required for the rocket. "Operational safety problems" with the shot, from the beginning, were a concern. Instead of using a target, test planners decided that the missile would be "armed to burst at a predetermined point in space." The flight path of the aircraft and the rocket, over the north end of Yucca Flat, were such that if the warhead failed to fire the rocket would "impact in a safe area" of the test site. If this occurred, an expected "one-point detonation" would cause no off-site fallout problems. Although the probability of a full-scale ground detonation was thought to be "very small," planners were sufficiently concerned about safety issues to conduct a one-point detonation safety test, Project 57, prior to Plumbbob on April 24, 1957.[32]

John took place at 7:00 a.m. on July 19. The delivery aircraft, accompanied by a highly instrumented F-89D alongside and an "alternate delivery aircraft" trailing behind, came in at an elevation of about 19,000 feet. Once the rocket was released, the two lead aircraft veered off sharply in opposite directions. The rocket traveled 4,240 meters in four-and-one-half seconds, and the warhead detonated at about 20,000-feet elevation

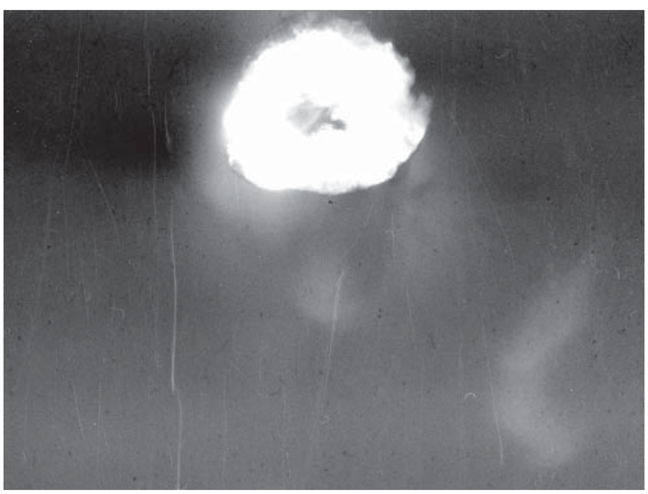
Genie MB-1 air-to-air rocket. Source: Atomic Testing Museum.

John Shot: Delivered by Air-to-Air Rocket

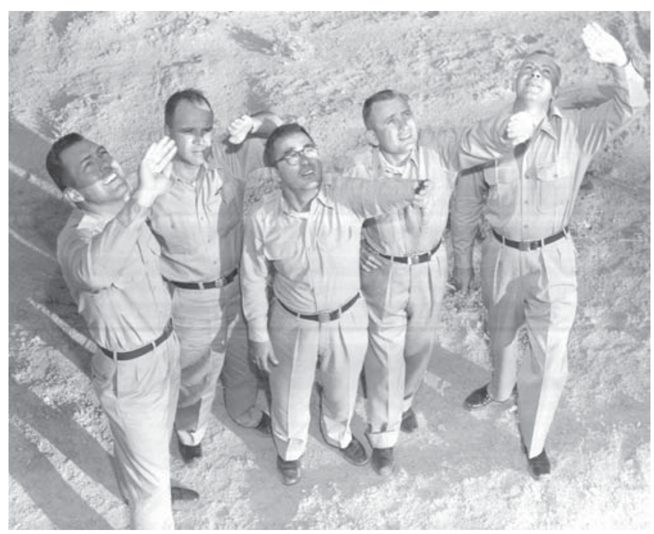
F-89J Scorpion has just launched the air-to-air MB-1 Genie rocket with the live warhead. Source: DOE, NNSA-Nevada Site Office.



The flash of the exploding nuclear warhead of the air-to-air rocket as seen at 7:00 a.m. July 19, 1957, from Indian Springs Air Force Base, some 30 miles away from the point of detonation. A Scorpion, sister ship of the launching aircraft, is in the foreground. Source: DOE, NNSA-Nevada Site Office.



Smoke-ring cloud forming above Yucca Flat, photographed approximately 5 miles from the detonation. Source: DOE, NNSA-Nevada Site Office.



Five Air Force officers who volunteered to be observers at ground zero beneath the John detonation mug for camera prior to the shot. During the burst, they stood "directly under the burst sans helmets, hats, caps, goggles, or protective clothing to illustrate that the civil populace need fear no harmful effects were it necessary to use the atomic rocket in a tactical situation." Source: DOE, NNSA-Nevada Site Office.

with a yield of about two kilotons. The lead aircraft were both about 3,350 meters distant at the time of detonation. Actual "gust loads" on the wings were larger than predicted, but the aircraft returned safely. Exposure to pilots and crew were between 1.1 and 2.2 roentgens. Five volunteer Air Force officers stood at ground zero directly below the burst to demonstrate that air defense could take place without harm over a populated area. No increase in radiation levels were detected at the test site.[33]

The Navy also conducted effects tests on ZSG-3 airships. Four of these lighter-than-air, Zeppelin-like airships were sent to the test site. Prior to any shot, two airships were destroyed when a "violent windstorm" tore them loose from their mooring masts on Yucca Lake. The remaining two airships participated in the Franklin shot. Moored with its tail to the burst at 5,460 meters from ground zero, and despite the fact that Franklin was a fizzle with a yield of only 140 tons, one airship experienced a structural failure of the nose cone when it smashed into the mooring mast and had to be deflated. The other airship survived and was retested at the Stokes shot. Mooring lines were released 20 seconds before the arrival of the shock wave to allow the airship to float free. Upon arrival of the shock wave, the airship broke in half and crashed. The project, the Defense Nuclear Agency later noted, "exposed the structural vulnerability of an airship when subjected to a nuclear detonation."[34]

Underground Testing: Caging the Dragon

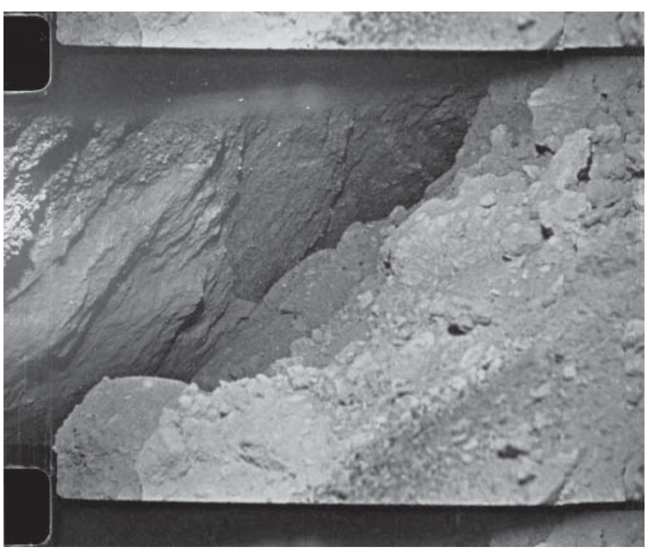
Fallout essentially is radioactive air pollution. Atmospheric testing's solution to this pollution problem had always been dispersal and dilution. As fallout dispersed into the atmosphere it would become so diluted as to render levels of radioactivity insignificant and therefore harmless. Worldwide concern over fallout and rising levels of radioactivity, however, made atmospheric testing increasingly moot, and by 1956 the "testing community" began to look at alternative modes of testing that would contain the radioactive pollution or at least keep it from getting into the atmosphere. These included testing deep in space, deep in the ocean, deep under the ice cap, either in Antarctica or in Greenland, and, what would become the preferred solution, deep underground. At the Livermore laboratory, David Griggs and Edward Teller, in a landmark paper entitled "Deep Underground Test Shots," concluded that the "long-term radiologic hazard" and the "seismic hazard to off site structures" from underground shots would be "nil." Yield could be calibrated by "seismic and time-of-shock arrival," they contended, and the radiochemistry of the explosion determined by "core drilling the molten sphere." Costs of "drilling a hole sufficiently large and deep" were estimated to be "comparable to the cost of erecting a tower." Griggs and Teller recommended that a low-yield shot be detonated "at such a depth that it will be contained" during the next Nevada test series, Plumbbob.[35]

The Atomic Energy Commission found the test method "very attractive." The commissioners, especially Chairman Strauss and Thomas Murray, nonetheless were concerned about the safety aspects. No one was certain the shot could be contained, and there were lingering fears that the blast would trigger an earthquake for which the AEC, and nuclear weapons testing, would be blamed. At Strauss's insistence, Livermore put together a team that included non-government seismologists to review the underground test. The seismologists concluded that the proposed shot, given its projected yield of 1.7 kilotons, would "do nothing seismically." Informed at a briefing on April 17, 1957, that the Livermore shot, Rainier, would not cause an earthquake, Strauss asked how large of a yield could be fired safely at the Nevada Test Site. "About a megaton," one of the seismologists replied. Following the briefing, the Commission approved going ahead with Rainier.[36]

Navy Blimp

Navy air ship, ZSG-1, top, tied up at mooring platform at Yucca Flat, having just arrived from Lakehurst (NJ) Naval Air Station. The tail, or after section, bottom, of a Navy blimp is shown with the Stokes shot cloud in background. Blimp was in temporary free flight in excess of five miles from ground zero when collapsed by the shock wave from the blast. The airship was unmanned. On ground to the left are remains of the forward section. Source: DOE, NNSA-Nevada Site Office.

Los Alamos, however, would conduct the first underground test. Alvin Graves, testing chief at the laboratory, had reached conclusions on underground testing similar to those of Griggs and Teller. "There isn't any doubt about it," he told a colleague in 1956. "If testing is to proceed, we're going to have to go underground." An opportunity arose with the one-point detonation safety tests scheduled for Plumbbob. Anticipating "some nuclear yield" from the tests, as high as .2 kiloton with the first, Pascal-A, Los Alamos testers decided to place the Pascal-A device at the bottom of a 500-foot deep shaft located in Area 3 of Yucca Flat. The shaft was not stemmed—filled in with dirt or plugged—but there was a lid and a five-foot thick concrete collimator part way down the shaft. Difficulties in getting the collimator down the shaft delayed the test into the evening hours of July 25, and, instead of waiting until the next morning, the decision was made to "just shoot it" at about midnight. Fired in the field using a "little handset" and in coordination with Control Point officials, the test blew the lid and the collimator out of the shaft and produced "blue fire" that "shot hundreds of feet in the air." It was, as one observer put it, "the world's finest Roman candle." The lid and collimator were never found, but the underground test successfully reduced the amount of fallout by a factor of ten. A second underground safety test, Pascal-B, again unstemmed, was conducted a month later.[37]*

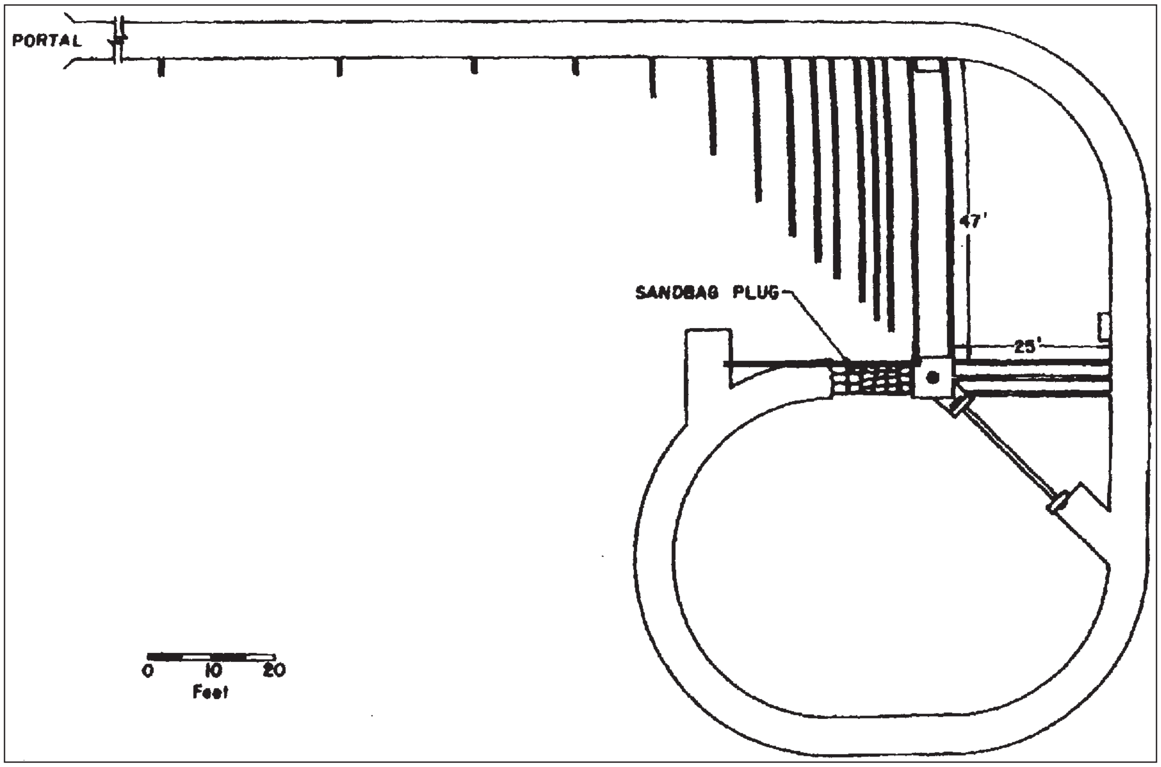


Pascal-A cavity following first underground test. Source: DOE, NNSA-Nevada Site Office.

For Rainier, Livermore used a horizontal tunnel and not a vertical shaft. A tunnel, laboratory scientists believed, would provide easy access to the device at all times, facilitate diagnostics, and more readily contain radioactive debris near the point of detonation. Drilled into volcanic tuff on the side of what would become known as Rainier Mesa at the north end of the test site, the Rainier tunnel was shaped like a buttonhook with the device placed at the eye of the button. The logic was that the radioactive debris would come "charging around the tunnel . . . and by the time it went around the spiral, the seismic shockwave would have come across and closed off the tunnel, trapping the radioactive debris." Ground zero was located 1,672 feet horizontally from the side of the mesa and 899 feet below the top. With geophysicists and seismologists the world over eagerly anticipating the shot, the AEC agreed to fire the device within a tenth of a second of a predetermined time. Detonated at precisely 10:00 a.m. on September 19, Rainier produced a cloud of dust from the surface of the ground being shaken by the blast but no vented radioactivity or unwanted earthquakes. Press response was generally positive, with some scientists being quoted to the effect that the heat generated could fuse the rocks and create rubies, sapphires, or even diamonds.[38]

Livermore scientists were anxious to drill back to the ground zero blast site, not to retrieve precious gems but to conduct radiochemical analysis of the blast and to determine exactly what

* Robert Brownlee, a Los Alamos astrophysicist who participated in the Pascal safety tests, calculated that the lid when it was blown out of the shaft was traveling at "six times the escape velocity of the earth." Brownlee later noted that he has sometimes been credited with launching the first man-made object—a "manhole cover"—into space. Robert R. Brownlee, "Learning to Contain Underground Nuclear Explosions," June 2002, at http://nuclearweaponarchive.org/Usa/Tests/Brownlee.html.



Rainier tunnel configuration. Source: James Carothers, et al., *Caging the Dragon: The Containment of Underground Explosions*, DOE/NV-388, 1995, p. 42a.

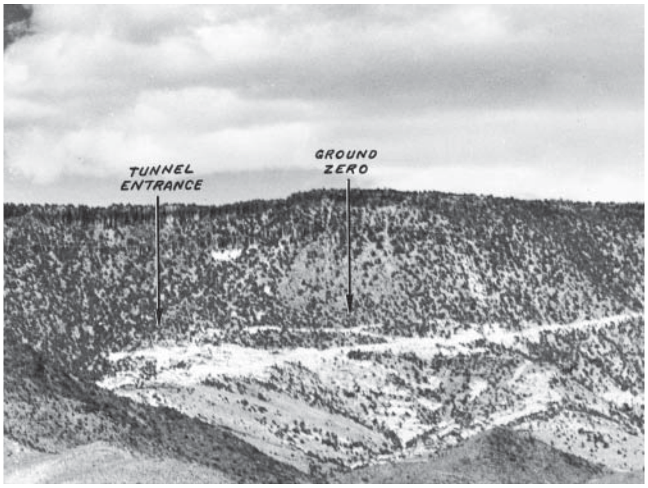
had taken place in the surrounding rock. Scientists were unsure what they would find. Although all thought some molten rock had been produced, opinions as to what existed in the aftermath ranged from a bubble of radioactive-debris laden molten rock two meters across to a 100-meter void with a thin shell of glass lining containing the debris. Drilling from the top of the mesa, begun two months after the shot, went slowly, partly because the drillers feared that they were drilling into something like a volcano. (Indeed, Livermore personnel were sent to Hawaii to drill into molten lava in rehearsal for the main event.) Drilling also began from within the tunnel. What they eventually found was that the blast initially created a gas-filled cavity with a radius of about 55 feet. A molten, glass skin, about 5 inches thick and containing the radioactive debris, surrounded the cavity. The remaining rocks outside the skin, shattered to rubble to a radius of 130 feet, collapsed within minutes of the blast, leaving the radioactive debris, covered with rock, at some 55 feet below the actual shot point.[39]

The Pascal and Rainier experiments proved to be major successes. By the end of 1958, underground testing was a well-established, if far from perfected, technique. "The dragon was caged," Livermore tester James Carothers later recalled, "and his foul breath no longer polluted the air."[40]

Test Ban: Lawrence and Teller Enter the Fray

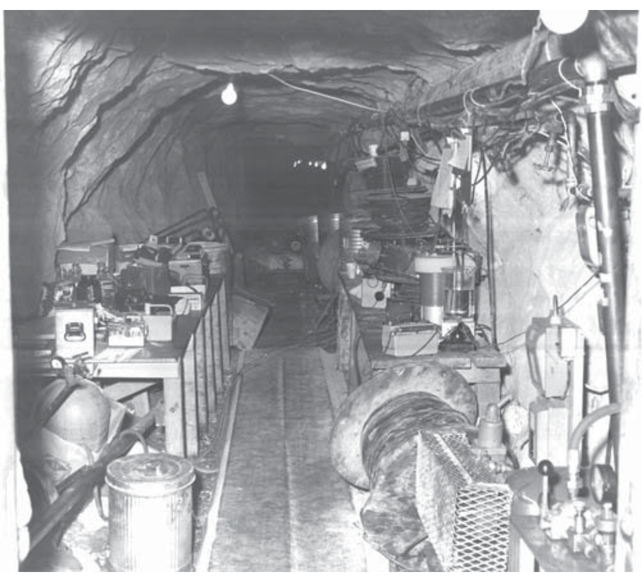
When Eisenhower on June 19, 1957, expressed his "delight" in the possibility of arranging a temporary suspension of nuclear weapons tests, the testing community responded with considerable unease. On June 20 and 21, Ernest Lawrence and

Rainier Underground Test



Face of the mesa at the northern edge of Yucca Basin in which Rainier was detonated at 10 a.m., Thursday, September 19, 1957. Ground zero was about 900 feet from the top of the mesa and about 1600 feet from the outside slope of the mesa. The long white diagonal slash is a road to the top of the mesa. Source: DOE, NNSA-Nevada Site Office.

Mouth of the Rainier tunnel prior to the shot while construction was still in progress. Large pipe at left is part of the blower system to supply fresh air to workmen in the tunnel. Source: DOE, NNSA-Nevada Site Office.

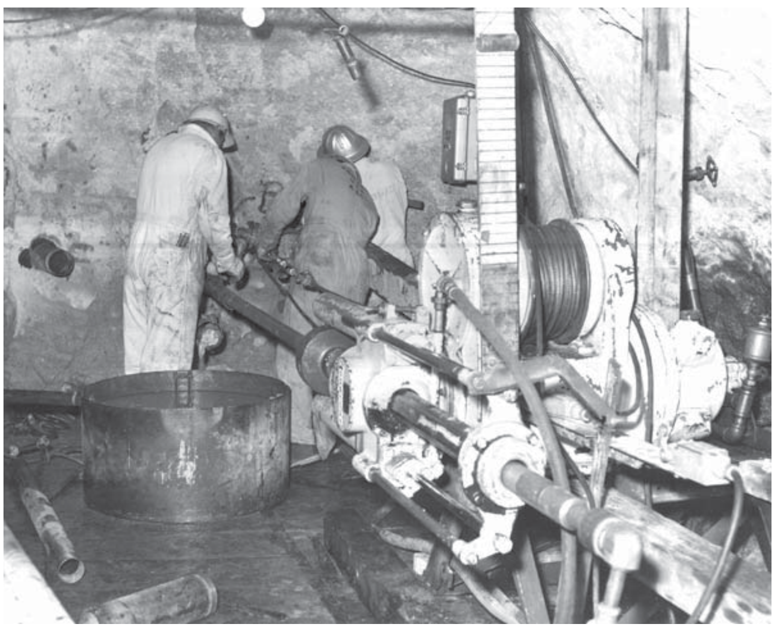


Diagnostic instruments in the diagnostics room of the Rainier tunnel. Source: DOE, NNSA-Nevada Site Office.

Post-shot view of a portion of the Rainier tunnel not far from its entrance with ventilation duct (large pipe) and diagnostics cable racks at left. Source: DOE, NNSA-Nevada Site Office.

Rainier Underground Test

Dust following September 19, 1957, detonation raised both by the shock wave traveling to the surface and by rocks rolling down the side of the mesa. Heat-created air currents raised the dust several hundred feet into the air. Monitors found no traces of radiation in the dust. Source: DOE, NNSA-Nevada Site Office.



Crew setting up a drill in the room where tunnel ended following the test to recover a core sample from the shot area. Source: DOE, NNSA-Nevada Site Office.

Pieces of weathered rock dislodged from the rim of the mesa rolled onto the road, which leads from near the tunnel entrance up the side of the mesa to the mesa top. Source: DOE, NNSA-Nevada Site Office.

Teller, founders of the Livermore laboratory, accompanied by Mark Mills, associate director at the lab, appeared before the Joint Committee on Atomic Energy. The scientists argued that it would be "a crime against the people" to stop testing. They knew how to build "dirty" bombs of almost unlimited size, Teller explained, but smaller fusion weapons using plutonium remained to be perfected. "If we stop testing," Lawrence warned the committee, "well, God forbid, if we have to have a war we will have to use weapons that will kill 50 million people that need not have been killed." As an example, Teller noted that an attack on Vladivostock could kill thousands of Japanese as fallout moved eastward. He also told the committee that, in the event of a test ban, the Soviets could use various techniques so that even megaton underground tests might not be detected. Observing that fallout hazards from current testing were negligible, the three concluded that it would be "wrong," "misguided," and "foolish" to ban the development of weapons that could save millions.[41]

Shocked by what they had heard, the Joint Committee arranged for the three scientists to meet with Eisenhower. In a forty minute meeting on June 24, they repeated their arguments against a test ban, with Lawrence again noting that the failure to develop clean weapons "could truly be a 'crime against humanity.'" The President calmly reminded them that in the mounting worldwide debate over testing the United States could not "permit itself to be 'crucified on a cross of atoms.'" The "fearsome and horrible" reports about fallout, he added, were having a substantial effect. Eisenhower, nonetheless, was profoundly shaken by what the Livermore scientists had to say. The next day, he told Dulles that he had received suggestions from so many people that he was confused. Strauss and the scientists, Eisenhower added, made "it look like a crime to ban tests." When Dulles reminded him, however, that "we are irrevocably committed to this," Eisenhower replied that he knew that.[42]

AEC Chairman Lewis L. Strauss confers with scientists from Livermore laboratory following June 24, 1957, meeting with the President to discuss "clean" weapons. Left to right: Ernest O. Lawrence, Strauss, Edward Teller, and Mark Mills. Source: Dwight D. Eisenhower Presidential Library.

Whatever the President's long-term commitment to a test ban, the testing community as the summer of 1957 wore on no doubt took some comfort from the short-term prospects for an international agreement. Testing by all three nuclear powers was proceeding at a record pace. The ongoing Plumbbob series was at its height, and the United States looked forward to more tests—the Hardtack series—in the Pacific in spring and summer 1958. The Soviets, at the end of August, began a series of tests, some of which were in the megaton range. The British planned a fall series of tests in Australia, with a thermonuclear shot for Christmas Island in November. During 1957, according to one source, the three nuclear powers conducted forty-two tests, compared to nineteen in 1956. Equally important, the London Disarmament Conference began to unravel. Despite the apparent Soviet concession on inspections, negotiations were going nowhere, and, in early September, the conference adjourned without setting a time or a place for the next session.[43]

Hardtack Under Attack

The Atomic Energy Commission, nonetheless, found the proposed Hardtack series in some jeopardy of, if not outright cancellation, at least severe limitation. By spring 1957, planning for Hardtack was well along. Even with a conscious effort to limit the number and yields of shots, Hardtack, by any standard, looked to be extraordinarily robust. Its thirty-one shots—twelve by Los Alamos, fourteen by Livermore, and five by the Department of Defense—and predicted overall fission yield were almost twice that of Redwing. In addition, planners contemplated testing a "clean" twenty-five megaton weapon, which would be ten megatons more than any other device ever tested by the United States. To speed the testing process along, shortening the estimated three month testing period by as much as three weeks, and to decrease the "possibility of fallout reaching the Rongelap Islands," the AEC proposed conducting tests at, in addition to Enewetak and Bikini, a third Marshall Islands atoll, Taongi, an uninhabited "desert island" 285 miles east of Bikini. The military, however, was not enthusiastic about the use of Taongi. Noting the increased logistical costs involved and the "likely public reaction" to adding another test site "in the face of an apparent international trend toward limitation of testing," the Department of Defense told the AEC that tests at Taongi would "not be desirable . . . at this time."[44]

The ambitious Hardtack testing program also gave the Commission pause. Harold S. Vance told his fellow commissioners that the "present climate of world opinion" made it "undesirable for a U.S. test operation to have such a substantial fission yield increase over previous operations." In late June 1957, as a test moratorium seemed more likely, the Commission, with the concurrence of the military, sought to accelerate Hardtack with a somewhat pared back test program. Strauss told Eisenhower that Hardtack would be "limited to essential tests"—still some 25 shots—and would start on April 1, 1958, and be completed within four months.[45]

Eisenhower was appalled. At a meeting with Strauss on August 9, Eisenhower told him that he disliked the number of tests, the length of the test series, and the size of some of the proposed shots. The main dilemma, Eisenhower observed, was "planning and carrying out extensive tests on the one hand while professing a readiness to suspend testing in a disarmament program on the other." Strauss responded that he had "cut in half" the number of tests actually requested by the laboratories and the military, and he agreed with the President that the number was still too large. Strauss also agreed that the duration of the test series seemed long, especially if disarmament talks were ongoing, but weather requirements dictated a lengthy schedule. On the issue of shot size, Strauss stated that the AEC and Department of State agreed there was no need to test "very large" weapons. The requirement to test multimegaton weapons came from the Department of Defense, which wanted to ascertain the size and yield a B-52 bomber could carry. When Eisenhower appeared skeptical about this justification, Strauss proposed limiting all Hardtack shots to a yield no larger than the 15-megaton Castle-Bravo test. The President agreed to this and granted authority to continue planning for Hardtack, but he ordered Strauss to condense the series to the maximum extent possible.[46]

Strauss took his mandate seriously. Following a trip to the Nevada Test Site to view Plumbbob in progress, he complained to Deputy Secretary of Defense Donald Quarles that the weapons program was similar to the affliction-plagued missile development program—too many designs, too much interservice competition, and too much time spent on engineering refinements at the expense of developing radically new approaches. This was, he noted, unhealthy and self-defeating. The laboratories were burdened with programmatic

Deputy Secretary of Defense Donald A. Quarles. Source: National Archives.

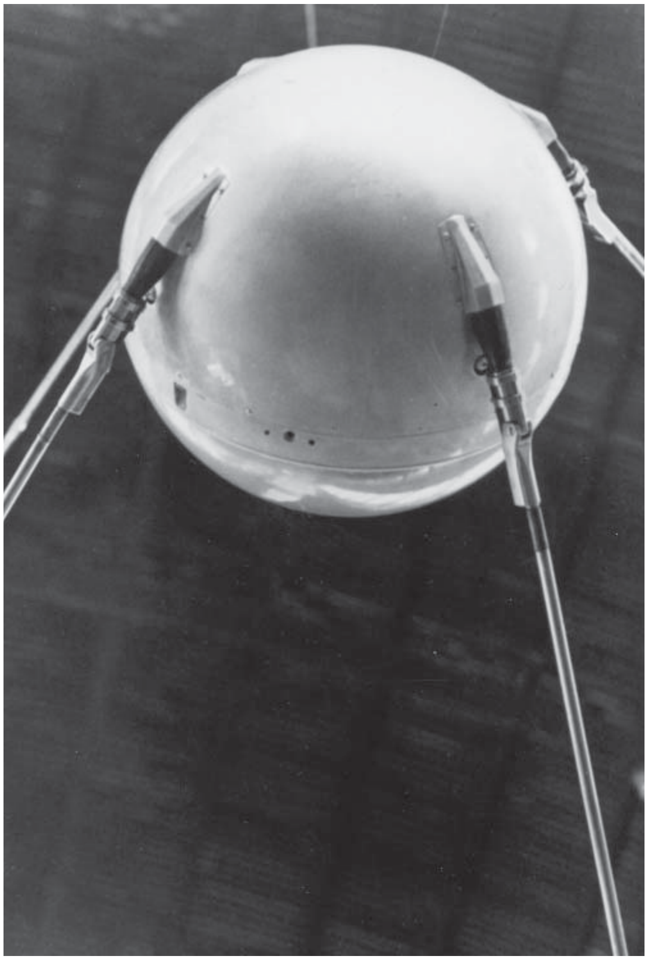
minutiae instead of original work. Although the AEC was not guiltless, Strauss pointed out that the Department of Defense was the primary culprit in the proliferation of unnecessary tests. Passing on to Quarles a clear mandate of his own, Strauss told him that he had assured Eisenhower that he would "not test beyond what is *necessary*."[47]

As if the President's charge was not sufficient, the AEC's Advisory Committee on Biology and Medicine also weighed in on the issue. In a statement on radioactive fallout released to the public on October 19, the committee stated that "it must be assumed that some harm will result from fallout radiation." Testing would bring about a small increase in leukemia deaths and cause some genetic damage that "in the course of time" could be "large in absolute terms." In view of the "adverse repercussions" from nuclear weapons testing, the committee recommended that "tests be held to a minimum consistent with scientific and military requirements."[48]

Sputnik and the Test Ban

The Soviet launch of Sputnik, the world's first satellite in space, on October 4, 1957, sent shock waves across America. Not only was the United States lagging in the "space race," but also the Soviets apparently were ahead in developing ballistic missiles that could carry a thermonuclear warhead. In an effort to reassure the public, Eisenhower appointed James A. Killian, Jr., president of Massachusetts Institute of Technology, as his special assistant for science and technology and made him chair of the newly created President's Science Advisory Committee (PSAC). As an unintended consequence, this would have major impact on the test ban issue. For the first time, scientists outside the testing community would have direct access to the President and be able to weigh in on internal debates on the administration's nuclear testing policies.[49]

Killian wasted little time in making his presence felt. At a January 6, 1958, National Security Council meeting discussing, once again, disarmament policy, Eisenhower complained about the lack of agreement amongst his scientific experts, with Teller, supported by Strauss, on one side and Isidor Rabi, another Manhattan Project veteran, supported by Stassen, on the other. Killian, from his "back bench," interrupted to report that the Science Advisory Committee was already looking at test ban verification issues. Eisenhower and Dulles expressed immediate interest, with Dulles, as Killian later put it, "looking for something to support his intuitive view that the United States should move toward a suspension of tests." Eisenhower then directed the National Security Council to sponsor a technical study on detecting nuclear tests. Killian



The Sputnik 1 satellite. Source: National Aeronautics and Space Administration.

James A. Killian, Jr., being sworn in as the first presidential science advisor. Source: Dwight D. Eisenhower Presidential Library.

at once set up an interagency panel headed by Hans Bethe, a Nobel Prize-winning nuclear physicist and member of PSAC.[50]

The Bethe panel submitted its report in late March. The panel identified "a practical detection system," consisting of observation stations, mobile ground units, and over-flight rights, which could detect nuclear explosions except for very small underground shots. Conceding that a test ban would have some negative effect on the weapons laboratories, the panel noted that continued testing would be beneficial in terms of developing clean and small, inexpensive weapons. The panel did not recommend suspending the Hardtack series and was not able to determine if a test ban would be to the net military advantage of the United States. Although the AEC and the Department of Defense were unwilling to support even these "moderate" conclusions, Defense officials failed to make a strong case for the military consequences of a test ban, leaving room for the President's Science Advisory Committee to make its own estimates.[51]

Meeting in early April, the Science Advisory Committee concluded that a test ban would "freeze the edge" that the United States possessed in nuclear weapons technology. The committee also agreed that the negotiating link between the test ban and other disarmament proposals should be broken. Finally, the committee recommended further technical study, possibly in cooperation with the Soviets, of a reliable test detection system.[52]

Killian promptly brought the committee's findings to Eisenhower. Killian told the President that continued testing would allow the Soviets to close the gap quickly in terms of nuclear weapons technology. The committee, therefore, recommended that the administration "stop testing after the Hardtack series." When Killian noted that the AEC and the Department of Defense did not agree with this assessment, Eisenhower confided that he had "never been too much impressed, or completely convinced by the views expressed by Drs. Teller, Lawrence and Mills that we must continue testing of nuclear weapons." Buoyed by the exchange, Killian told his colleagues at the PSAC that their views would "receive real attention" despite the opposition of the AEC and the military. For its part, the testing community could see the writing on the wall and was painfully aware that atmospheric testing could not long be sustained.[53]

Hardtack and Millrace

Planning for Hardtack, meanwhile, proceeded apace. By early November 1957, Strauss and the AEC, true to the mandate given by Eisenhower to reduce the scope of Hardtack, had winnowed the total number of shots down from 25 to 22. This included 17 laboratory shots and 5 by the Department of Defense. The reduction in Hardtack tests was made possible by shifting several "very small-yield full-scale" shots to the Nevada Test Site. These would be detonated, following the Hardtack series, underground in the same tunnel used for the Rainier test. Also new on the agenda for the test site were two safety tests to be conducted by the end of December so that device designs could be "frozen" prior to full-scale tests at Hardtack.[54]

No significant "reaction" was expected from either of these safety tests, but the second, Coulomb-C, a surface test conducted on December 9, produced an unanticipated yield of 500 tons. Shortly after detonation, fallout readings of fifty roentgens per hour were recorded on the Mercury Highway, and, as the cloud moved toward the southwest, personnel at Jackass Flats involved in construction for future nuclear rocket testing were forced to take cover. Eventually, the cloud reached the Los Angeles area where very low readings briefly caused some public concern.[55]

Coulomb-C safety test, December 9, 1957. Source: Los Alamos National Laboratory.

Hardtack continued to evolve. By early January 1958, the series was back up to twenty-four shots. Several shots had been deleted from the schedule, with at least one moved to Nevada, but more had been added, principally in connection with the development of the warhead for the accelerated Polaris missile program. Up to ten safety shots were now planned for the Nevada Test Site, three for the spring and seven in the fall. Two of the three spring tests were connected with the Polaris "speed-up." The planned Nevada fall tests had morphed into Operation Millrace, with three or four low-yield devices of four kilotons or less to be fired underground in existing tunnels. These detonations, Division of Military Application Director Starbird confidently told the Commission, would be "completely contained with no fallout resulting from the shots." Livermore also wanted to detonate a higher yield device of 20 to 40 kilotons underground at Nevada as a "step in proving the capability of testing devices with yields of 200 KT and higher underground at NTS." Starbird, in view of the "current international tension over the rate of nuclear testing," thought this unwise and disapproved the shot. The Commission, however, decided to request input from the General Advisory Committee before the test was "definitely postponed" for 1958.[56]

In late January, Los Alamos added another shot to the Hardtack schedule. Strauss complained that the number of shots, contrary to Eisenhower's direction, was now back at twenty-five. The constant proliferation of tests, he observed, "seemed to be a reflection of the DOD's requirement for an increasing number of different nuclear weapons types." Strauss nonetheless forwarded the Hardtack plan to the White House for presidential approval. Eisenhower approved Hardtack but not the fall series in Nevada. This, Strauss noted, the President had "some questions" about.[57]

High-Altitude and Underwater Shots: Hardtack, Newsreel, and Argus

As Hardtack drew near, concerns focused increasingly on the high-altitude shots planned for the series. In these weapon effects tests—Yucca, Teak, and Orange—collectively known as Operation Newsreel, the Department of Defense sought to study problems associated with air and missile defense and the detection of high-altitude explosions. The latter two tests, involving multimegaton weapons to be launched from Bikini by Redstone rockets and detonated at elevations of 250,000 and 120,000 feet respectively, raised serious safety questions. Fallout appeared not to be a significant risk, but by March 1958 studies indicated that the high-altitude flash from the detonation could cause potentially severe retinal eye burns out to a radius of 400 miles. This put thousands of Marshall islanders in the danger area, and, although test personnel could be issued high density goggles, the safety of the Marshallese could not be guaranteed. As a result, Teak and Orange were moved to Johnston Island, a small, low sand and coral island 700 miles west of Hawaii and outside the range of any innocent civilians.[58]

Yucca was the first test of the Hardtack series. Yielding 1.7 kilotons, the Yucca device detonated at 2:40 p.m. on April 28, 1958, at an altitude of 86,000 feet some eighty-five miles northeast of Enewetak. The device was carried by an untethered, helium-filled balloon launched from the aircraft carrier U.S.S. *Boxer*. Although the test was carefully controlled with redundant safety measures, it was, as one observer put it, "still hair-raising to have a free-floating nuclear weapon on a balloon headed in the general direction of Japan."[59]

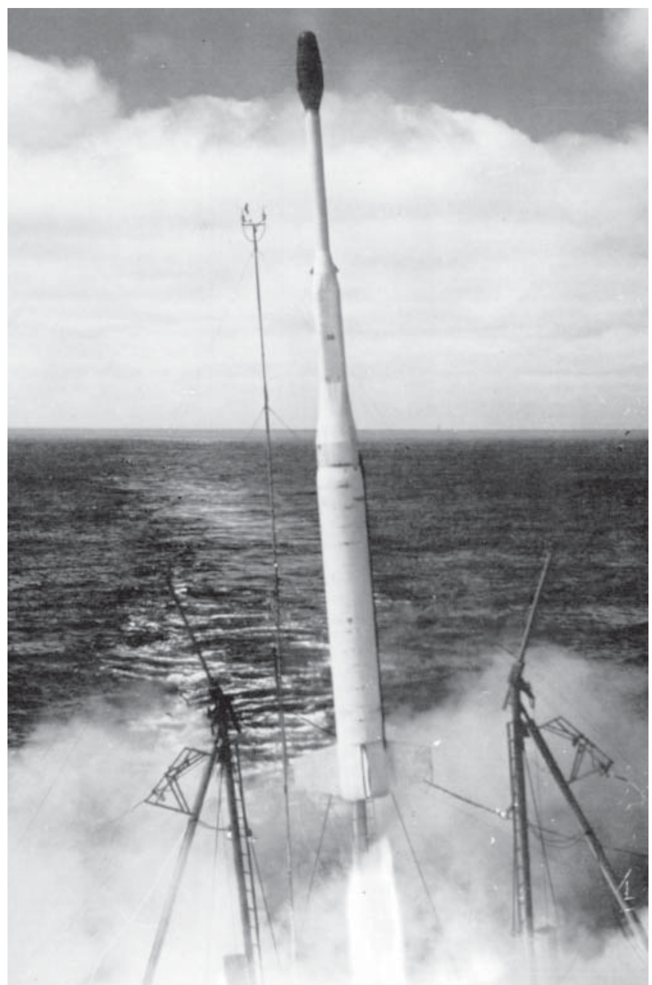
Two underwater effects tests—Wahoo and Umbrella—were conducted during Hardtack. Wahoo, with a yield of nine kilotons, was detonated on May 16 about 8,000 feet off the south edge of Enewetak atoll. Umbrella, with a yield of eight kilotons, was detonated on June 8 on the bottom of the Enewetak lagoon. Both shots, with target arrays of ships and submarines moored nearby, produced plumes of water rising upwards of 1,000 feet.[60]

Due to their relocation to Johnston Island, Teak and Orange were not fired until the close of the Hardtack series. Detonated with a yield of 3.8 megatons at an elevation of 252,000 feet at 11:50 p.m. on July 31, three minutes after the Redstone missile lifted off its launch pad, Teak produced a spectacular display in the night sky, with an aftermath of colors that eyewitnesses described as rivaling the Aurora Australis, also known as the "Southern Lights." Teak also triggered the first high-altitude electromagnetic pulse (EMP). At the time of detonation, radio communications throughout most of the Pacific basin suddenly stopped. Lack of communications grounded civilian and military aircraft in Hawaii for a number of hours. Johnston Island itself was cut off from the outside world, to the heightened concern of

Umbrella shot, Enewetak Atoll, June 8, 1958. Source: DOE, NNSA-Nevada Site Office.

military officials. Not until the next morning did a message reach Johnston Island, asking "Are you still there?" Orange, fired eleven days later at 141,000 feet, considerably above the planned 125,000 feet due to a safety interlock switch not being thrown, was somewhat less visually impressive than Teak and had none of the attendant radio communication problems.[61]

Later that same month and into early September, the Department of Defense also conducted three clandestine high-altitude nuclear weapons tests in the south Atlantic. More of a "grand experiment" than a nuclear test series, Operation Argus evolved from a proposal by the physicist Nicholas C. Christofilos to erect an electromagnetic shield against nuclear weapons. The theory was that a high-yield nuclear weapon exploded at a very high altitude would create a long-lasting radiation belt that would interfere with communications and degrade weapon function. For each of the tests, a three-stage ballistic missile, launched from the U.S.S. *Norton Sound*, part of a task force composed of nine ships and 4,500 men, carried the low-yield, one to two kiloton devices to an altitude of about 300 miles where they were detonated. The shots were conducted without incident and with no fallout detected. Argus demonstrated that the earth's magnetic field was not strong enough to maintain a long-lasting radiation shield.[62]



Missile launch on the deck of the U.S.S. *Norton Sound* during Operation Argus. Source: Defense Threat Reduction Agency, via Atomic Testing Museum.

Testing Moratorium Declared

Events were now moving inexorably toward some sort of testing moratorium. On March 31, 1958, the Soviet Union, having concluded an extensive test series, announced a unilateral suspension of all tests and called on the United States and the United Kingdom to do the same. With Hardtack less than a month away, Eisenhower was not inclined to respond in kind, but, when queried by a reporter, he did state that under the right conditions it would be "perfectly proper" for the United States to institute a unilateral suspension of tests. Stunned by the prospect of a unilateral test suspension, the Commission proposed limitations on testing rather than an outright ban. Atmospheric testing, under the Commission's formula, would be limited to twenty per year, with no single test exceeding 100 kilotons. Underground testing would be unrestricted. The Commission, nonetheless, found itself increasingly isolated within the administration, and not even the Department of Defense would commit to the AEC's limitations proposal. Eisenhower, meanwhile, for the first time separating testing from other disarmament issues, invited Khrushchev to join in technical studies as a prelude to test ban negotiations. The Soviet leader accepted Eisenhower's invite on May 9, and technical discussions began in Geneva on July 1.[63]

Realizing that Hardtack and Millrace might be the last opportunity to test, the laboratories and the military rushed to add shots to the two series. On June 12, Strauss sought and received Eisenhower's approval for seven additional tests for Hardtack and an expanded Millrace to consist of five small underground diagnostic shots, the twenty to forty-kiloton underground follow-up to Rainier, and eight safety tests. When it was all over, Hardtack counted thirty-four development and effects tests and one safety test. At the end of July, the expanded Millrace series remained on schedule, with the first shot set for the test site on October 1.[64]

Besides adding more shots, the testing community sought to rally around underground testing as an alternative to a complete test ban. In response to a request from the Commission to evaluate the weapons program if only underground tests were allowed, the General Advisory Committee, with considerable input from Teller, determined that all tests could be conducted successfully underground with the exception of "ditch-digger" peaceful uses and antimissile tests. "To go any farther than this in the restriction of testing," the committee unanimously agreed, "would seriously endanger the security of the United States." On May 28, the Commission met with laboratory representatives to discuss limiting tests to underground shots. Teller favored moving all tests underground except for those involving weapon effects and antimissile systems. Duane Sewell, operations manager at Livermore, predicted that there would be many advantages to testing underground. These included greater flexibility in scheduling tests and developing weapons, continuous underground testing that would allow scientists to test when they were ready to test, substantial cost savings, and the elimination of fallout and public opposition to testing. Although not embracing underground testing to the same degree as their Livermore colleagues, Norris Bradbury and Alvin Graves of Los Alamos agreed that many tests could be moved underground. Bradbury even noted that it might not be "absolutely necessary" to "proof-test" a missile system and its warhead if the two could be tested apart satisfactorily.[65]

Barriers to a test ban continued to crumble. On June 30, Congress amended the Atomic Energy Act, authorizing the transfer of nonnuclear weapons parts and special nuclear materials for military uses to nations that had "made substantial progress in the development of atomic weapons." This effectively mollified British objections to a test ban. Moreover, the Geneva Conference of Experts, beginning sessions the next day, made considerable progress in putting together what became known as "the Geneva system." The major concern on both sides was in detecting clandestine underground tests. Data from the Rainier test, nonetheless, convinced at least the Western experts that most tests larger than a kiloton could be detected by a network of up to 170 land-based control posts and perhaps ten ships.[66]

Increasingly isolated, the Commission and the laboratories made one last effort to avoid a moratorium. On August 12, AEC Chairman John McCone, who had replaced Strauss when his term expired at the end of June, Teller, and Bradbury met with Eisenhower to discuss the results of the Hardtack series. Noting the significance of a "very small weapon" that had been fired, Teller told the President that Hardtack had improved weapons "by a factor two to five over the previously existing models." Similar progress, he added, could be made in the next year or two if testing continued. Eisenhower got the point and admitted that he favored continued testing underground, but he noted that world opinion against testing obliged the United States to follow certain lines of policy. Clearly losing the ongoing battle within the administration to persuade the President, McCone, on August 20, asked Strauss to put on his "bullet-proof vest" and speak to him on the issue. Strauss, once again, presented Eisenhower with arguments for allowing some testing. Eisenhower, in turn, showed Strauss a copy of the forthcoming presidential announcement on the moratorium. Although not as damaging as he expected, the statement, Strauss told Eisenhower, was a "surrender to the views of Stassen and Stevenson." Dropping his conciliatory tone, the President declared that the Commission's alternatives led only to an indefinite arms race.[67]

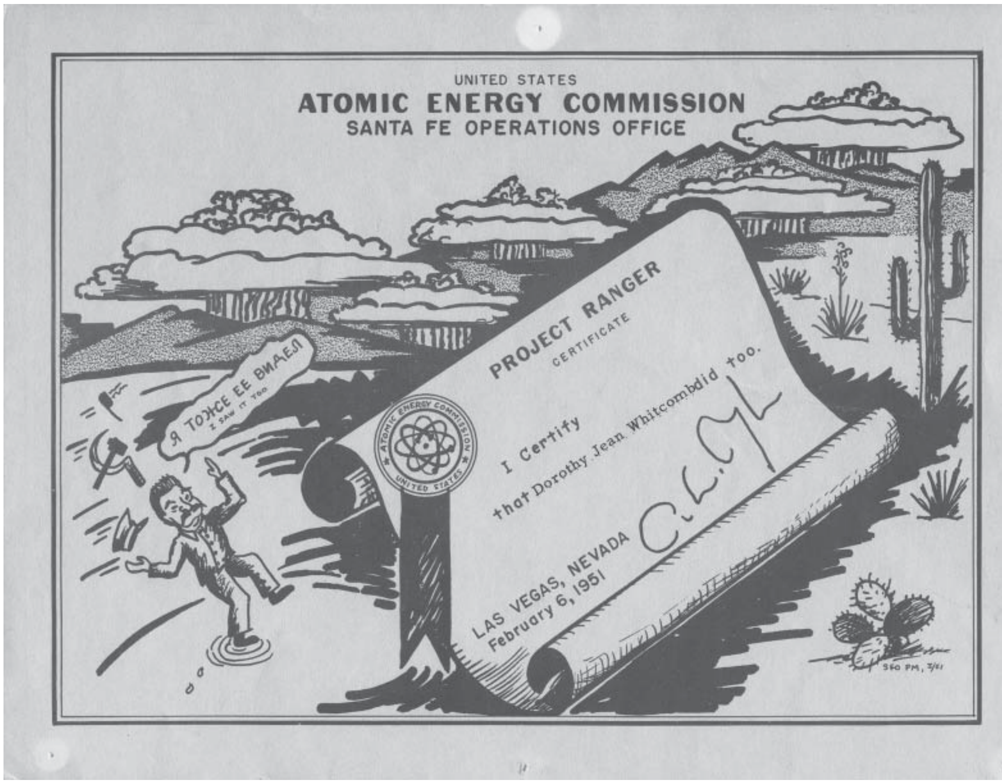
AEC Chairman John A. McCone. Source: Department of Energy.

Two days later, Eisenhower announced that the United States was ready to begin negotiations on a test ban on October 31. At that time, a one-year testing moratorium would begin. Testing would be suspended indefinitely provided the nuclear powers implemented an effective inspection system and made progress on other arms control issues. Despite his ridicule of the proposal, Khrushchev agreed to join the negotiations scheduled for Geneva.[68]

Hardtack II

With the moratorium scheduled to begin at midnight on October 31, 1958, a two-month window existed to conduct any and all needed tests. Testing in the Pacific concluded with the Fig shot at Enewetak on August 18. Additional tests would be done at the Nevada Test Site. On August 22 and 27, AEC Chairman McCone discussed the Nevada test program with the President. On August 28, McCone wrote to Eisenhower seeking official approval for the fall 1958 test series. No longer called Millrace, the series would be a second phase of Hardtack and would consist of nine shots, five of which would be under one kiloton in yield, and seven safety tests. Reserving the right to "review

Test Series Participation Certificates



Participation certificates were given to workers involved in a nuclear test series at the Nevada Test Site. In later years, event stickers and patches also were distributed. Source: Atomic Testing Museum.

further" the shot list to determine if additional tests were needed, McCone in fact came back to the President five more times. Not until October 29 did Eisenhower approve the final changes to the test program.[69]

Hardtack II, conducted over a fifty-day period, witnessed an extraordinary burst of activity at the test site. Beginning with the first shot on September 12, nineteen full-scale and eighteen safety tests were conducted. On October 22 and 30, an unprecedented four tests were conducted in one day. October 26 and 29 each witnessed three tests. Even aside from the frenetic pace, Hardtack II differed considerably from the previous Nevada test series. A third of the tests were conducted underground in shafts or tunnels. Short wooden towers were used for the first time for very small-yield tests. As time grew short and emplacement positions difficult to find, testers used "Gravel Gerties" to fire primarily safety shots. These small buildings on the surface with huge amounts of dirt piled over them were designed to capture most of the radioactive material. In addition, yields for Hardtack II shots in comparison with other Nevada series were much reduced. Eleven of the full-scale tests were less than one kiloton. None of the rest

Debris and flames from the Luna safety experiment in an unstemmed hole rise over the desert September 21, 1958, after the device was detonated. Source: DOE, NNSA-Nevada Site Office.

was over six kilotons, except for the twenty-two-kiloton Blanca, the underground follow-up to the Rainier shot.[70]

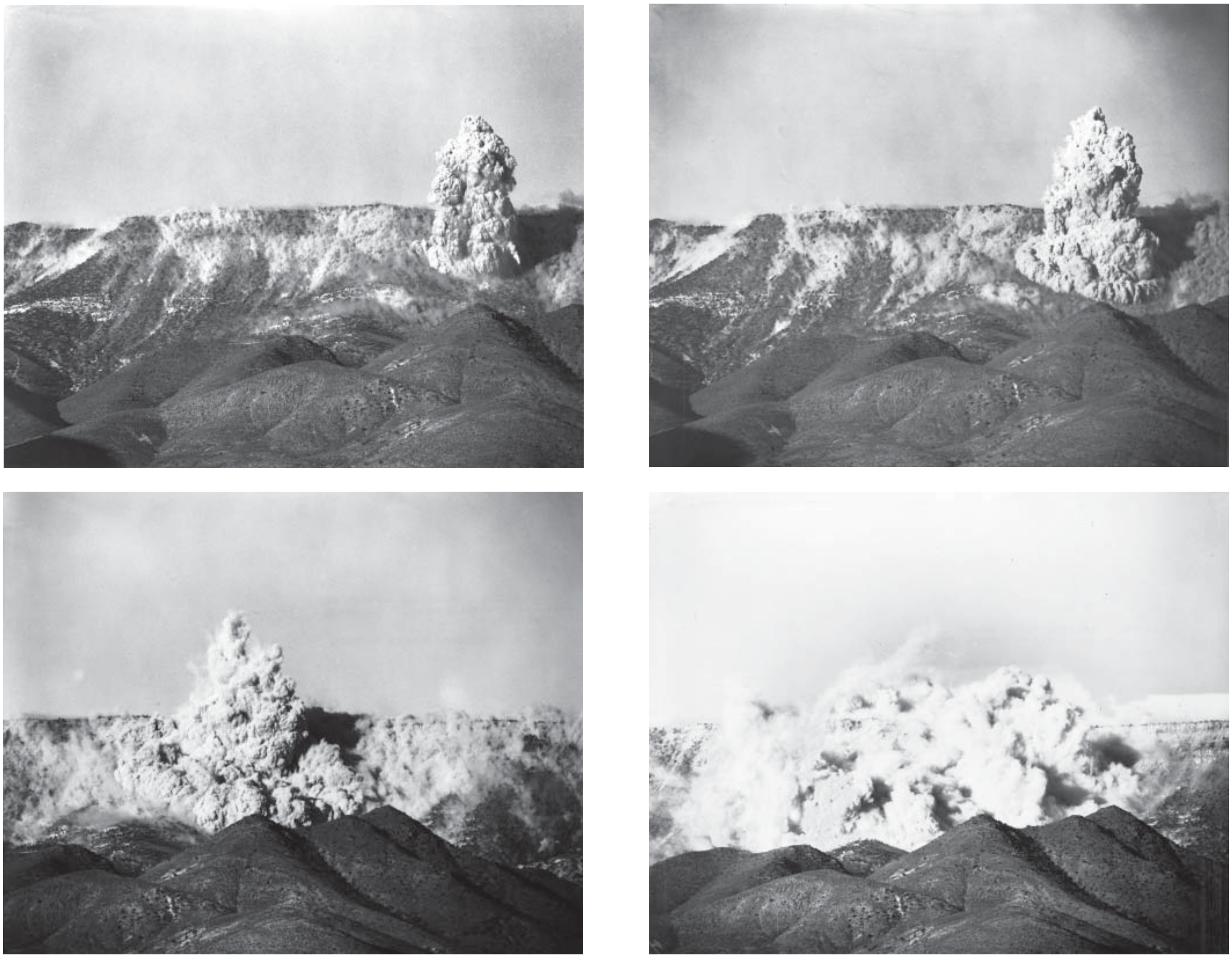
No troop maneuvers took place at Hardtack II, but the military did conduct effects experiments. The underground Logan shot sought to investigate the effects of radiation on various materials using a 2-foot diameter, 150-foot long vacuum line-of-sight pipe extending from the device. Hamilton, a small device that the press speculated might be adapted to an "infantryman's weapon," was detonated atop a 50-foot wooden tower at Frenchman Lake. As part of the Hamilton effects tests, 500 pigs, with small dosimeters sewn under their skins, were placed at varying distances from ground zero. Hamilton produced a yield of 1.2 tons, much lower than the anticipated 20 to 50 tons. The pigs, nonetheless, were airlifted to Walter Reed hospital in Washington, D.C., where they were checked out by "the finest surgeons in the world." "I don't let anyone touch my pigs," observed one official, "unless they have operated on human beings for ten years."[71]

Livermore, somewhat inadvertently, conducted its own cratering experiment. Neptune, an underground safety experiment with an expected possible yield of 10 tons or so, produced 115 tons when it was detonated on October 14. In a tunnel positioned only 100 feet from the side of the mesa, the shot created the first subsidence crater from an underground test. Resourceful Livermore officials promptly dubbed Neptune a "nuclear cratering experiment." A technical report was produced describing the "major contributions of the data to the theory and prediction of cratering phenomenology."[72]

As a result of the size of the Hardtack II shots and the containment measures implemented, off-site fallout was relatively minor. Most of the underground shots nonetheless vented some radioactivity into the atmosphere. Blanca, in a "spectacular fashion," noted one observer, "vented out the face of the mesa." Moreover, in the last week of October the Los Angeles area went into a state of "near panic" as Nevada fallout pushed radiation levels somewhat above that of background. Los Angeles Mayor Norris Poulson phoned AEC Commissioner Libby who assured him that the levels were not dangerous. When the mayor discovered that the AEC planned one more shot, Adam, for October 31, however, he "blew up": "We don't like to be talked to like children! If they shoot that last shot, there will be repercussions!" The balloon-borne Adam remained hanging in the air all day and into the evening, but atmospheric conditions were such that a potentially damaging shock wave might be inflicted on Las Vegas. At midnight, the shot was cancelled.[73]

And then it was over. The moratorium went into effect, although the Soviets in a mad rush to complete their own series did not quite make it, testing on November 1 and 3, much to the consternation of Eisenhower, and the last atmospheric testing series to be conducted at the Nevada Test Site was complete. [74]

Blanca Venting



Time-sequence photos of the underground Blanca shot venting from the side of the mesa, October 30, 1958. Source: DOE, NNSA-Nevada Site Office.

Epilogue

From Moratorium to Atmospheric Test Ban Treaty, 1958-1963

The moratorium was not entirely unwelcome in the testing community. After a record seventy-seven nuclear weapons tests in 1958, the testing system, noted one participant, "was tired, tired, tired." Sufficient data existed from the Hardtack I and II and Argus shots to keep weapon scientists busy for at least a year or two. In addition, strong support from the military and the Atomic Energy Commission (AEC) for maintaining a strong and viable readiness program inspired some optimism that the moratorium would not last long.[1]

When the moratorium on nuclear weapons testing went into effect on November 1, 1958, activity at the Nevada Test Site slowed down but did not cease. The AEC attempted to keep the site in a state of readiness that would allow for full-scale testing within ninety days of notification. If and when testing resumed, the AEC and the testing community believed that tests would be conducted underground or possibly in deep space. As part of the readiness effort, therefore, an appreciable amount of work went into constructing primarily new tunnels but also new shafts.[2]

Other activities at the test site, not necessarily directly related to nuclear weapons testing, also helped maintain the future viability of both the site and the testing community during the moratorium. These included:

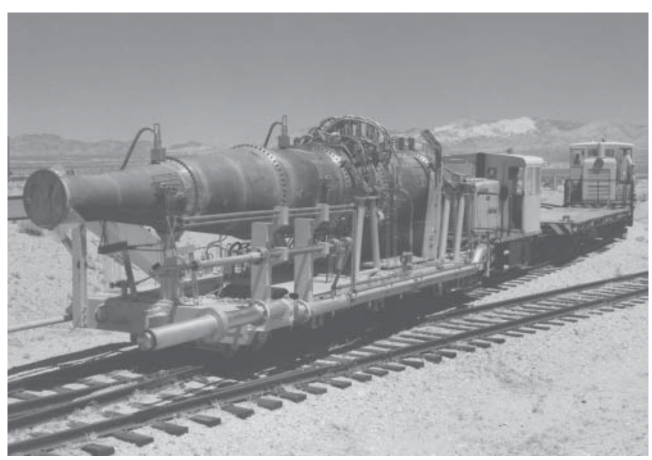
- **Vela Uniform**: Analysis of data from the Hardtack II series indicated that the "Geneva system" of control posts and inspections agreed to by the Geneva Conference of Experts during summer 1958 would be inadequate. Officials and scientists determined that additional underground nuclear explosions would be necessary, and, at the Geneva test ban negotiations, the United States proposed to undertake with the Soviet Union a joint research program to improve underground detection techniques. Preparations for such a program, dubbed Vela Uniform by testing officials, began in earnest in late 1959. Although the joint program was never agreed to, construction activities at the test site for Vela Uniform supplemented and to a certain extent displaced those for the readiness effort.

- **Hydronuclear Tests**: Weapon designers looking at the data from the safety tests conducted during Hardtack II concluded that four weapons systems in the stockpile or about to go into the stockpile might not be "one-point safe." As a result, the military halted production in several cases and severely constrained weapons handling procedures. Los Alamos proposed conducting hydronuclear tests, which, similar to one-point safety tests, would use high explosives in a weapon configuration but with much reduced amounts of fissile material so that the nuclear yield would be very small, although not necessarily zero. Following a determination by President Eisenhower that this type of experiment was "not a nuclear weapon test" and thus did not violate the moratorium, Los Alamos in early 1960 began a series of thirty-five hydronuclear tests at a remote location on the Los Alamos site. Most of the tests yielded less than one-thousandth of a pound of high explosive equivalent, but one experiment did produce four-tenths of a pound of fission energy. Livermore also conducted hydronuclear tests at the Nevada Test Site.

- **Nuclear Rockets: Rover**: A joint project of the AEC and the National Aeronautics and Space Administration (NASA), Rover sought to develop a nuclear-powered rocket for space travel. Rover involved the full-scale testing of nuclear rocket reactors and engines. Two massive maintenance and assembly facilities, two test cells, and an engine test stand were built at Jackass Flats in the southwest corner of the test site, partly on newly acquired land from the adjacent Nellis Air Force Range. A railroad line connected the various facilities. The first test on July 1, 1959, of a Kiwi reactor, a complete—albeit flightless— test unit using liquid hydrogen as both coolant and propellant, was a spectacular success with a jet of hydrogen heated in the reactor core shooting hundreds of feet into the air from the up turned nozzle. Despite several mishaps including a hydrogen explosion during one test and the loss of a reactor core in another, the program achieved considerable technical success. The program eventually was terminated in 1973 when no near term mission for Rover could be found.

Kiwi-A “fire-up.” Source: Los Alamos National Laboratory.

- **Nuclear Ramjet: Pluto**: Funded by the Air Force, the Pluto program sought to produce a system that could propel a supersonic low-altitude missile. Using a relatively simple operational concept, the nuclear ramjet would draw air in at great force at the front of the missile, heat it in the nuclear reactor to make it expand, and then exhaust it out the back, providing thrust. Also located at Jackass Flats, the test area for Pluto consisted of two reactors, with a special heated air storage system to permit full-power testing, as well as a control facility, test bunker, and railroad spur line. Mounted on a railroad car, the Tory-IIA reactor for Pluto performed its



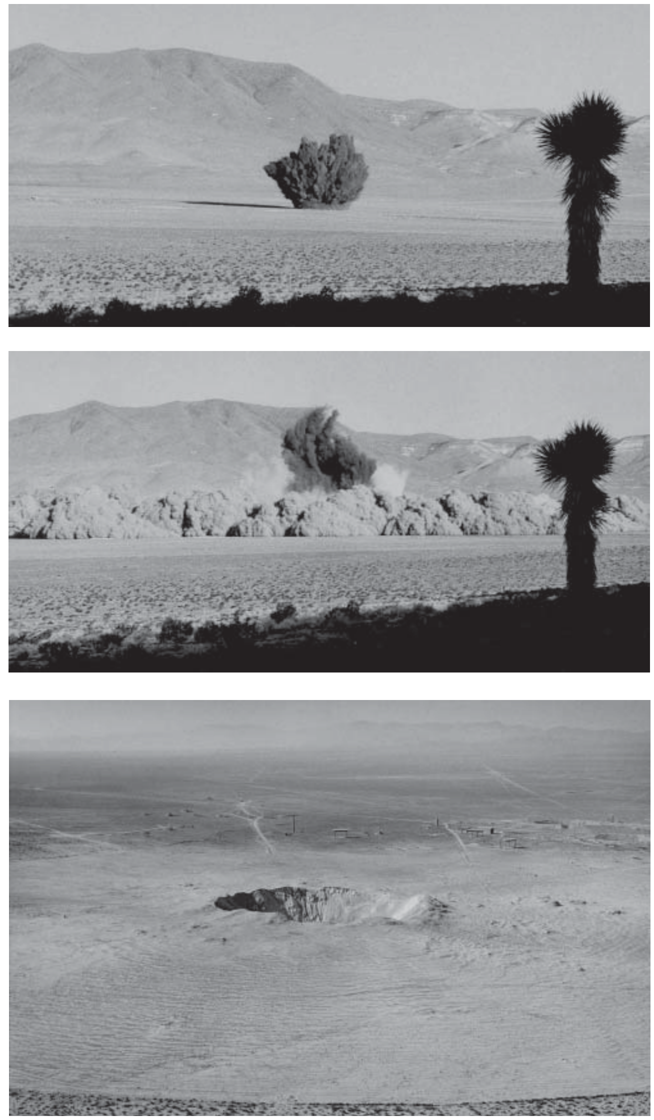
Nuclear ramjet engine on its test bed facility, a railroad flatcar. Source: DOE, NNSA-Nevada Site Office.

first test run on May 14, 1961. Pluto, as with Rover, achieved considerable technical success but, also like its counterpart, was cancelled for lack of mission in 1964.

- **Plowshare**: Launched in 1957 and largely a Livermore initiative, the Plowshare program sought to develop peaceful uses for nuclear explosives. The Livermore laboratory proposed over a half-dozen nuclear explosives experiments, with the earliest being Gnome, a shot in bedded salt at a site near Carlsbad, New Mexico, that would investigate using the heat from a nuclear explosion to generate power, and Chariot, an excavation project to produce a harbor in Alaska. Some peaceful tests were planned for the test site. With the moratorium, the various experiments were put on hold, there being no easy way to distinguish between weapons tests and peaceful nuclear explosions. A number of high-explosives cratering experiments were conducted at the test site in summer and fall 1960. Most notable was Project Scooter, a 500-ton sphere of high explosives that was to be detonated 125-feet under ground at Yucca Flat. The shot misfired, apparently due to dud detonators. Following two months of somewhat risky work in placing new detonators in the middle of the high-explosives sphere, the shot successfully fired.

These various activities helped maintain the test site organization at a considerable level of strength. Tunnels were dug. Contractors kept working. Radiation safety and weather groups remained in place. Overall, a level of readiness was maintained so that nuclear weapons testing could successfully resume when needed.[3]

The Conference on the Discontinuance of Nuclear Weapons Tests meeting in Geneva, meanwhile, had not gone well. For all the apparent

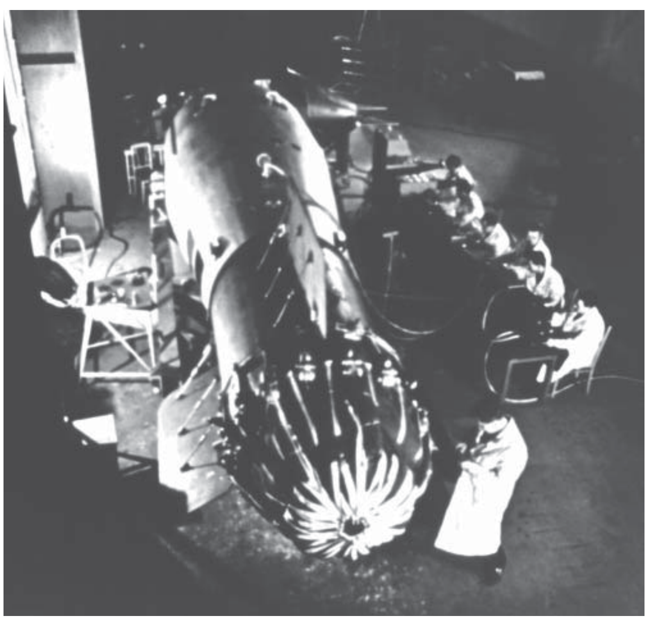


Time-sequence photos of the high-explosives Scooter blast. Source: Lawrence Livermore National Laboratory.

scientific agreement on the Geneva system, the Soviet Union, in the political negotiations, insisted on veto power over any proposed inspection, with Soviet Premier Nikita Khrushchev indicating that the inspection system was nothing more than "a military espionage plan." Nor did American efforts to reopen the technical issues of the detection system help matters. On December 29, 1959, Eisenhower announced that the "voluntary moratorium" on testing would expire on December 31, and that although the United States was now free to resume testing it would not do so without announcing any resumption in advance.

Negotiations at Geneva dragged on, and in early 1961, with Eisenhower leaving the issue to his successor, newly elected President John F. Kennedy faced increasing pressure from the military and the AEC to resume testing. Still hoping for a breakthrough at Geneva, Kennedy in June allowed preliminary planning for test resumption to begin. On August 30, the Soviets announced that they would resume testing and two days later conducted their first test, an atmospheric shot yielding approximately 150 kilotons. More tests quickly followed, including that of a 50-megaton weapon. In a period of sixty days, the Soviets conducted fifty atmospheric tests, with a total yield exceeding that of all previous test series, by all nations, combined.[4]

On September 5, President Kennedy announced that the United States would resume testing "in the laboratory and underground, with no fallout." Ten days later, the first test of the Nougat series at the Nevada Test Site, Antler, with a yield of 2.6 kilotons, vented a cloud of radioactive gas that eventually made its way off site. Shrew, the next shot on October 10, also vented, as did the next eight test site shots. During this time, Gnome, a Plowshare shot, conducted in New Mexico, vented as well. Although the administration was somewhat embarrassed, the radioactive releases proved relatively minor, especially in comparison to previous atmospheric series and to what the Soviets currently were doing. All forty-four of the Nougat series tests were underground, except for Danny Boy, a cratering experiment, which only was buried deep enough to limit and not contain escaping radioactivity. Nougat also marked the start of year-round testing, with the series running continuously from September 1961 to June 30, 1962, the end of the fiscal year. Tests held during Fiscal Year 1963 were part of Operation Storax.[5]



The Soviet Union's Tsar Bomba, "King of Bombs," tested at 50 megatons but designed to yield 100 megatons, was the world's largest nuclear weapon ever constructed or detonated. Source: Peter Kuran, Visual Concept Entertainment, VCE.com, via Atomic Testing Museum.

Antler and the shots that followed at the test site were a relatively puny response to the Soviets' megaton tests, and pressure soon began building for an atmospheric test series in the Pacific. In March 1962, Kennedy approved Operation Dominic, which was conducted, in a bow to international opinion, not in the Marshall Islands but at the uninhabited Christmas Island owned by the British and lying 1,160 miles south of Honolulu. Dominic included twenty-four airdrops toward target rafts moored 10 to 20 miles south of the island and which burst high enough so that the fireball did not touch the water, five similar airdrops in a target zone 250 to 400 miles east and south of Johnston Island, five nuclear-tipped rocket launches from Johnston Island, a test launch and detonation of a stockpile Polaris missile from a submerged Polaris submarine, and a proof-test of the stockpile ASROC antisubmarine rocket-launched nuclear depth charge in the deep ocean 370 miles west and south of San Diego, the same general area where the 1955 Wigwam test had been conducted. Dominic was the last atmospheric test series conducted in the Pacific.[6]

Back in Nevada, meanwhile, Storax began on July 6 with the Plowshare nuclear excavation experiment Sedan, perhaps the most spectacular shot ever conducted at the test site. Buried 635 feet below ground level at a site in the far north end of Yucca Flat, the 104–kiloton blast lifted a huge dome of earth 290 feet in the air, moved 6.5 million cubic yards of earth and rock, and left a crater 1,200 feet across and 320 feet deep. The lip of the crater towered as high as 100 feet into the air. Sedan also sent a cloud of radioactivity off in the direction of Salt Lake City, creating a brief scare when radioactive iodine–131 turned up in the local milk supply. Inability to totally contain the radioactivity coupled with disappointing results eventually signaled the death knell of the program in the mid–1970s.[7]

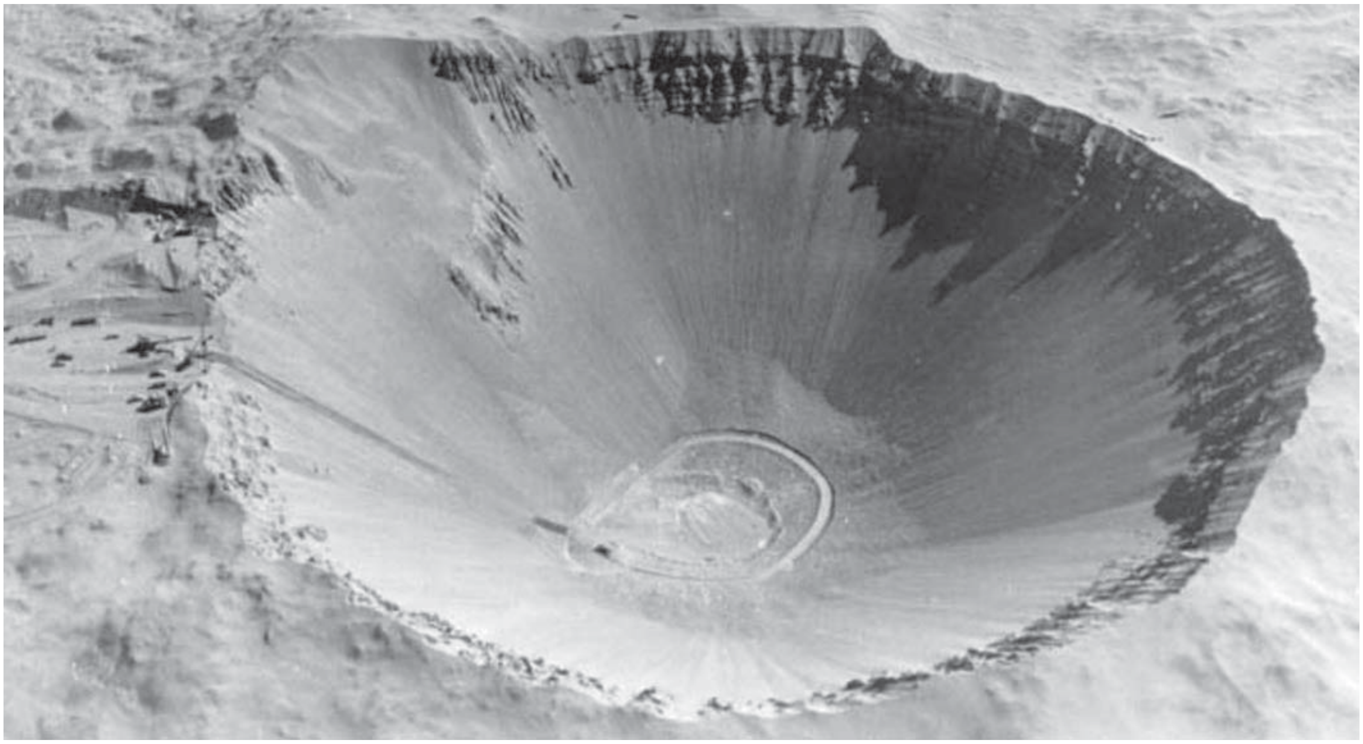
Operation Sunbeam, or Operation Dominic II as the AEC referred to it, was a low-yield series of four aboveground weapon effects tests sponsored by the Department of Defense that immediately followed Sedan from July 7 to 17, 1962. The final shot, Little Feller I, was conducted in Area 18 in the northwest part of the test site and held in conjunction with the Army's Exercise Ivy Flats, which involved military maneuvers with tanks and a thousand troops. Little Feller I was fired by an army crew aboard an armored personnel carrier who launched a stockpile rocket-propelled Davy Crockett tactical nuclear warhead that exploded on target, at a height of three feet, 3,000 yards away. Observers watched the test and the subsequent maneuvers from bleachers two miles from ground zero. Once radiation monitors gave their approval, troops positioned nearby in trenches mounted their vehicles and conducted maneuvers for almost an hour. Little Feller I was the test site's last atmospheric test.[8]

With the resumption of nuclear weapons testing, the Geneva test ban talks collapsed in January 1962. Continuing worldwide concerns with radioactive fallout and the chastening influence—on both sides—of the October 1962 Cuban Missile Crisis, however, revived the prospects for a test ban. Despite the Soviets having conducted another atmospheric test series in response to Dominic, Kennedy, with increased strength from the missile crisis that allowed for moderation, announced in his June 10, 1963, "peace speech" at American University that the United States would not "conduct nuclear tests in the atmosphere so long as other states do not do so" and expressed the hope that this might help achieve a test ban. Khrushchev, apparently more amenable after the missile crisis humiliation, agreed to receive high-level British and American emissaries for direct talks on the test ban in Moscow. On July 2, the Soviet premier proposed a treaty that would ban tests in the atmosphere, in outer space, and underwater. After two weeks of negotiations in Moscow, W. Averell Harriman on July 25 initialed the Limited Test Ban Treaty of 1963 for the United States.[9]

The test ban treaty banned atmospheric testing but legitimized underground testing. The treaty eliminated concern about fallout but had the unintended consequence, as George Kistiakowsky, Eisenhower's second science advisor, and Herbert York, first director of the Livermore laboratory, later noted, of making "the continuation of uninhibited weapons development politically respectable." For the next thirty years, the Nevada Test Site would be the locus of the nation's nuclear weapons testing program. From August 1963 to September 1992, the Nevada Test Site played host to 713 nuclear tests. Ten shots were conducted at other locations. Weapons development and testing became routinized. Underground testing dampened most of the concern with blast effects and radiological safety. Full–time professional test personnel constantly occupied themselves with either testing or preparing for the next test. Underground testing also made possible the use of significantly larger devices at the test site, with the 1968 Boxcar test registering at 1.3 megatons, nearly sixty times the yield of the "big" Fox shot in the test site's initial Ranger series. While the tests got larger, public attention and apprehension diminished considerably. In stark contrast to the bold headlines and general

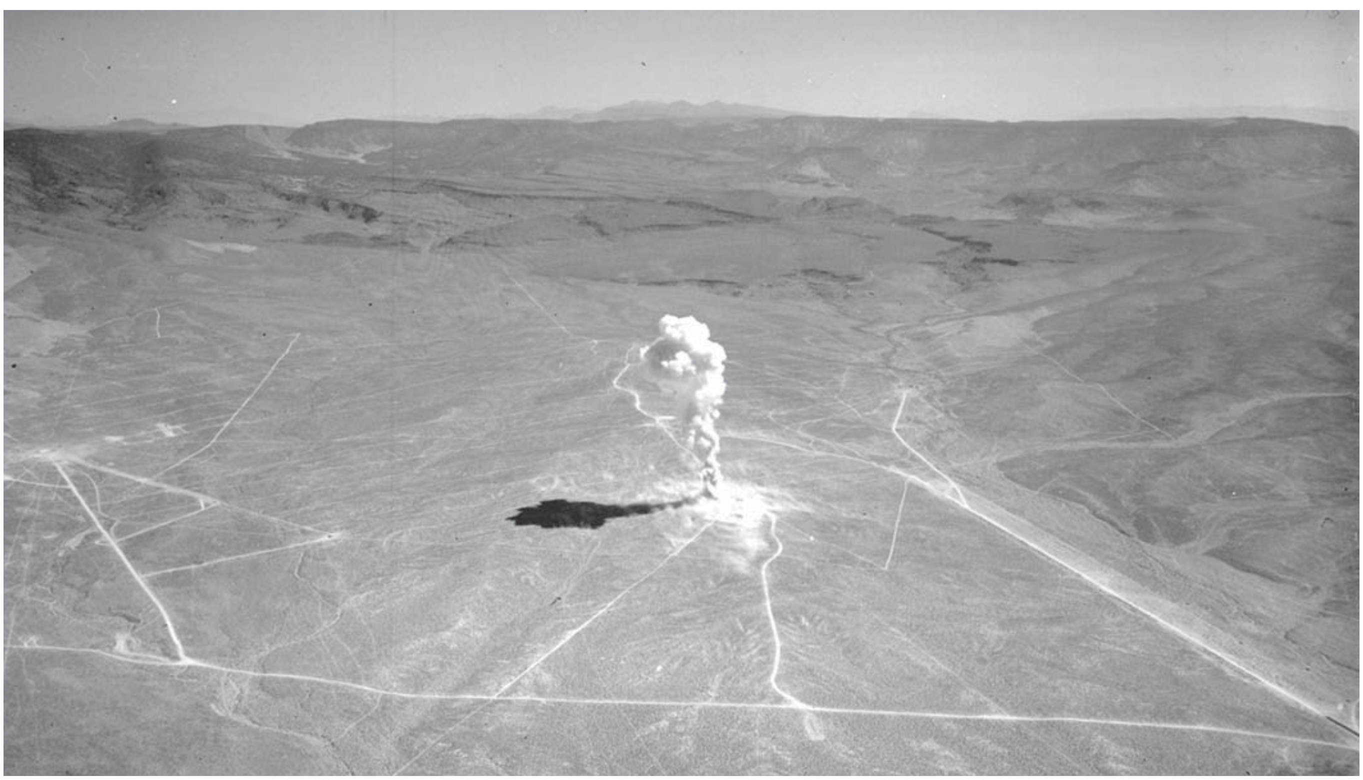
Sedan

Plumes of sand and dust formed by boulders and clumps of gravel ejected from the desert by the July 6, 1962, Sedan Plowshare test. Source: DOE, NNSA-Nevada Site Office.



Sedan crater. Note the vehicles on the lip of the crater to the left. Source: DOE, NNSA-Nevada Site Office.

Little Feller I



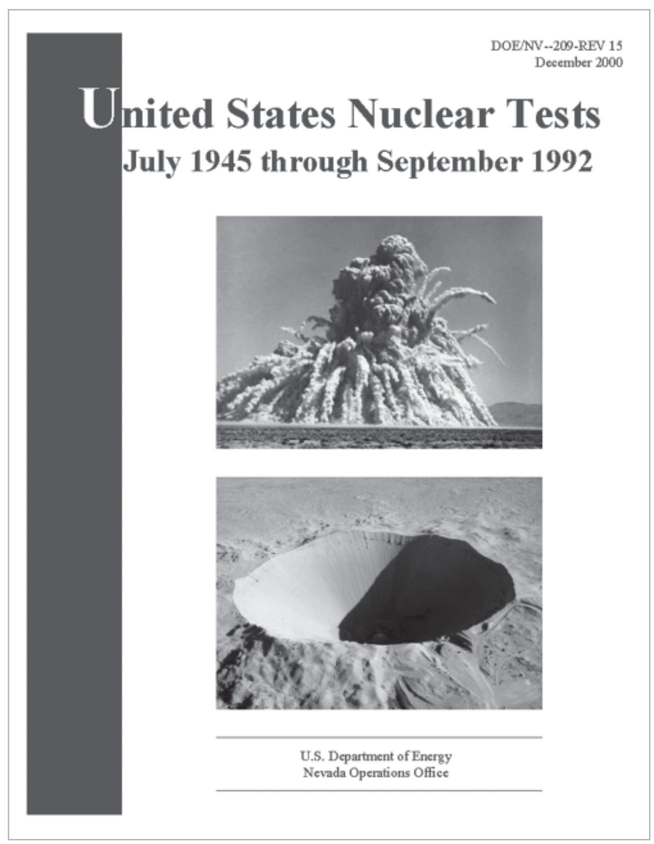
Little Feller I test device, top, on display at the observation area. Little Feller I detonation, bottom, July 17, 1962, looking north. Source: Defense Threat Reduction Agency.

commotion during Ranger, residents in Las Vegas and other communities surrounding the test site paid scant attention to underground testing. The last underground test at the site, Divider, occurred on September 23, 1992, after which Congress imposed a moratorium on nuclear weapons testing. In 1996, international negotiations produced a Comprehensive Test Ban Treaty. The United States signed the treaty, but the Senate has not ratified it. The moratorium on testing remains in effect.[10]

Appendix

United States Nuclear Tests, 1945-1958

Following is a chronological list of all nuclear tests conducted by the United States from July 1945 through October 1958. The list is excerpted from the Department of Energy publication, *United States Nuclear Tests, July 1945 through September 1992*, DOE/NV--209-REV 15 (December 2000), which can be found online at http://www.nv.doe.gov/library/publications/historical/DOENV_209_REV15.pdf.



The two nuclear weapons that the United States exploded over Japan in World War II are not listed. The nuclear weapon dropped August 6, 1945, from a United States Army Air Force B-29 bomber (the *Enola Gay*) and detonated over Hiroshima, Japan, had an energy yield equivalent to that of 15,000 tons of TNT. The nuclear weapon exploded in a similar fashion August 9, 1945, over Nagasaki, Japan, had a yield of 21,000 tons of TNT.

Detonation time and date for all detonations listed have been converted from local time to Greenwich Mean Time (GMT). The date listed is the GMT date for the detonation.

United States Nuclear Tests - By Date					
	Test	Date (mm/dd/yyyy) (GMT)	Sponsor	Location	Hole
1	Trinity First test of a nuclear weapon (“Fat Man”) Plutonium as sole fissile material	07/16/1945	LANL	Alamogordo, New Mexico	- - - -
Operation Crossroads					
2	Able Plutonium as sole fissile material Mark 3 device identical to “Fat Man”	06/30/1946	LANL/DoD	Bikini Island	- - - -
3	Baker Plutonium as sole fissile material Mark 3 device identical to “Fat Man”	07/24/1946	LANL/DoD	Bikini Island	- - - -
Operation Sandstone					
4	X-Ray	04/14/1948	LANL	Enewetak	- - - -
5	Yoke	04/30/1948	LANL	Enewetak	- - - -
6	Zebra	05/14/1948	LANL	Enewetak	- - - -
Operation Ranger					
7	Able	01/27/1951	LANL	NTS	Area 5
8	Baker	01/28/1951	LANL	NTS	Area 5
9	Easy	02/01/1951	LANL	NTS	Area 5
10	Baker-2	02/02/1951	LANL	NTS	Area 5
11	Fox	02/06/1951	LANL	NTS	Area 5
Operation Greenhouse					
12	Dog	04/07/1951	LANL	Enewetak	- - - -
13	Easy	04/20/1951	LANL	Enewetak	- - - -
14	George First thermonuclear test explosion	05/08/1951	LANL	Enewetak	- - - -
15	Item First test of the boosting principle	05/24/1951	LANL	Enewetak	- - - -
Operation Buster					
16	Able Radioactivity not detected offsite	10/22/1951	LANL	NTS	Area 7
17	Baker	10/28/1951	LANL	NTS	Area 7
18	Charlie	10/30/1951	LANL	NTS	Area 7
19	Dog	11/01/1951	LANL	NTS	Area 7
20	Easy	11/05/1951	LANL	NTS	Area 7
Operation Jangle					
21	Sugar	11/19/1951	LANL/DoD	NTS	Area 9
22	Uncle First underground test at the Nevada Test Site	11/29/1951	LANL/DoD	NTS	Area 10

July 1945 through October 1958							
Time (GMT)	Latitude (degrees)	Longitude (degrees)	Surface Elevation (meters)	Type	Purpose	Yield Range	
				Tower	Weapons Related	21 kt	1
Operation Crossroads							
				Airdrop	Weapons Effects	21 kt	2
				Underwater	Weapons Effects	21 kt	3
Operation Sandstone							
				Tower	Weapons Related	37 kt	4
				Tower	Weapons Related	49 kt	5
				Tower	Weapons Related	18 kt	6
Operation Ranger							
				Airdrop	Weapons Related	1 kt	7
				Airdrop	Weapons Related	8 kt	8
				Airdrop	Weapons Related	1 kt	9
				Airdrop	Weapons Related	8 kt	10
				Airdrop	Weapons Related	22 kt	11
Operation Greenhouse							
				Tower	Weapons Related	81 kt	12
				Tower	Weapons Related	47 kt	13
				Tower	Weapons Related	225 kt	14
				Tower	Weapons Related	45.5 kt	15
Operation Buster							
				Tower	Weapons Related	Less than 0.1 kt	16
				Airdrop	Weapons Related	3.5 kt	17
				Airdrop	Weapons Related	14 kt	18
				Airdrop	Weapons Related	21 kt	19
				Airdrop	Weapons Related	31 kt	20
Operation Jangle							
				Surface	Weapons Effects	1.2 kt	21
20:00:00.00	37.168	-116.043	1283	Crater	Weapons Effects	1.2 kt	22

United States Nuclear Tests - By Date

Test		Date (mm/dd/yyyy) (GMT)	Sponsor	Location	Hole
Operation Tumbler-Snapper					
23	Able	04/01/1952	LANL/DoD	NTS	Area 5
24	Baker	04/15/1952	LANL/DoD	NTS	Area 7
25	Charlie	04/22/1952	LANL/DoD	NTS	Area 7
26	Dog	05/01/1952	LANL	NTS	Area 7
27	Easy	05/07/1952	LANL	NTS	Area 1
28	Fox	05/25/1952	LANL	NTS	Area 4
29	George	06/01/1952	LANL	NTS	Area 3
30	How	06/05/1952	LANL	NTS	Area 2
Operation Ivy					
31	Mike Experimental thermonuclear device	10/31/1952	LANL	Enewetak	- - - -
32	King Largest fission device	11/15/1952	LANL	Enewetak	- - - -
Operation Upshot-Knothole					
33	Annie	03/17/1953	LANL	NTS	Area 3
34	Nancy	03/24/1953	LANL	NTS	Area 4
35	Ruth	03/31/1953	LLNL	NTS	Area 7
36	Dixie	04/06/1953	LANL	NTS	Area 7
37	Ray	04/11/1953	LLNL	NTS	Area 4
38	Badger	04/18/1953	LANL	NTS	Area 2
39	Simon	04/25/1953	LLNL	NTS	Area 1
40	Encore	05/08/1953	LANL/DoD	NTS	Area 5
41	Harry	05/19/1953	LANL	NTS	Area 3
42	Grable Fired from 280mm gun	05/25/1953	LANL	NTS	Area 5
43	Climax	06/04/1953	LANL	NTS	Area 7
Operation Castle					
44	Bravo Experimental thermonuclear device Highest yield nuclear tests	02/28/1954	LANL	Bikini Island	- - - -
45	Romeo	03/26/1954	LANL	Bikini Island	- - - -
46	Koon	04/06/1954	LLNL	Bikini Island	- - - -
47	Union	04/25/1954	LANL	Bikini Island	- - - -
48	Yankee	05/04/1954	LANL	Bikini Island	- - - -
49	Nectar	05/13/1954	LANL	Enewetak	- - - -
Operation Teapot					
50	Wasp	02/18/1955	LANL	NTS	Area 7
51	Moth	02/22/1955	LANL	NTS	Area 3

July 1945 through October 1958							
Time (GMT)	Latitude (degrees)	Longitude (degrees)	Surface Elevation (meters)	Type	Purpose	Yield Range	
Operation Tumbler-Snapper							
				Airdrop	Weapons Effects	1 kt	23
				Airdrop	Weapons Effects	1 kt	24
				Airdrop	Weapons Related	31 kt	25
				Airdrop	Weapons Related	19 kt	26
				Tower	Weapons Related	12 kt	27
				Tower	Weapons Related	11 kt	28
				Tower	Weapons Related	15 kt	29
				Tower	Weapons Related	14 kt	30
Operation Ivy							
				Surface	Weapons Related	10.4 Mt	31
				Airdrop	Weapons Related	500 kt	32
Operation Upshot-Knothole							
				Tower	Weapons Related	16 kt	33
				Tower	Weapons Related	24 kt	34
				Tower	Weapons Related	200 tons	35
				Airdrop	Weapons Related	11 kt	36
				Tower	Weapons Related	200 tons	37
				Tower	Weapons Related	23 kt	38
				Tower	Weapons Related	43 kt	39
				Airdrop	Weapons Effects	27 kt	40
				Tower	Weapons Related	32 kt	41
				Airburst	Weapons Related	15 kt	42
				Airdrop	Weapons Related	61 kt	43
Operation Castle							
				Surface	Weapons Related	15 Mt	44
				Barge	Weapons Related	11 Mt	45
				Surface	Weapons Related	110 kt	46
				Barge	Weapons Related	6.9 Mt	47
				Barge	Weapons Related	13.5 Mt	48
				Barge	Weapons Related	1.69 Mt	49
Operation Teapot							
				Airdrop	Weapons Effects	1 kt	50
				Tower	Weapons Related	2 kt	51

United States Nuclear Tests - By Date					
Test		Date (mm/dd/yyyy) (GMT)	Sponsor	Location	Hole
Operation Teapot - Continued					
52	Tesla	03/01/1955	LLNL	NTS	Area 9
53	Turk	03/07/1955	LLNL	NTS	Area 2
54	Hornet	03/12/1955	LANL	NTS	Area 3
55	Bee	03/22/1955	LANL	NTS	Area 7
56	Ess	03/23/1955	LANL	NTS	Area 10
57	Apple-1	03/29/1955	LANL	NTS	Area 4
58	Wasp Prime	03/29/1955	LANL	NTS	Area 7
59	HA (High Altitude) Named “HA” for “high altitude” in reference to its intended detonation at an altitude of 40,000 feet	04/06/1955	LANL	NTS	Area 1
60	Post	04/09/1955	LLNL	NTS	Area 9
61	MET (Military Effects Test)	04/15/1955	LANL/DoD	NTS	Area 5
62	Apple-2	05/05/1955	LANL	NTS	Area 1
63	Zucchini	05/15/1955	LANL	NTS	Area 7
Operation Wigwam					
64	Wigwam North 29 degrees, West 126 degrees	05/14/1955	LANL/DoD	Pacific	- - - -
Operation Project 56					
65	Project 56 No. 1	11/01/1955	LANL	NTS	Area 11 a
66	Project 56 No. 2 Plutonium dispersal	11/03/1955	LANL	NTS	Area 11 b
67	Project 56 No. 3 Plutonium dispersal	11/05/1955	LANL	NTS	Area 11 c
68	Project 56 No. 4 Plutonium dispersal	01/18/1956	LANL	NTS	Area 11 d
Operation Redwing					
69	Lacrosse	05/04/1956	LANL	Enewetak	- - - -
70	Cherokee First airdrop by U.S. of a thermonuclear weapon	05/20/1956	LANL	Bikini Island	- - - -
71	Zuni	05/27/1956	LLNL	Bikini Island	- - - -
72	Yuma	05/27/1956	LLNL	Enewetak	- - - -
73	Erie	05/30/1956	LANL	Enewetak	- - - -
74	Seminole	06/06/1956	LANL	Enewetak	- - - -
75	Flathead	06/11/1956	LANL	Bikini Island	- - - -
76	Blackfoot	06/11/1956	LANL	Enewetak	- - - -
77	Kickapoo	06/13/1956	LLNL	Enewetak	- - - -
78	Osage	06/16/1956	LANL	Enewetak	- - - -

July 1945 through October 1958							
Time (GMT)	**Latitude (degrees)**	**Longitude (degrees)**	**Surface Elevation (meters)**	**Type**	**Purpose**	**Yield Range**	
Operation Teapot - Continued							
				Tower	Weapons Related	7 kt	52
				Tower	Weapons Related	43 kt	53
				Tower	Weapons Related	4 kt	54
				Tower	Weapons Related	8 kt	55
20:30:00.00	37.170	-116.045	1280	Crater	Weapons Effects	1 kt	56
				Tower	Weapons Related	14 kt	57
				Airdrop	Weapons Related	3 kt	58
				Airdrop	Weapons Effects	3 kt	59
				Tower	Weapons Related	2 kt	60
				Tower	Weapons Effects	22 kt	61
				Tower	Weapons Related	29 kt	62
				Tower	Weapons Related	28 kt	63
Operation Wigwam							
				Underwater	Weapons Effects	30 kt	64
Operation Project 56							
				Surface	Safety Experiment	Zero	65
				Surface	Safety Experiment	Zero	66
				Surface	Safety Experiment	No yield	67
				Surface	Safety Experiment	Very slight	68
Operation Redwing							
				Surface	Weapons Related	40 kt	69
				Airdrop	Weapons Related	3.8 Mt	70
				Surface	Weapons Related	3.5 Mt	71
				Tower	Weapons Related	190 tons	72
				Tower	Weapons Related	14.9 kt	73
				Surface	Weapons Related	13.7 kt	74
				Barge	Weapons Related	365 kt	75
				Tower	Weapons Related	8 kt	76
				Tower	Weapons Related	1.49 kt	77
				Airdrop	Weapons Related	1.7 kt	78

United States Nuclear Tests - By Date

	Test	Date (mm/dd/yyyy) (GMT)	Sponsor	Location	Hole
Operation Redwing - Continued					
79	Inca	06/21/1956	LLNL	Enewetak	- - - -
80	Dakota	06/25/1956	LANL	Bikini Island	- - - -
81	Mohawk	07/02/1956	LLNL	Enewetak	- - - -
82	Apache	07/08/1956	LLNL	Enewetak	- - - -
83	Navajo	07/10/1956	LANL	Bikini Island	- - - -
84	Tewa	07/20/1956	LLNL	Bikini Island	- - - -
85	Huron	07/21/1956	LANL	Enewetak	- - - -
Operation Project 57					
86	Project 57 No.1 Plutonium dispersal	04/24/1957	LANL/DoD	NAFR	- - - -
Operation Plumbob					
87	Boltzmann	05/28/1957	LANL	NTS	Area 7
88	Franklin	06/02/1957	LANL	NTS	Area 3
89	Lassen Radioactivity not detected offsite	06/05/1957	LLNL	NTS	Area 9
90	Wilson	06/18/1957	LLNL	NTS	Area 9
91	Priscilla	06/24/1957	LANL/DoD	NTS	Area 5
92	Coulomb-A Radioactivity not detected offsite	07/01/1957	LANL	NTS	Area 3
93	Hood Highest yield Nevada Test Site atmospheric test	07/05/1957	LLNL	NTS	Area 9
94	Diablo	07/15/1957	LLNL	NTS	Area 2
95	John Air-to-air missile	07/19/1957	LANL/DoD	NTS	Area 10
96	Kepler	07/24/1957	LANL	NTS	Area 4
97	Owens	07/25/1957	LLNL	NTS	Area 9
98	Pascal-A Unstemmed hole	07/26/1957	LANL	NTS	U3j
99	Stokes	08/07/1957	LANL	NTS	Area 7
100	Saturn No radioactive release detected	08/10/1957	LLNL	NTS	U12c.02
101	Shasta	08/18/1957	LLNL	NTS	Area 2
102	Doppler	08/23/1957	LANL	NTS	Area 7
103	Pascal-B Unstemmed hole No radioactive release detected	08/27/1957	LANL	NTS	U3d
104	Franklin Prime	08/30/1957	LANL	NTS	Area 7
105	Smoky	08/31/1957	LLNL	NTS	Area 2

July 1945 through October 1958							
Time (GMT)	Latitude (degrees)	Longitude (degrees)	Surface Elevation (meters)	Type	Purpose	Yield Range	
Operation Redwing - Continued							
				Tower	Weapons Related	15.2 kt	79
				Barge	Weapons Related	1.1 Mt	80
				Tower	Weapons Related	360 kt	81
				Barge	Weapons Related	1.85 Mt	82
				Barge	Weapons Related	4.5 Mt	83
				Barge	Weapons Related	5 Mt	84
				Barge	Weapons Related	250 kt	85
Operation Project 57							
				Surface	Safety Experiment	Zero	86
Operation Plumbob							
				Tower	Weapons Related	12 kt	87
				Tower	Weapons Related	140 tons	88
				Balloon	Weapons Related	0.5 tons	89
				Balloon	Weapons Related	10 kt	90
				Balloon	Weapons Related	37 kt	91
				Surface	Safety Experiment	Zero	92
				Balloon	Weapons Related	74 kt	93
				Tower	Weapons Related	17 kt	94
				Rocket	Weapons Effects	About 2 kt	95
				Tower	Weapons Related	10 kt	96
				Balloon	Weapons Related	9.7 kt	97
08:00:00.00	37.052	-116.034	1202	Shaft	Safety Experiment	Slight	98
				Balloon	Weapons Related	19 kt	99
00:59:55.10	37.194	-116.034	- - - -	Tunnel	Safety Experiment	Zero	100
				Tower	Weapons Related	17 kt	101
				Balloon	Weapons Related	11 kt	102
22:35:00.00	37.049	-116.035	1201	Shaft	Safety Experiment	Slight	103
				Balloon	Weapons Related	4.7 kt	104
				Tower	Weapons Related	44 kt	105

United States Nuclear Tests - By Date					
Test		Date (mm/dd/yyyy) (GMT)	Sponsor	Location	Hole
Operation Plumbob - Continued					
106	Galileo	09/02/1957	LANL	NTS	Area 1
107	Wheeler	09/06/1957	LLNL	NTS	Area 9
108	Coulomb-B	09/06/1957	LANL	NTS	S3g
109	Laplace	09/08/1957	LANL	NTS	Area 7
110	Fizeau	09/14/1957	LANL	NTS	Area 3
111	Newton	09/16/1957	LANL	NTS	Area 7
112	Rainier First detonation contained underground No radioactive release detected	09/19/1957	LLNL	NTS	U12b
113	Whitney	09/23/1957	LLNL	NTS	Area 2
114	Charleston	09/28/1957	LLNL	NTS	Area 9
115	Morgan	10/07/1957	LLNL	NTS	Area 9
Operation Project 58					
116	Pascal-C Unstemmed hole Radioactivity not detected offsite	12/06/1957	LANL	NTS	U3e
117	Coulomb-C	12/09/1957	LANL	NTS	S3i
Operation Project 58 A					
118	Venus No radioactive release detected	02/22/1958	LLNL	NTS	U12d.01
119	Uranus No radioactive release detected	03/14/1958	LLNL	NTS	U12c.01
Operation Hardtack I					
Note: Three DoD high-altitude tests were conducted in the Pacific during Operation Hardtack I.					
120	Yucca Operation Newsreel North 12 degrees 37 minutes, East 163 degrees 01 minute High altitude - 86,000 feet	04/28/1958	LANL/DoD	Pacific	- - - -
121	Cactus	05/05/1958	LANL	Enewetak	- - - -
122	Fir	05/11/1958	LLNL	Bikini Island	- - - -
123	Butternut	05/11/1958	LANL	Enewetak	- - - -
124	Koa	05/12/1958	LANL	Enewetak	- - - -
125	Wahoo	05/16/1958	LANL/DoD	Enewetak	- - - -
126	Holly	05/20/1958	LANL	Enewetak	- - - -
127	Nutmeg	05/21/1958	LLNL	Bikini Island	- - - -
128	Yellowwood	05/26/1958	LANL	Enewetak	- - - -
129	Magnolia	05/26/1958	LANL	Enewetak	- - - -
130	Tobacco	05/30/1958	LANL	Enewetak	- - - -

July 1945 through October 1958							
Time (GMT)	Latitude (degrees)	Longitude (degrees)	Surface Elevation (meters)	Type	Purpose	Yield Range	
Operation Plumbob - Continued							
				Tower	Weapons Related	11 kt	106
				Balloon	Weapons Related	197 tons	107
				Surface	Safety Experiment	300 tons	108
				Balloon	Weapons Related	1 kt	109
				Tower	Weapons Related	11 kt	110
				Balloon	Weapons Related	12 kt	111
16:59:59.45	37.196	-116.204	- - - -	Tunnel	Weapons Related	1.7 kt	112
				Tower	Weapons Related	19 kt	113
				Balloon	Weapons Related	12 kt	114
				Balloon	Weapons Related	8 kt	115
Operation Project 58							
22:15:00.00	37.050	-116.032	1202	Shaft	Safety Experiment	Slight	116
				Surface	Safety Experiment	500 tons	117
Operation Project 58 A							
01:00:00.00	37.113	-116.115	- - - -	Tunnel	Safety Experiment	Less than 1 ton	118
22:00:00.00	37.113	-116.115	- - - -	Tunnel	Safety Experiment	Less than 1 ton	119
Operation Hardtack I							
These tests were conducted as Operation Newsreel.							
				Balloon	Weapons Effects	1.7 kt	120
				Surface	Weapons Related	18 kt	121
				Barge	Weapons Related	1.36 Mt	122
				Barge	Weapons Related	81 kt	123
				Surface	Weapons Related	1.37 Mt	124
				Underwater	Weapons Effects	9 kt	125
				Barge	Weapons Related	5.9 kt	126
				Barge	Weapons Related	25.1 kt	127
				Barge	Weapons Related	330 kt	128
				Barge	Weapons Related	57 kt	129
				Barge	Weapons Related	11.6 kt	130

United States Nuclear Tests - By Date

	Test	Date (mm/dd/yyyy) (GMT)	Sponsor	Location	Hole
Operation Hardtack I - Continued					
131	Sycamore	05/31/1958	LLNL	Bikini Island	- - - -
132	Rose	06/02/1958	LANL	Enewetak	- - - -
133	Umbrella	06/08/1958	LANL/DoD	Enewetak	- - - -
134	Maple	06/10/1958	LLNL	Bikini Island	- - - -
135	Aspen	06/14/1958	LLNL	Bikini Island	- - - -
136	Walnut	06/14/1958	LANL	Enewetak	- - - -
137	Linden	06/18/1958	LANL	Enewetak	- - - -
138	Redwood	06/27/1958	LLNL	Bikini Island	- - - -
139	Elder	06/27/1958	LANL	Enewetak	- - - -
140	Oak	06/28/1958	LANL	Enewetak	- - - -
141	Hickory	06/29/1958	LLNL	Bikini Island	- - - -
142	Sequoia	07/01/1958	LANL	Enewetak	- - - -
143	Cedar	07/02/1958	LLNL	Bikini Island	- - - -
144	Dogwood	07/05/1958	LLNL	Enewetak	- - - -
145	Poplar	07/12/1958	LLNL	Bikini Island	- - - -
146	Scaevola	07/14/1958	LANL	Enewetak	- - - -
147	Pisonia	07/17/1958	LANL	Enewetak	- - - -
148	Juniper	07/22/1958	LLNL	Bikini Island	- - - -
149	Olive	07/22/1958	LLNL	Enewetak	- - - -
150	Pine	07/26/1958	LLNL	Enewetak	- - - -
151	Teak Operation Newsreel High altitude - 77 kilometers	08/01/1958	LANL/DoD	Johnston Island area	- - - -
152	Quince	08/06/1958	LLNL/DoD	Enewetak	- - - -
153	Orange Operation Newsreel High altitude - 43 kilometers	08/12/1958	LANL/DoD	Johnston Island area	- - - -
154	Fig	08/18/1958	LLNL/DoD	Enewetak	- - - -
Operation Argus					
155	Argus I About 300 miles altitude Aouth 38.5 degrees, West 11.5 degrees	08/27/1958	LANL/DoD	South Atlantic	- - - -
156	Argus II About 300 miles altitude South 49.5 degrees, West 8.2 degrees	08/30/1958	LANL/DoD	South Atlantic	- - - -
157	Argus III About 300 miles altitude South 48.5 degrees, West 9.7 degrees	09/06/1958	LANL/DoD	South Atlantic	- - - -

July 1945 through October 1958

Time (GMT)	Latitude (degrees)	Longitude (degrees)	Surface Elevation (meters)	Type	Purpose	Yield Range	
Operation Hardtack I - Continued							
				Barge	Weapons Related	92 kt	131
				Barge	Weapons Related	15 kt	132
				Underwater	Weapons Effects	8 kt	133
				Barge	Weapons Related	213 kt	134
				Barge	Weapons Related	319 kt	135
				Barge	Weapons Related	1.45 Mt	136
				Barge	Weapons Related	11 kt	137
				Barge	Weapons Related	412 kt	138
				Barge	Weapons Related	880 kt	139
				Barge	Weapons Related	8.9 Mt	140
				Barge	Weapons Related	14 kt	141
				Barge	Weapons Related	5.2 kt	142
				Barge	Weapons Related	220 kt	143
				Barge	Weapons Related	397 kt	144
				Barge	Weapons Related	9.3 Mt	145
				Barge	Safety Experiment	Zero	146
				Barge	Weapons Related	255 kt	147
				Barge	Weapons Related	65 kit	148
				Barge	Weapons Related	202 kt	149
				Barge	Weapons Related	2 Mt	150
				Rocket	Weapons Effects	3.8 Mt	151
				Surface	Weapons Related	Zero	152
				Rocket	Weapons Effects	3.8 Mt	153
				Surface	Weapons Related	20 tons	154
Operation Argus							
				Rocket	Weapons Effects	1-2 kt	155
				Rocket	Weapons Effects	1-2 kt	156
				Rocket	Weapons Effects	1-2 kt	157

United States Nuclear Tests - By Date					
Test		Date (mm/dd/yyyy) (GMT)	Sponsor	Location	Hole
Operation Hardtack II					
158	Otero Unstemmed hole	09/12/1958	LANL	NTS	U3q
159	Bernalillo Unstemmed hole Radioactivity not detected offsite	09/17/1958	LANL	NTS	U3n
160	Eddy	09/19/1958	LANL	NTS	Area 7
161	Luna Unstemmed hole Radioactivity not detected offsite	09/21/1958	LANL	NTS	U3m
162	Mercury No radioactive release detected	09/23/1958	LLNL	NTS	U12f.01
163	Valencia Unstemmed hole Radioactivity not detected offsite	09/26/1958	LANL	NTS	U3r
164	Mars Slight venting Radioactivity not detected offsite	09/28/1958	LLNL	NTS	U12f.02
165	Mora	09/29/1958	LANL	NTS	Area 7
166	Colfax Unstemmed hole Radioactivity not detected offsite	10/05/1958	LANL	NTS	U3k
167	Hidalgo	10/05/1958	LANL	NTS	Area 7
168	Tamalpais Slight venting Radioactivity not detected offsite	10/08/1958	LLNL	NTS	U12b.02
169	Quay	10/10/1958	LANL	NTS	Area 7
170	Lea	10/13/1958	LANL	NTS	Area 7
171	Neptune Slight venting Radioactivity not detected offsite First underground test to form a subsidence crater	10/14/1958	LLNL	NTS	U12c.03
172	Hamilton	10/15/1958	LLNL/DoD	NTS	Area 5
173	Logan No radioactive release detected	10/16/1958	LLNL	NTS	U12e.02
174	Dona Ana	10/16/1958	LANL	NTS	Area 7
175	Vesta Fired in surface structure	10/17/1958	LLNL	NTS	S9e
176	Rio Arriba	10/18/1958	LANL	NTS	Area 3
177	San Juan Unstemmed hole No radioactive release detected	10/20/1958	LANL	NTS	U3p

July 1945 through October 1958							
Time (GMT)	Latitude (degrees)	Longitude (degrees)	Surface Elevation (meters)	Type	Purpose	Yield Range	
Operation Hardtack II							
20:00:00.00	37.050	-116.033	1202	Shaft	Safety Experiment	38 tons	158
19:30:00.00	37.050	-116.034	1201	Shaft	Safety Experiment	15 tons	159
				Balloon	Weapons Related	83 tons	160
19:00:00.00	37.049	-116.035	1201	Shaft	Safety Experiment	1.5 tons	161
22:00:00.00	37.113	-116.121	2021	Tunnel	Safety Experiment	Slight	162
20:00:00.00	37.050	-116.031	1201	Shaft	Safety Experiment	2 tons	163
00:00:00.00	37.193	-116.201	2021	Tunnel	Safety Experiment	13 tons	164
				Balloon	Weapons Related	2 kt	165
16:15:00.00	37.049	-116.035	1201	Shaft	Safety Experiment	5.5 tons	166
				Balloon	Safety Experiment	77 tons	167
22:00:00.13	37.195	-116.201	2000	Tunnel	Weapons Related	72 tons	168
				Tower	Weapons Related	79 tons	169
				Balloon	Weapons Related	1.4 kt	170
18:00:00.00	37.194	-116.201	2045	Tunnel	Safety Experiment	115 tons	171
				Tower	Weapons Related	1.2 tons	172
06:00:00.14	37.184	-116.202	- - - -	Tunnel	Weapons Related	5 kt	173
				Balloon	Weapons Related	37 tons	174
				Surface	Safety Experiment	24 tons	175
				Tower	Weapons Related	90 tons	176
14:30:00.00	37.050	-116.033	1201	Shaft	Safety Experiment	Zero	177

United States Nuclear Tests - By Date					
Test		Date (mm/dd/yyyy) (GMT)	Sponsor	Location	Hole
Operation Hardtack II - Continued					
178	Socorro	10/22/1958	LANL	NTS	Area 7
179	Wrangell	10/22/1958	LLNL	NTS	Area 5
180	Rushmore	10/22/1958	LLNL	NTS	Area 9
181	Oberon No radioactive release detected	10/22/1958	LANL	NTS	Area 8
182	Catron	10/24/1958	LANL	NTS	Area 3
183	Juno Fired in surface structure Radioactivity not detected offsite	10/24/1958	LLNL	NTS	S9f
184	Ceres Radioactivity not detected offsite	10/26/1958	LLNL	NTS	Area 8
185	Sanford	10/26/1958	LLNL	NTS	Area 5
186	De Baca	10/26/1958	LANL	NTS	Area 7
187	Chaves (Chavez)	10/27/1958	LANL	NTS	Area 3
188	Evans Venting Radioactivity not detected offsite	10/29/1958	LLNL	NTS	U12b.04
189	Humboldt	10/29/1958	LLNL/DoD	NTS	Area 3
190	Mazama No radioactive release detected	10/29/1958	LLNL	NTS	Area 9
191	Santa Fe	10/30/1958	LANL	NTS	Area 7
192	Blanca Slight venting	10/30/1958	LLNL	NTS	U12e.05
193	Ganymede Contained in surface structure No radioactive release detected	10/30/1958	LLNL	NTS	S9g
194	Titania	10/30/1958	LLNL	NTS	Area 8

July 1945 through October 1958

Time (GMT)	Latitude (degrees)	Longitude (degrees)	Surface Elevation (meters)	Type	Purpose	Yield Range	
Operation Hardtack II - Continued							
				Balloon	Weapons Related	6 kt	178
				Balloon	Weapons Related	115 tons	179
				Balloon	Weapons Related	188 tons	180
				Tower	Safety Experiment	Zero	181
				Tower	Safety Experiment	21 tons	182
				Surface	Safety Experiment	1.7 tons	183
				Tower	Safety Experiment	0.7 tons	184
				Balloon	Weapons Related	4.9 kt	185
				Balloon	Weapons Related	2.2 kt	186
				Tower	Safety Experiment	0.6 tons	187
00:00:00.15	37.195	-116.206	2000	Tunnel	Weapons Related	55 tons	188
				Tower	Weapons Related	7.8 tons	189
				Tower	Weapons Related	Zero	190
				Balloon	Weapons Related	1.3 kt	191
15:00:00.15	37.186	-116.203	2145	Tunnel	Weapons Related	22 kt	192
				Surface	Safety Experiment	Zero	193
				Tower	Safety Experiment	0.2 tons	194

Acronyms and Abbreviations

AEC	Atomic Energy Commission
AFB	Air Force Base
AFSWP	Armed Forces Special Weapons Project
CDC	Center for Disease Control
CM	Atomic Energy Commission meeting
DBM	Division of Biology and Medicine
DMA	Division of Military Application
DNA	Defense Nuclear Agency
DOD	Department of Defense
DOE	Department of Energy
DOS	Department of State
EG&G	Edgerton, Germeshausen and Grier, Inc.
EMP	Electromagnetic pulse
FCDA	Federal Civil Defense Administration
GMT	Greenwich Mean Time
GPO	Government Printing Office
ICBM	Intercontinental Ballistic Missile
KT	Kiloton
LANL	Los Alamos National Laboratory
LASL	Las Alamos Scientific Laboratory
LLNL	Lawrence Livermore National Laboratory
MLC	Military Liaison Committee
MT	Megaton
NAFR	Nellis Air Force Range
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NPG	Nevada Proving Ground
NSC	National Security Council
NTS	Nevada Test Site
PSAC	President's Science Advisory Committee
REECo	Reynolds Electrical and Engineering Company, Inc.
TIO	Test Information Office

Endnotes

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Epilogue: From Moratorium to Atmospheric Test Ban Treaty, 1958-1963

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