U.S. NUCLEAR TESTING FROM PROJECT TRINITY TO THE PLOWSHARE PROGRAM

[From For the Record – A History of the Nuclear Test Personnel Review Program, 1978-1986, by Abby A. Johnson, et al, Defense Nuclear Agency, DNA 6041F, 1986.

The United States conducted Project TRINITY, the world's first nuclear detonation, in 1945. From 1946 to 1963, when the limited nuclear test ban treaty was signed, the U.S. conducted 18 atmospheric nuclear test series, identified below as operations, and a program of testing called PLOWSHARE. In addition, the U.S. staged safety experiments to determine the weapons' susceptibility to fission due to accidents in storage and transport. This chapter provides historical summaries of the tests, listed below in the order in which they occurred and are addressed:

- Project TRINITY, 1945 (CONUS)
- Operation CROSSROADS, 1946 (Oceanic)
- Operation SANDSTONE, 1948 (Oceanic)
- Operation RANGER, 1951 (CONUS)
- Operation GREENHOUSE, 1951 (Oceanic)
- Operation BUSTER-JANGLE, 1951 (CONUS)
- Operation TUMBLER-SNAPPER, 1952 (CONUS)
- Operation IVY, 1952 (Oceanic)
- Operation UPSHOT-KNOTHOLE, 1953 (CONUS)
- Operation CASTLE, 1954 (Oceanic)
- Operation TEAPOT, 1955 (CONUS)
- Operation WIGWAM, 1955 (Oceanic)
- Operation REDWING, 1956 (Oceanic)
- Operation PLUMBBOB, 1957 (CONUS)
- Operation HARDTACK I, 1958 (Oceanic)
- Operation ARGUS, 1958 (Oceanic)
- Operation HARDTACK II, 1958 (CONUS)
- Safety Experiments, 1955-1958 (CONUS)
- Operation DOMINIC I, 1962 (Oceanic)
- Operation DOMINIC II, 1962 (CONUS)
- PLOWSHARE Program, 1961-1962 (CONUS).

Most of the oceanic tests were conducted at the Pacific Proving Ground, which consisted principally of the Enewetak and Bikini Atolls in the northwestern Marshall Islands of the Pacific Ocean. The Marshall Islands are in the easternmost part of Micronesia. The Marshalls spread over about 2 million km^2 of the earth's surface, but the total land area is only about 180 km^2 * . Two parallel chains form the islands: Ratak (or Sunrise) to the east, and Ralik (or Sunset) to the west; both Enewetak and Bikini are in the Ralik chain at its northern extreme. Figure 5 shows these islands in the central Pacific. It also indicates the locations of the Christmas and Johnston Islands, the sites for most of the DOMINIC I tests.

* Throughout this chapter, surface distances are given in metric units. The metric conversion factors include: 1 meter = 3.28 feet; 1 meter = 1.09 yards; and 1 kilometer = 0.62 miles. Vertical distances are given in feet; altitudes are measured from mean sea level, while heights are measured from surface level, unless otherwise noted.

Most of the continental U.S. (CONUS) atmospheric tests were conducted at the Nevada Test Site (NTS). Established by the Atomic Energy Commission (AEC) in December 1950, the NTS is in the southeastern part of Nevada, 100 kilometers northwest of Las Vegas. Figure 6 shows the current NTS, an area of high desert and mountain terrain now encompassing approximately 3,500 square kilometers in Nye County. On its eastern, northern, and western boundaries, the NTS adjoins the Nellis Air Force Range.

The format of this chapter is generally consistent for the following sections, each of which summarizes a nuclear test series. The section begins by identifying the nuclear events and continues by discussing relevant background and objectives, test operations, and radiation doses.

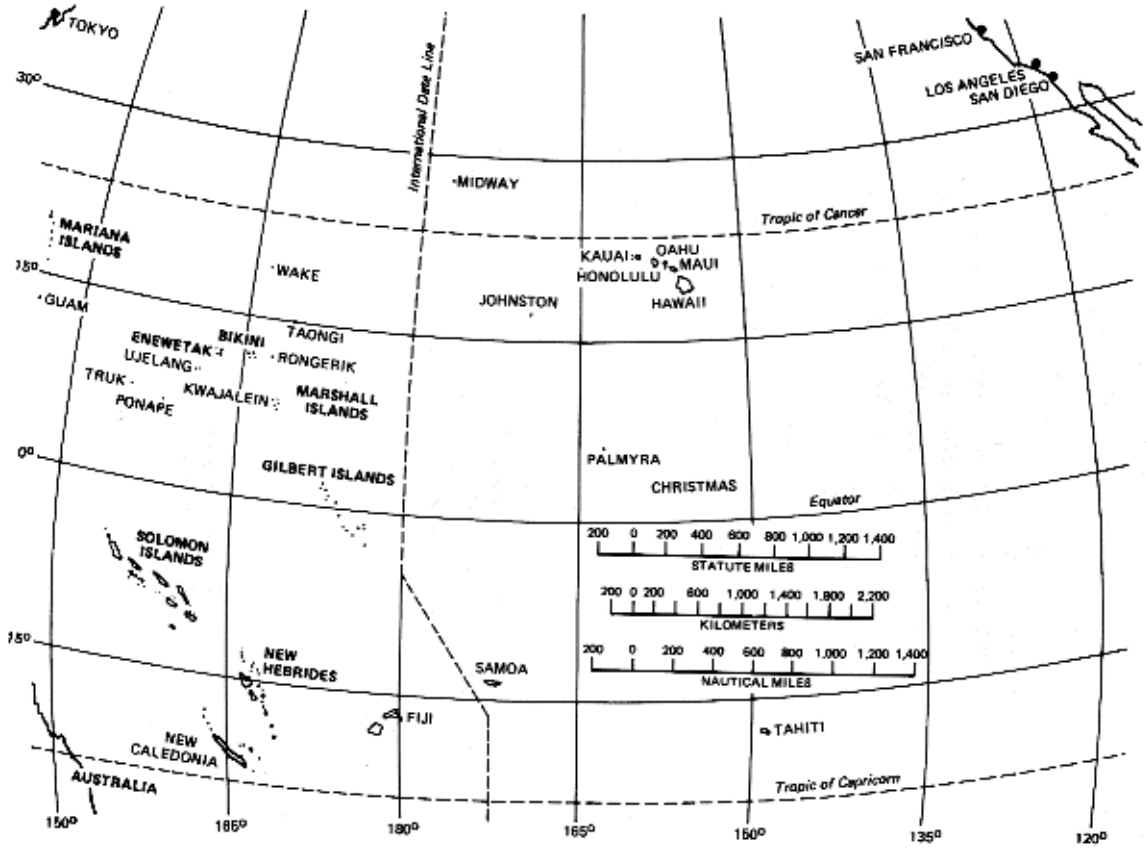


Figure 5. The Pacific Proving Ground.

The NTPR teams provided data current as of 1 May 1986 on the radiation doses. The rest of the material derives from the volumes published by the Defense Nuclear Agency (DNA) on the nuclear test series. These volumes, listed in Appendix E, can be consulted for further information.

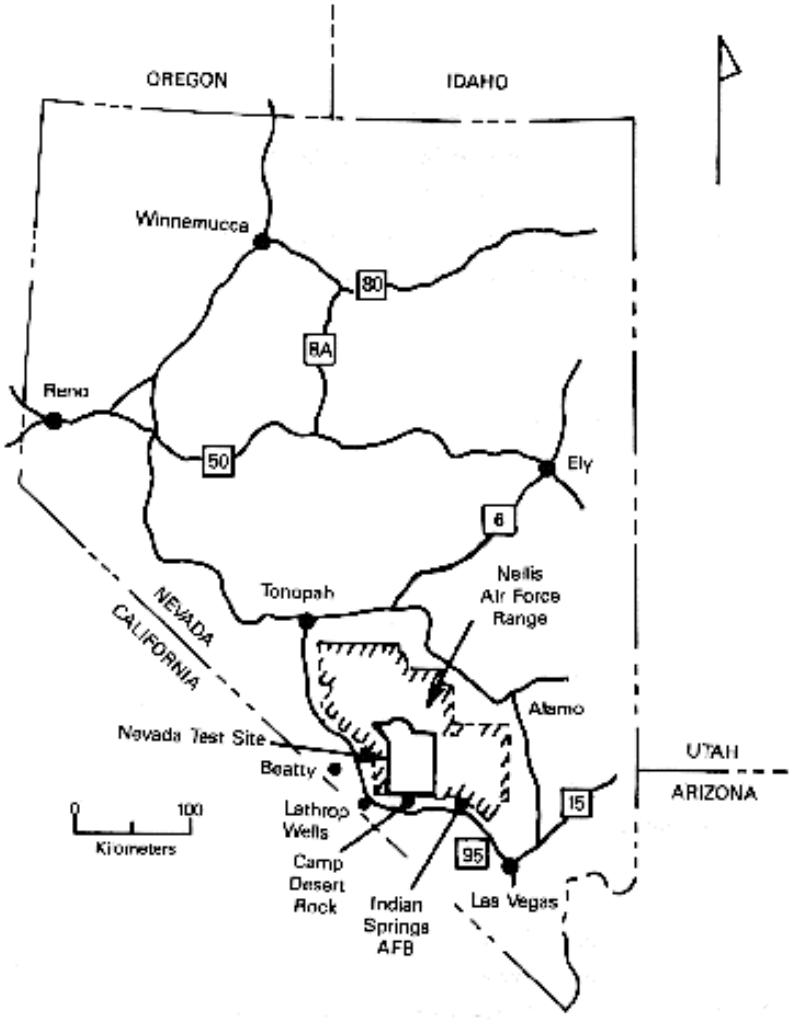


Figure 6. The Nevada Test Site

4.1 Project TRINITY

Project TRINITY was the first detonation of a nuclear weapon. The plutonium-fueled implosion device was detonated on a 100-foot tower at 0530 hours, 16 July 1945. The test, which occurred on the Alamogordo Bombing Range in south-central New Mexico, had a nuclear yield equivalent to the energy released by exploding 21 kilotons of TNT. It left a depression in the desert 2.9 meters deep and 335 meters wide (1: 1,23).

People as far away as Santa Fe and El Paso saw the brilliant light of the detonation. Windows rattled in the areas immediately surrounding the test site, waking sleeping ranchers and

townspeople. To dispel any rumors that might compromise the security of this first nuclear test, the Government announced that an Army munitions dump had exploded. However, immediately after the bombing of Hiroshima, Japan, on 6 August 1945, the Government revealed to the public what had actually occurred in the New Mexico desert (1: 33).

4.1.1 Background and Objectives of Project TRINITY.

The United States' effort to develop a nuclear weapon came during World War II in response to the potential threat of a German nuclear weapon. On 6 December 1941, President Roosevelt appointed a committee to determine if the United States could construct a nuclear weapon. Six months later, the committee gave the President its report, recommending a fast-paced program that would cost up to $100 million and that might produce the weapon by July 1944 (1: 12,13).

The President accepted the committee's recommendation. The effort to construct the weapon was turned over to the War Department, which assigned the task to the Army Corps of Engineers. In September 1942, the Corps of Engineers established the Manhattan Engineer District (MED), under the command of Major General Leslie Groves, to oversee the development of a nuclear weapon. This effort was code named the "Manhattan Project" (1: 13).

During the first 2 years of the Manhattan Project, work proceeded at a slow but steady pace. Significant technical problems had to be solved, and difficulties in the concentration of uranium-235 and production of plutonium, particularly the inability to process large amounts, often frustrated the scientists. Nonetheless, by 1944 sufficient progress had been made to persuade the scientists that their efforts might succeed. A test of the plutonium implosion device was necessary to determine if it would work and what its effects would be. Led by Dr. J. Robert Oppenheimer, Manhattan Project scientists at Los Alamos Laboratory (later to become the Los Alamos National Laboratory) were "to make preparations for a field test in which blast, earth shock, neutron and gamma radiation would be studied and complete photographic records made of the explosion and any atmospheric phenomena connected with the explosion" (1: 13,14).

The planned firing date for the TRINITY device was originally 4 July 1945. On 14 June 1945, Dr. Oppenheimer changed the test date to no earlier than 13 July and no later than 23 July. On 30 June, the earliest firing date was moved to 16 July, even though better weather was forecast for 18 and 19 July. The TRINITY test organization adjusted the schedule because the Allied conference in Potsdam, Germany, was about to begin and the President needed the results of the test as soon as possible (1: 26).

On 6 August 1945, 3 weeks after the detonation of TRINITY, the first uranium-fueled nuclear bomb, a gun-type weapon code named LITTLE BOY, was detonated over Hiroshima. On 9 August, FAT MAN, a plutonium-fueled implosion weapon with the same design as the TRINITY device, was detonated over another Japanese city, Nagasaki. Two days later, the Japanese Government informed the United States of its decision to surrender. On 2 September 1945, Japan officially surrendered to the Allied Governments, thereby bringing World War II to an end (1: 11).

4.1.2 TRINITY Test Operations.

From 16 July 1945 through 1946, about 1,000 military and civilian personnel took part in Project TRINITY or visited the test site. All participants, civilian as well as military, were under the authority of the MED. Project activities included scientific studies. Military exercises were not conducted at TRINITY (1: 1).

The Los Alamos Laboratory, which was staffed and administered by the University of California (under contract to the MED), conducted diagnostic experiments. Before the detonation, civilian and military scientists and technicians, assisted by other military personnel, placed gauges, detectors, and other instruments around ground zero. Four offsite monitoring posts were established in the towns of Nogal, Roswell, Socorro, and Fort Sumner, New Mexico. An evacuation detachment consisting of 144 to 160 enlisted men and officers was established in case protective measures or evacuation of civilians living offsite became necessary. Such action was not deemed necessary, however, and the evacuation detachment was dismissed late on the day of the detonation for return to Los Alamos (1: 1).

For the detonation, at least 263 DOD participants were at the test site. Among this group were 99 personnel occupying shelters approximately 9,175 meters north, south, and west of ground zero. No one was closer to ground zero at shot-time (1: 31).

To determine the extent of the radiation resulting from the detonation, a network of detectors with remote read-out was installed along routes between ground zero and each shelter. In addition, trained monitors with portable radiation survey instruments were assigned to each shelter. No radiation was detected at the south and west shelters. The remote detectors north of ground zero indicated that the radioactive cloud was moving in that direction, and a monitor in the north shelter observed a sharp increase in the radiation level. The shelter was consequently evacuated shortly after the detonation. It was learned later that the monitor had inadvertently changed an adjustment on his instrument, which resulted in a false reading. Very little contamination occurred at the north shelter (1: 1,2).

A substantial amount of activity took place at the test site during the first 3 days following the detonation, as scientists entered the ground zero area to retrieve instruments or to perform experiments. Their entry into, activities at, and exit from the test site were carefully controlled. When the itinerary indicated operations in regions of known radiation intensity, a limit was set on the time spent in the area. Radiation detectors were provided, when possible, to permit continuous monitoring of the exposure. Film badges were also provided to each person for subsequent determination and recording of the doses received. The number of personnel at the TRINITY test site diminished rapidly after 19 July, as the emphasis shifted to preparing the devices that were to be used over Japan (1: 38).

4.1.3 Dose Summary for Project TRINITY.

The dose limit for TRINITY participants was 5.0 rem (roentgen equivalent man) of gamma radiation during a 2-month period (2: 29). The table below summarizes the available dosimetry information:

Summary of External Doses for Project TRINITY as of 1 May 1986
Gamma Dose (rem)

	0-0.5	0.5-1	1-3	3-5	5-10	10+
Army	103	15	30	10	1	1
Navy	2	0	2	0	0	0

4.2 OPERATION CROSSROADS.

Conducted in 1946 at Bikini, CROSSROADS involved approximately 42,000 personnel, 251 ships, and 156 aircraft. The series consisted of an airdrop detonated at a height of 520 feet and an underwater shot conducted at a depth of 90 feet:

Event	Date	Type	Yield (kilotons)
ABLE	1 July	Airdrop	21
BAKER	25 July	Underwater	21

The nuclear devices were similar to the TRINITY device and to the weapon detonated over Nagasaki, Japan (3: 17).

Among the numerous observers of these two detonations was an Army doctor trained as a radiological safety monitor. He made the following observations of ABLE and BAKER from a Navy aircraft approximately 20 nautical miles from each detonation:

ABLE: At twenty miles [it] gave us no sound or flash or shock wave. . . . Then, suddenly we saw it -- a huge column of clouds, dense, white, boiling up through the strato-cumulus, looking much like any other thunderhead but climbing as no storm cloud ever could. The evil mushrooming head soon began to blossom out. It climbed rapidly to 30,000 or 40,000 feet, growing a tawny-pink from oxides of nitrogen, and seemed to be reaching out in an expanding umbrella overhead. . . . For minutes the cloud stood solid and impressive, like some gigantic monument, over Bikini. Then finally the shearing of the winds at different altitudes began to tear it up into a weird zigzag pattern (4: 55).

BAKER: This shot in broad day, at fifteen miles, seemed to spring from all parts of the target fleet at once. A gigantic flash -- then it was gone. And where it had been now stood a white chimney of water reaching up and up. Then a huge hemispheric mushroom of

> vapor appeared like a parachute suddenly opening. . . . By this time the great geyser had climbed to several thousand feet. It stood there as if solidifying for many seconds, its head enshrouded in a tumult of steam. Then slowly the pillar began to fall and break up. At its base a tidal wave of spray and steam arose, to smother the fleet and move on toward the islands. All this took only a few seconds, but the phenomenon was so astounding as to seem to last much longer (4: 93).

Figure 7 shows the BAKER detonation (A). Credits for Figure 7 and the subsequent photographs follow the references at the end of this chapter.

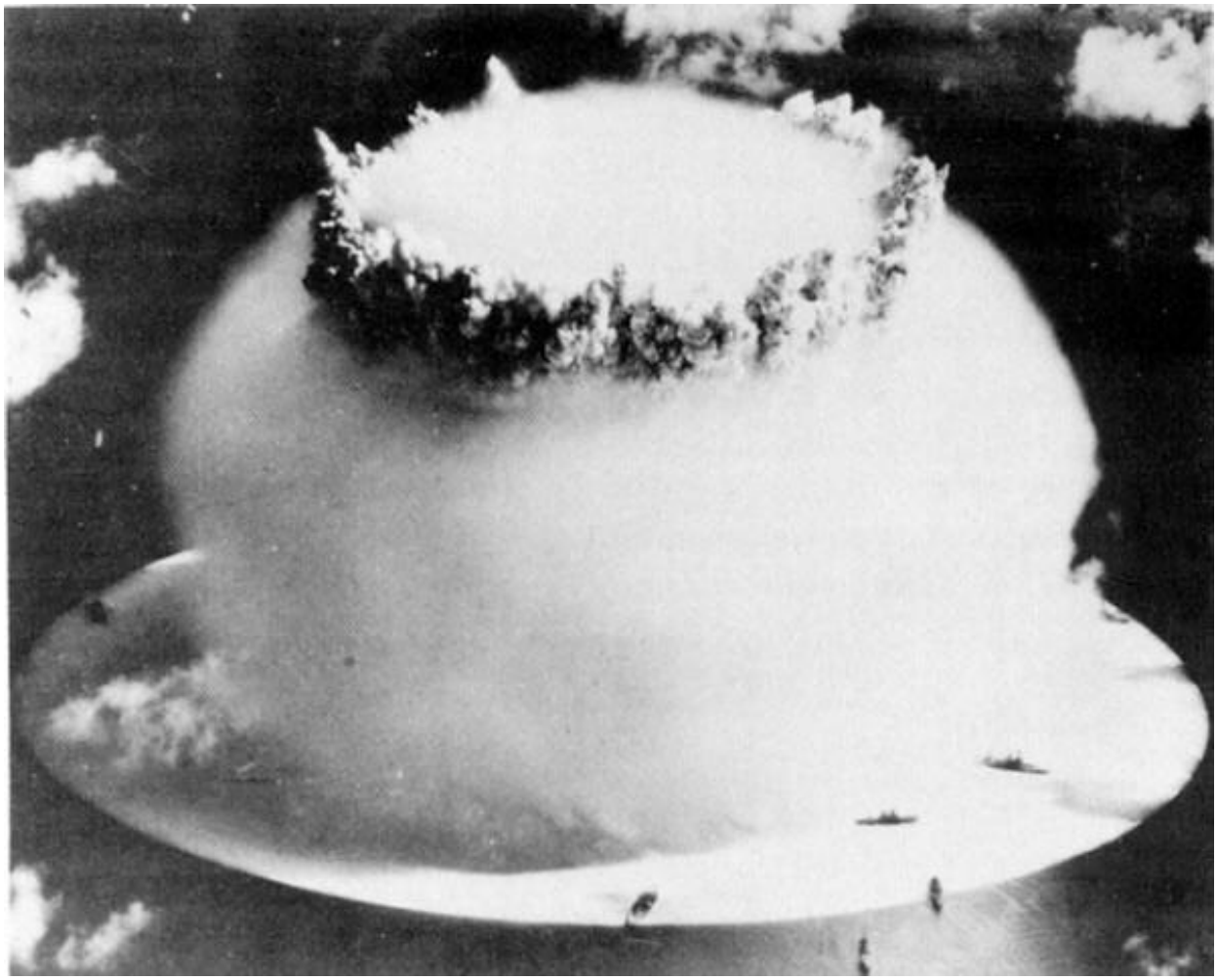


Figure 7. Shot BAKER emerging amidst the unmanned target fleet, 25 July 1946.

4.2.1 Background and Objectives of CROSSROADS.

After the atomic bomb attacks on Japan had abruptly ended World War II, many military leaders felt that military science was at a crossroads. The admiral who directed CROSSROADS declared that "warfare, perhaps civilization itself, had been brought to a turning point by this

revolutionary weapon." With this thought in mind, he named the initial postwar test series (3: 17).

As early as August 1945, the Chairman of the Senate's Special Committee on Atomic Energy proposed that the effectiveness of atomic bombs be demonstrated on captured Japanese ships. In September, the Commanding General of the Army Air Forces put the question of such a test before the Joint Chiefs of Staff (JCS). The ensuing discussion and recommendations led President Harry Truman to announce, on 10 December 1945, that the U.S. would further explore the capabilities of atomic energy in the form of scientific atomic bomb tests under JCS jurisdiction (3: 18).

CROSSROADS was designed to produce information not available from the TRINITY test or the Hiroshima and Nagasaki bombings. The primary purpose was to determine the effects of atomic bombs on naval vessels. The secondary purposes were to provide training for aircrews in attack techniques using atomic bombs against ships and to determine atomic bomb effects upon other military equipment and installations (3: 18).

4.2.2 CROSSROADS Test Operations.

A fleet of more than 90 target vessels was assembled in Bikini Lagoon for CROSSROADS. The target fleet consisted of older U.S. ships, such as the aircraft carriers USS Saratoga and the USS Independence, the battleships USS Nevada, USS Arkansas, USS Pennsylvania, and USS New York, surplus U.S. cruisers, destroyers, submarines, and a large number of auxiliary and amphibious vessels. The German cruiser Prinz Eugen and two major captured Japanese ships, the battleship Nagato and the cruiser Sakawa, also were targets. The support fleet comprised more than 150 ships that provided quarters, experimental stations, and workshops for most of the approximately 42,000 participants, more than 37,000 of whom were Navy personnel (3: 1,84).

ABLE operations went smoothly. The radioactivity created by the airburst had only a transient effect. Within a day, radiation intensities in the lagoon had decayed to less than 0.1 R/24 hours, and nearly all the surviving target ships had been safely reboarded. The ship inspections, instrument recoveries, and remooring necessary for the BAKER test proceeded on schedule (3: 1,217).

BAKER, on the other hand, presented difficulties. The underwater detonation caused most of the target fleet to be bathed in radioactive water spray and radioactive debris. With the exception of 12 target vessels in the lagoon and the landing craft beached on Bikini Island, the surviving target fleet was too radiologically contaminated for many days for more than brief on-board activities. During the first week of August, attempts were made to decontaminate the vessels. By 10 August, upon the advice of the Chief of the Radiological Safety Division, the Task Force Commander decided to terminate these efforts and tow most of the remaining target fleet to Kwajalein Atoll for possible decontamination (3: 2).

In the latter half of August 1946, the surviving target ships were towed or sailed to Kwajalein Atoll. Eight of the major ships and two submarines were towed back to the U.S. for radiological inspection. Twelve target ships were so lightly contaminated that their crews remanned them and sailed them back to the United States. The remaining target ships were destroyed by sinking off Bikini Atoll, off Kwajalein Atoll, or near the Hawaiian Islands during 1946-1948. The support ships were decontaminated as necessary at U.S. Navy shipyards, primarily in San Francisco and in Bremerton, Washington (3: 2).

4.2.3 Dose Summary for CROSSROADS.

CROSSROADS operations were undertaken under radiological supervision intended to keep personnel doses below 0.1 rem of gamma radiation per day. About 15 percent of the participants were issued film badges. Personnel anticipated to have the most potential for exposure were badged, and a percentage of each group working in less radioactive areas were badged (3: 2,3).

Because radiation dose data are not complete, reconstructions have been made of personnel doses for unbadged crewmembers of the ships involved. The calculations relied upon the radiation measurements recorded by radiation safety personnel in 1946 and used the types of methods discussed in chapter 7. The table below summarizes the available dosimetry information:

Summary of External Doses for Operation CROSSROADS
as of 1 May 1986
Gamma Dose (rem)

	0-0.5	0.5-1	1-3	3-5	5-10	10+
Army	3,250	25	15	10	0	0
Navy	28,436	4,883	2,939	4	0	0
Marine Corps	550	0	0	0	0	0

4.3 OPERATION SANDSTONE.

Conducted at the Enewetak Atoll in 1948, Operation SANDSTONE consisted of three tower shots, all detonated at a height of 200 feet (5: 1):

Event	Date	Type	Yield (kilotons)
X-RAY	15 April	Tower	37
YOKE	1 May	Tower	49
ZEBRA	15 May	Tower	18

4.3.1 Background and Objectives of Operation SANDSTONE.

Operation SANDSTONE was the second test series carried out in the Marshall Islands. It differed from the first, CROSSROADS, in that it was primarily a scientific series conducted by the Atomic Energy Commission. The AEC was activated on 1 January 1947 to assume the responsibilities formerly held by the Manhattan Engineer District, dissolved at the end of 1946. The Armed Forces had a supporting role in SANDSTONE, whereas they had assumed a lead role in CROSSROADS (5: 1).

SANDSTONE was a proof-test of second-generation nuclear devices. The two weapons detonated at CROSSROADS were the same type of weapon dropped on Nagasaki. On 3 April 1947, the General Advisory Committee to the AEC recommended development and testing of new weapons. When the President approved the preliminary SANDSTONE test program on 27 June 1947, the U.S. apparently had only 13 nuclear weapons in its stockpile. One year later, despite heavy emphasis on increased production of fissionable material, the number of weapons was only about 50, far short of the number that military planners calculated would be required in a war with the Soviet Union. The great expansion in the U.S. stockpile evident by the end of 1949 was the direct result of the higher production rates of fissionable material and the more efficient weapons designs proof-tested at SANDSTONE (5: 17,18).

Meetings were held on 9 July 1947 at Los Alamos, New Mexico, to define test responsibilities for SANDSTONE. The Los Alamos National Laboratory (LANL), the organization that had developed the wartime atomic weapons and that did research and laboratory development of new nuclear weapons designs, was to provide technical leadership and the military services were to provide supplies and support (5: 18).

4.3.2 SANDSTONE Test Operations.

Numerous technical experiments were conducted in conjunction with each of the three detonations. These experiments measured the yield and efficiency of the devices and attempted to gauge the military effects of the events. The studies were similar at each of the shots but were carried out more precisely with YOKE and ZEBRA as collective experience grew (5: 2,102).

Peak DOD numerical strength at SANDSTONE was approximately 11,500 participants, 95 percent of whom were military personnel. The DOD personnel had support roles and some had duty stations at the AEC weapons design and development laboratories or were part of units performing separate experiments (5: 1,2).

4.3.3 Dose Summary for Operation SANDSTONE.

The dose limit for SANDSTONE participants was 0.1 rem of gamma radiation per 24-hour period and a maximum 3.0 rem for certain approved and specific missions (5: 2). The following table summarizes the available dosimetry information:

Summary of External Doses for Operation SANDSTONE as of 1 May 1986

	Gamma Dose (rem)					
	0-0.5	0.5-1	1-3	3-5	5-10	10+
Army	1,703	2	7	0	1	0
Navy	7,731	17	9	1	1	0
Air Force	2,075	27	8	1	0	0
Marine Corps	180	1	1	0	0	0
Civilian DOD Participants	17	0	0	0	0	0

4.4 OPERATION RANGER.

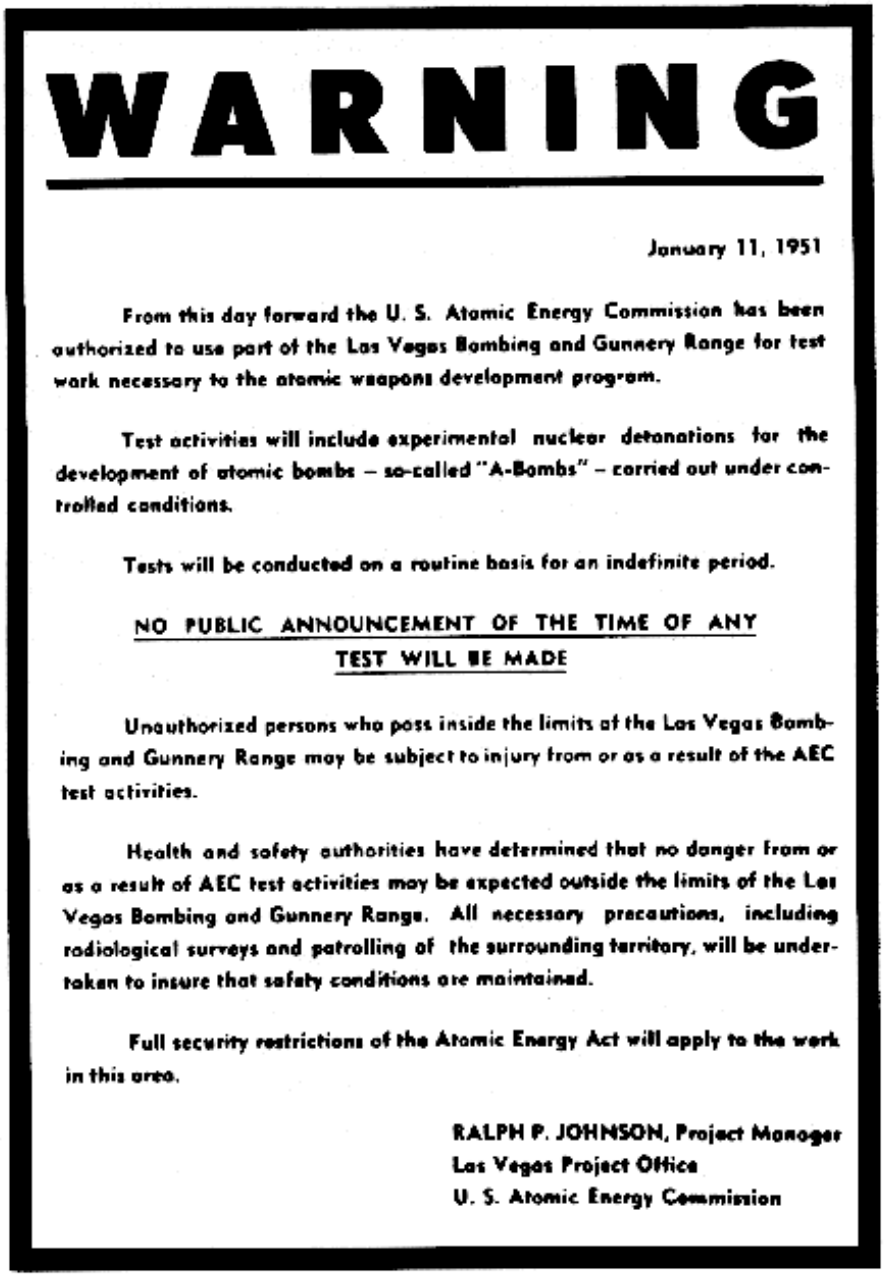
Operation RANGER was the first atmospheric nuclear weapons test series conducted by the Atomic Energy Commission at the Nevada Test Site. This 1951 series consisted of five nuclear events, all of which were airdrops detonated at heights of about 1,000-1,400 feet. In addition, RANGER included one nonnuclear high-explosive test detonated 2 days before the first nuclear event. The following table provides specifics on the nuclear shots (6: 1,4):

Event	Date	Type	Yield (kilotons)
ABLE	27 January	Airdrop	1
BAKER	28 January	Airdrop	8
EASY	1 February	Airdrop	1
BAKER-2	2 February	Airdrop	8
FOX	6 February	Airdrop	22

4.4.1 Background and Objectives of Operation RANGER.

In November 1950, the Los Alamos National Laboratory discovered that insufficient data were available to determine satisfactory design criteria for nuclear devices to be tested in Operation GREENHOUSE, a series of AEC nuclear tests scheduled for the Pacific from 7 April through 24 May 1951. The LANL scientists believed that variations in the compression of the critical material could affect the yields of the GREENHOUSE devices. To confirm this hypothesis, LANL held conferences on 6 and 11 December 1950 and concluded that a series of small nuclear tests should be conducted to improve the GREENHOUSE design criteria. On 22 December 1950, LANL requested approval for a continental series from the AEC Division of Military Application (DMA). DMA approved the request and asked for Presidential approval to expend the fissionable material required for the series and to use part of the Las Vegas Bombing and Gunnery Range in Nevada for the tests. The White House responded affirmatively to both requests on 11 January 1951, formally creating Operation RANGER (6: 18).

The same day that Operation RANGER was approved by the President, the AEC distributed its only announcements of the coming tests. Handbills were circulated in the area of the test site, stating that from 11 January 1951 the Government would be conducting nuclear tests at the Las Vegas Bombing and Gunnery Range. Figure 8 shows this handbill (6: 18-20).



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

Figure 8. AEC handbill announcing the beginning the RANGER tests.

4.4.2 Establishment of the Nevada Test Site.

Nearly 6 years passed between the detonation of TRINITY at Alamogordo, New Mexico, on 16 July 1945, and the next CONUS nuclear test, ABLE of the RANGER series. The AEC had considered establishing a continental test site in 1948 after SANDSTONE, as a way to reduce construction and logistic costs, but rejected the idea after concluding that the physical problems and domestic political concerns would be too complicated. When the Korean War began in the summer of 1950, however, the AEC doubted that the Pacific could be used for nuclear weapons testing because of the possibility of the Korean War expanding throughout the Far East, thus endangering shipping lanes. On 13 July 1950, the AEC Chairman wrote the Chairman of the Military Liaison Committee that the possibility of a national emergency required a joint effort by the AEC and DOD to find a continental test site. The DOD agreed, and the search began for a suitable site.

The AEC and DOD surveyed six sites within the continental United States before choosing the Frenchman Flat area of the Las Vegas Bombing and Gunnery Range, renamed the Nellis Air Force Range in 1956. The Government picked this site because it best suited AEC criteria for favorable meteorological conditions, distance from population areas, and proximity to operational facilities (6: 19-20). Known first as the Nevada Test Site (NTS), then as the Nevada Proving Ground (NPG) beginning in early 1952, the site since 1955 has again been called the Nevada Test Site, the designation used throughout this volume.

4.4.3 RANGER Test Operations.

Only about 280 DOD personnel took part in RANGER, which was primarily an AEC activity. They were engaged in support services, scientific experiments, weather support, communications security, and observer activities. The majority participated in the air support services conducted primarily by Air Force personnel from the Special Weapons Command (SWC) and Headquarters, Air Force. At each event, air support activities included the airdrop of the nuclear device, cloud sampling, cloud tracking, aerial surveys of the terrain, and courier service. Air Force personnel also provided meteorological services and communications security and monitored worldwide radioactivity from the RANGER test for the Atomic Energy Detection System. Since RANGER was only a 13-day operation, the same units and participants performed the same duties throughout the series (6: 1).

4.4.4 Dose Summary for Operation RANGER.

The summary table given below indicates that four doses exceeded the 3.0-rem limit of gamma radiation per 13-week period (6: 3):

Summary of External Doses for Operation RANGER as of 1 May 1986

Gamma Dose (rem)					
0-0.5	0.5-1	1-3	3-5	5-10	10+

Army	8	2	2	2	0	0
Navy	3	1	0	1	1	0
Air Force	213	0	0	0	0	0
Marine Corps	0	1	0	0	0	0
Civilian DOD Participants	17	6	9	0	0	0

4.5 OPERATION GREENHOUSE.

GREENHOUSE was the fourth postwar atmospheric nuclear weapons test series. Conducted in 1951 on the northeastern islands of the Enewetak Atoll, the series consisted of four tower shots, two at 200 feet and two at 300 feet (7: 1):

Event	Date	Type	Yield (kilotons)
DOG	8 April	Tower	81*
EASY	21 April	Tower	47
GEORGE	9 May	Tower	225
ITEM	25 May	Tower	45.5

*Some yields marked "Not announced" in the original report have been declassified since then and are included in this online version.

4.5.1 Background and Objectives of Operation GREENHOUSE.

The purpose of the four GREENHOUSE tests was to continue development of nuclear weapons for defense. More specifically, work was proceeding at this time on developing thermonuclear weapons, and the GREENHOUSE tests were part of this process (7: 1).

In 1949, the Soviet Union detonated its first atomic bomb, providing the impetus for the United States to proceed with development of a bomb whose energy would come from the fusion, or joining, of light elements. Such a weapon is also called a thermonuclear, or hydrogen, bomb. The Atomic Energy Commission received Presidential approval for work in this area in January 1950 after lengthy debate in high defense circles over the feasibility and advisability of such weapons (7: 21).

Although the GREENHOUSE nuclear devices were not thermonuclear devices, two of them involved thermonuclear experiments, and one test, GEORGE, was an important step toward thermonuclear devices. GEORGE demonstrated the initiation of a sustained thermonuclear reaction by use of a fission reaction. This led directly to the first successful thermonuclear test, MIKE (Operation IVY), some 16 months later. In addition, ITEM, the fourth test of the series, involved boosting the efficiency of fission explosions. Development of this experiment had been planned before the Soviet test in 1949 (7: 21).

4.5.2 GREENHOUSE Test Operations.

The Navy had provided most of the personnel for the earlier Pacific nuclear test series. It contributed the largest number to GREENHOUSE, too, but the Army and Air Force were also well represented, as the following numbers show (7: 1):

Organization	Estimated Number of Participants
Army	1,500
Navy	2,900
Air Force	2,550
Marine Corps	80
Civilian DOD Participants	560
Total	7,590

Participants supported the eight GREENHOUSE scientific programs, which consisted of projects recommended by the Army, Navy, Air Force, Armed Forces Special Weapons Project (AFSWP), and the Atomic Energy Commission. The programs were of three types: those dealing with the chemistry and physics of atomic explosions; those dealing with the effects of such explosions on the natural environment, on man-made objects, and on various plants and animals; and those designed to help develop means to detect nuclear detonations at great distances so that U.S. authorities could monitor nuclear developments in other countries (7: 130).

4.5.3 Dose Summary for Operation GREENHOUSE.

The maximum permissible dose for Operation GREENHOUSE participants was 0.1 rem of gamma radiation per day (0.7 rem per week), not to exceed a total of 3.9 rem for 13 weeks. A total of up to 3.0 rem on any one day could be authorized in specific cases. When this authorization was made, however, individuals were not to exceed 0.1 rem per day during the remainder of the operation (7: 64).

Film badges were issued to individuals who might be exposed to radiation while performing their duties. In addition, over 75 film badges for each test were distributed among the six participating ships, to be worn from the day of the test to 7 days thereafter. Among the men in the test area during all or part of the testing operations, 2,416 were badged one or more times (7: 2).

Fallout occurred on the inhabited islands of Enewetak, Parry, and Japtan and on the six task force ships after three of the four shots in the series. Fallout from Shot DOG was approximately twice as great on Parry and Japtan than it was on Enewetak, where the majority of the island-based participants were located. Shot EASY fallout was insignificant and affected all residence

islands equally. Shot ITEM fallout, on the other hand, was approximately twice as great on Enewetak as it was on Japtan (7: 3). Overall, calculated fallout doses for personnel remaining on the residence islands until the end of May, when the rollup phase was virtually complete, were nearly equal on all three of the islands: Enewetak, 2.93 rem; Parry, 3.10 rem; and Japtan, 2.87 rem.

The amount of fallout received by the six ships varied with their locations and decontamination procedures. Nearly all crewmembers on five of these ships were assigned a fallout dose immediately after GREENHOUSE, and these doses were recorded in Navy medical records. The assigned doses ranged from 0.334 rem on USS LST-859 to 1.1 rem on USS Cabildo (LSD-16) and USS Sproston (DDE-577). Boat pool doses ranged from 0.700 to 2.1 rem. The fallout exposure was lower aboard ship than on the islands due to water washdown, shielding, and decontamination of external surfaces (7: 3).

Summary of External Doses for Operation GREENHOUSE as of 1 May 1986
Gamma Dose (rem)

	0-0.5	0.5-1	1-3	3-5	5-10	10+
Army	105	80	115	1,174	26	0
Navy	1,045	481	1,137	180	56	4
Air Force	721	326	223	1,022	214	14
Marine Corps	4	0	41	1	1	0
Civilian DOD Participants	356	67	96	42	0	0

4.6 OPERATION BUSTER-JANGLE.

Conducted from 22 October to 29 November 1951, Operation BUSTER-JANGLE was the second series of atmospheric nuclear weapons tests at the NTS. The series consisted of seven nuclear detonations, summarized below:

Event	Date	Type	Yield (kilotons)
ABLE	22 October	Tower	<0.1
BAKER	28 October	Airdrop	3.5
CHARLIE	30 October	Airdrop	14
DOG	1 November	Airdrop	21
EASY	5 November	Airdrop	31
SUGAR	19 November	Surface	1.2
UNCLE	29 November	Underground	1.2

SUGAR was the first surface and UNCLE the first underground (-17 feet) detonation of a nuclear device (8: 1,6).

4.6.1 Background and Objectives of Operation BUSTER-JANGLE.

This series was originally planned as two separate weapons testing programs: Operation BUSTER and Operation JANGLE. BUSTER, the plans for which began in late 1950, was to evaluate new devices developed by the Los Alamos National Laboratory and to obtain data on the basic phenomena associated with these devices. Plans for JANGLE originated with Operation CROSSROADS, conducted at Bikini in 1946. Scientific studies of the underwater CROSSROADS detonation led to inquiries concerning the effects and possible military value of an underground nuclear detonation. The Joint Chiefs of Staff accordingly obtained AEC agreement to conduct tests involving an underground and a surface nuclear detonation. The general objectives of the tests were to determine the effects of these detonations and to study the devices for inclusion in the nuclear arsenal (8: 20-21).

In 1950, AEC and DOD representatives selected Amchitka Island, one of the Aleutian Islands, as the site for the underground and surface tests, to be called Operation WINDSTORM and to be conducted from 15 September to 15 November 1951. During March 1951, they decided that the tests should be conducted at the NTS and should be coordinated by the Air Force. The two nuclear events were subsequently renamed Operation JANGLE (8: 21).

Because BUSTER and JANGLE were then both scheduled for the fall of 1951 at the NTS, the Armed Forces Special Weapons Project recommended that the two series be conducted as consecutive phases of one series, Operation BUSTER-JANGLE. On 19 June 1951, the AEC approved the AFSWP recommendation (8: 21-22).

4.6.2 BUSTER-JANGLE Test Operations.

Operation BUSTER-JANGLE involved an estimated 7,800 DOD personnel in observer programs, tactical maneuvers, damage effects tests, scientific and diagnostic studies, and support activities. Approximately 6,500 of these participants took part in Exercises Desert Rock I, II, and III, Army programs involving members from all four armed services. The remaining DOD personnel provided support for the Desert Rock exercises or participated in scientific activities (8: 1).

Exercise Desert Rock I was conducted at Shot DOG, and Exercises Desert Rock II and III at Shots SUGAR and UNCLE, respectively. The troop exercises were the first staged by the Armed Forces during continental nuclear weapons testing. The Desert Rock exercises included observer programs, tactical maneuvers, and damage effects tests. Observer programs, conducted at DOG, SUGAR, and UNCLE, generally involved briefings on nuclear weapons effects, observation of the nuclear detonation, and a subsequent tour of a display of military equipment exposed to the detonation. Tactical maneuvers, conducted after DOG, were designed both to train troops and to test military tactics. Damage effects tests, at DOG, SUGAR, and UNCLE,

were performed to determine the effects of a nuclear detonation on military equipment and field fortifications (8: 1).

4.6.3 Dose Summary for Operation BUSTER-JANGLE.

The AEC established a dose limit of 1.0 rem of gamma radiation for participants in Exercise Desert Rock I and a limit of 3.0 rem for the following: participants in Exercises Desert Rock II and III; the test organization, which coordinated BUSTER-JANGLE; and Special Weapons Command, which provided weather and air support, among other functions, for the test organization. SWC sampling pilots and crews were authorized to receive up to 3.9 rem because their mission required them to penetrate the clouds resulting from the detonations (8: 4). The following table summarizes the available dosimetry information:

Summary of External Doses for Operation BUSTER-JANGLE as of 1 May 1986
Gamma Dose (rem)

	0-0.5	0.5-1	1-3	3-5	5-10	10+
Army	6,503	85	33	5	4	0
Navy	156	57	90	16	0	0
Air Force	502	16	45	18	0	0
Marine Corps	186	0	2	0	0	0
Civilian DOD Participants	65	4	20	3	0	0

4.7 OPERATION TUMBLER-SNAPPER.

Operation TUMBLER-SNAPPER, conducted from 1 April to 5 June 1952, was the third series of nuclear weapons tests at the NTS. The operation consisted of eight nuclear detonations, identified below:

Event	Date	Type	Yield (kilotons)
ABLE	1 April	Airdrop	1
BAKER	15 April	Airdrop	1
CHARLIE	22 April	Airdrop	31
DOG	1 May	Airdrop	19
EASY	7 May	Tower	12
FOX	25 May	Tower	11
GEORGE	1 June	Tower	15
HOW	5 June	Tower	14

The detonations were part of two phases of the series, as explained in the next section (9: 1,9).

4.7.1 Background and Objectives of Operation TUMBLER-SNAPPER.

As the defense policy evolved in the early 1950s, two particular factors challenged the ability of U.S. Armed Forces to defend American interests and to protect its allies during limited hostilities:

- The commitment of U.S. ground forces to the Korean peninsula
- The inability of European allies of the U.S. to develop effective military capabilities.

In both cases, the United States experienced difficulties because of limitations in military manpower, which emphasized the need for a new U.S. policy based not on large standing armies, but on new technological advances, particularly in nuclear weapons (9: 25).

In 1951, the Chairman of the AEC strongly advocated the development of nuclear weapons for tactical purposes. "We could," he asserted, "use an atomic bomb today in a tactical way against enemy troops in the field, against military concentrations near battle areas and against other vital military targets without risk to our own troops." TUMBLER-SNAPPER was accordingly designed both to advance the development of effective nuclear weapons and to train troops in tactical nuclear warfare (9: 25).

The series, like BUSTER-JANGLE, was originally planned as two separate testing programs: Operation TUMBLER, to be conducted at the NTS before 1 May 1952; and Operation SNAPPER, scheduled to begin at the NTS on 1 May 1952. Because the programs planned for the two series sometimes overlapped, they were combined into one operation, TUMBLER-SNAPPER (9: 26-28).

The series consisted of two phases. The TUMBLER phase, of primary concern to the DOD, featured four weapons effects tests: ABLE, BAKER, CHARLIE, and DOG. These airdropped devices were detonated to collect information on the effect of the height of burst on overpressure. Shots CHARLIE and DOG were also part of the SNAPPER phase, of primary concern to the AEC and the Los Alamos National Laboratory. The other weapons development tests in the SNAPPER phase were EASY, FOX, GEORGE, and HOW. The primary purpose of these four tower shots was to gather information on nuclear phenomena and to improve the design of nuclear weapons (9: 1).

4.7.2 TUMBLER-SNAPPER Test Operations.

About 7,350 of the estimated 8,700 DOD participants in Operation TUMBLER-SNAPPER took part in Exercise Desert Rock IV. The remaining DOD personnel assisted in scientific experiments, air support activities, or administrative and support activities at the NTS (9: 1).

Exercise Desert Rock IV, an Army training program involving personnel from the armed services, included observer programs at Shots CHARLIE, DOG, FOX, and GEORGE and tactical maneuvers after Shots CHARLIE, DOG, and GEORGE. The tactical maneuvers were designed

in part to provide realistic training for ground units when supported by tactical atomic weapons and to determine the psychological reactions of troops participating in the exercise. The DOG tactical maneuver was the first Marine Corps maneuver of the CONUS tests. In addition to these activities, Exercise Desert Rock IV involved psychological tests at CHARLIE, FOX, and GEORGE to gauge the troops' reactions to witnessing a nuclear detonation (9: 1,5).

Figure 9 shows troops advancing into the test area behind a radiological safety monitor on 2 May 1952, 1 day after the detonation of DOG. The troops halted as the monitor took measurements with a Geiger Counter (B).

Figure 9. Troops advancing into the test area behind a radiological safety monitor on 2 May 1952, one day after the detonation of DOG.

4.7.3 Dose Summary for Operation TUMBLER-SNAPPER.

A dose limit of 3.0 rem of gamma radiation per 13-week period was established for participants in Exercise Desert Rock IV, the joint AEC-DOD organization (coordinator of the series), and most of the Air Force Special Weapons Center (AFSWC) activities (9: 7). The following table presents the available dosimetry information:

Summary of External Doses for Operation TUMBLER-SNAPPER as of 1 May 1986
Gamma Dose (rem)

	0-0.5	0.5-1	1-3	3-5	5-10	10+
Army	3,848	467	61	17	6	1
Navy	446	45	61	4	0	0
Air Force	1,112	35	42	17	3	0
Marine Corps	2,033	8	1	0	0	0
Civilian DOD Participants	368	43	82	10	0	0

4.8 OPERATION IVY.

IVY, conducted at Enewetak Atoll during autumn 1952, consisted of two detonations. These two detonations, identified in the following table, were the largest nuclear explosions up to that time:

Event	Date	Type	Yield
MIKE	1 November	Surface	10.4 megatons
KING	16 November	Airdrop	500 kilotons

The description of the MIKE detonation by the author of History--Task Group 132.1 and reproduced in History of Operation IVY bears repeating (10: 1,187):

> The Shot, as witnessed aboard the various vessels at sea, is not easily described. Accompanied by a brilliant light, the heat wave was felt immediately at distances of thirty to thirty-five miles. The tremendous fireball, appearing on the horizon like the sun when half-risen, quickly expanded after a momentary hover time and appeared to be approximately a mile in diameter before the cloud-chamber effect and scud clouds partially obscured it from view. A very large cloud-chamber effect was visible shortly after the detonation and a tremendous conventional mushroom-shaped cloud soon appeared, seemingly balanced on a wide dirty stem. Apparently, the dirty stem was due to the coral particles, debris, and water which were sucked high into the air. Around the base of the stem, there appeared to be a curtain of water which soon dropped back around the area where the island of Elugelab [Eluklab] had been.

Figure 10 presents a photograph of the MIKE cloud (C).

Figure 10. Shot MIKE, 1 November 1952.

4.8.1 Background and Objectives, of Operation IVY.

President Truman made the decision to pursue the development of thermo-nuclear weapons in 1950. Operation GREENHOUSE was an initial step toward this end, as section 4.5 explains. Operation IVY considerably extended the GREENHOUSE advances. MIKE, an experimental device, produced the first thermonuclear detonation, which means that a substantial portion of its energy was generated by the fusion, or joining, of hydrogen and other light atoms. KING was a stockpile weapon, modified to produce a large yield. The energy from KING was generated by the fission, or splitting, of plutonium atoms (10: 1).

The IVY test program was the result not only of scientific and technical considerations, but also of an intense controversy within elements of the U.S. Government concerned with foreign policy and defense matters. During the early 1950s, various plans rapidly evolved to meet the challenge posed by the initial Soviet detonation of 1949. Most plans called for increased development and

production of fission weapons and the required delivery systems. One plan called for the development of fusion, or thermonuclear, weapons with vastly greater explosive power. Opponents of fusion weapons argued that the Soviets could be persuaded not to develop these weapons if the United States would refrain. A further argument, among others, was that such weapons were not much more effective than high-yield fission weapons (10: 18).

The advocates of fusion weapons prevailed, and MIKE became the centerpiece of Operation IVY and the proof-test of the new technology. KING, however, represented a test of the kind of high-yield fission weapon some of the fusion opponents had in mind. To a degree, the KING device also offered a backup to help ease the national sense of vulnerability in the event that the initial attempt at a fusion reaction detonation was unsuccessful (10: 18-19).

4.8.2 IVY Test Operations.

IVY engaged nearly 11,650 participants, of whom approximately 9,350 were military and about 2,300 were civilians. Most of the civilians and over 6,600 of the military personnel operated from Enewetak Atoll and from task force ships based there. These personnel were removed to evacuation ships before the detonation of MIKE. Most of the additional military were Air Force personnel who were based at Kwajalein, 350 nautical miles southeast of Enewetak (10: 2,178-181).

The experimental program for IVY focused primarily on the MIKE experiment and secondarily on KING. The effort, subdivided into 11 specific programs, was heavily oriented to weapons development experiments and focused to a lesser extent on effects experiments (10: 118).

4.8.3 Dose Summary for Operation IVY.

The generally smooth MIKE operations were marred by an accident when a cloud-sampling pilot was lost at sea after his aircraft ran out of fuel. A seven-man rescue crew flew their aircraft over a fallout zone to reach the area of the downed airplane as soon as possible. In the process, the crewmembers received radiation doses ranging from 10 to 17.8 rem. These levels considerably exceeded the maximum permissible limit of 3.9 rem of gamma radiation established for Operation IVY participants (10: 3).

A crew of 12 in a second aircraft was overexposed when caught in fallout debris while on a photographic mission just after the MIKE shot. The highest dose for a member of this crew was 11.6 rem. Other than these two events, no cases exceeded the established limit during IVY (10: 3).

Summary of External Doses for Operation IVY as of 1 May 1986
Gamma Dose (rem)

	0-0.5	0.5-1	1-3	3-5	5-10	10+
Army	1,300	1	1	0	0	0
Navy	5,191	23	42	2	0	0
Air Force	2,199	325	37	4	9	10
Marine Corps	169	1	8	0	0	0
Civilian DOD Participants	28	0	3	0	0	0

4.9 OPERATION UPSHOT-KNOTHOLE.

Conducted at the NTS from 17 March to 4 June 1953, Operation UPSHOT-KNOTHOLE consisted of 11 nuclear tests, a number exceeding that of any previous nuclear test series. The following table summarizes these shots:

Event	Date	Type	Yield (Kilotons)
ANNIE	17 March	Tower	16
NANCY	24 March	Tower	24
RUTH	31 March	Tower	0.2
DIXIE	6 April	Airdrop	11
RAY	11 April	Tower	0.2
BADGER	18 April	Tower	23
SIMON	25 April	Tower	43
ENCORE	8 May	Airdrop	27
HARRY	19 May	Tower	32
GRABLE	25 May	Airburst	15
CLIMAX	4 June	Airdrop	61

ANNIE, the first device tested, was an "open shot," meaning that reporters were allowed to view the detonation from News Nob, 11 kilometers south of the shot-tower. The Government wanted to show the American public that nuclear weapons could be used defensively, without destroying large urban centers and populations (11: 1,13,2,30,31).

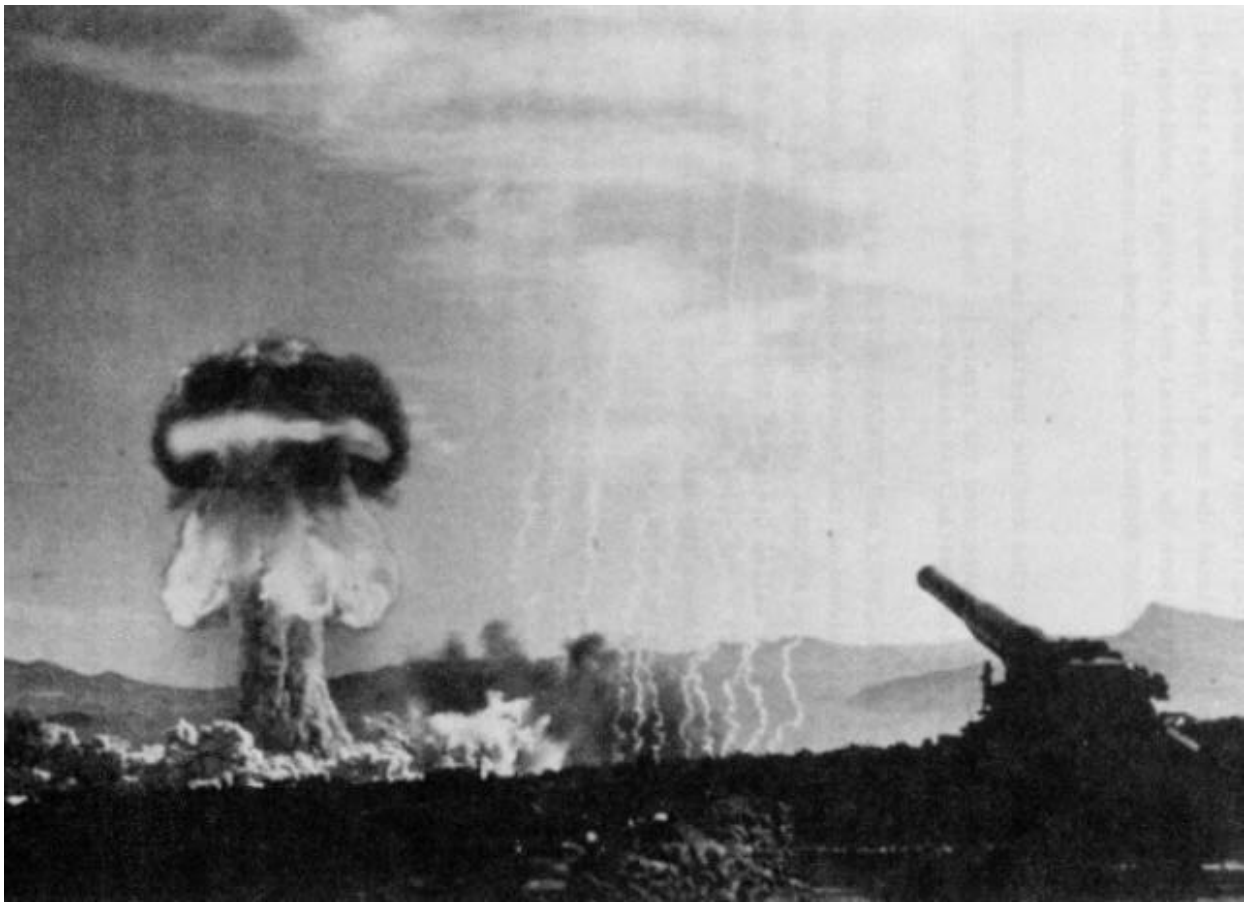


Figure 11. Shot GRABLE, only test of the 280mm atomic artillery shell, 25 May 1953.

The firing of GRABLE from a 280 mm cannon, shown in figure 11, marked the first time an atomic artillery shell was fired and detonated (D). The Secretary of Defense, the Secretary of the Army, and the Army Chief of Staff, along with 96 Congressional observers, viewed the detonation from an area 11 kilometers west of ground zero (12: 120).

4.9.1 Background and Objectives of Operation UPSHOT-KNOTHOLE.

UPSHOT-KNOTHOLE went a step further than the previous CONUS series, TUMBLER-SNAPPER, which had explored the use of nuclear weapons for tactical purposes. Designed to address both the tactical and strategic considerations of the U.S. defense policy, UPSHOT-KNOTHOLE was designed to accomplish the following (11: 33):

- Establish military doctrine for the tactical use of nuclear weapons
- Improve the nuclear weapons used for strategic bomber delivery and those used for tactical battlefield situations.

Like the earlier BUSTER-JANGLE and TUMBLER-SNAPPER series, UPSHOT-KNOTHOLE was initially envisioned as two separate weapons testing programs: Operation UPSHOT and

Operation KNOTHOLE. Plans began in late 1951 for a large military effects test, later called Operation KNOTHOLE, to be conducted during the spring of 1953 at the NTS. The objective was to obtain general weapons effects information to supplement the data obtained from Operation GREENHOUSE, conducted at the Pacific during spring 1951 (11: 32).

Meanwhile, the AEC was planning Operation UPSHOT, with the earliest test date set for spring 1953. The DOD consequently accelerated its planning for Operation KNOTHOLE so that arrangements for the AEC and DOD tests could be coordinated. In June 1952, the DOD and AEC agreed to conduct the spring 1953 tests as a combined operation, designated UPSHOT-KNOTHOLE (11: 32).

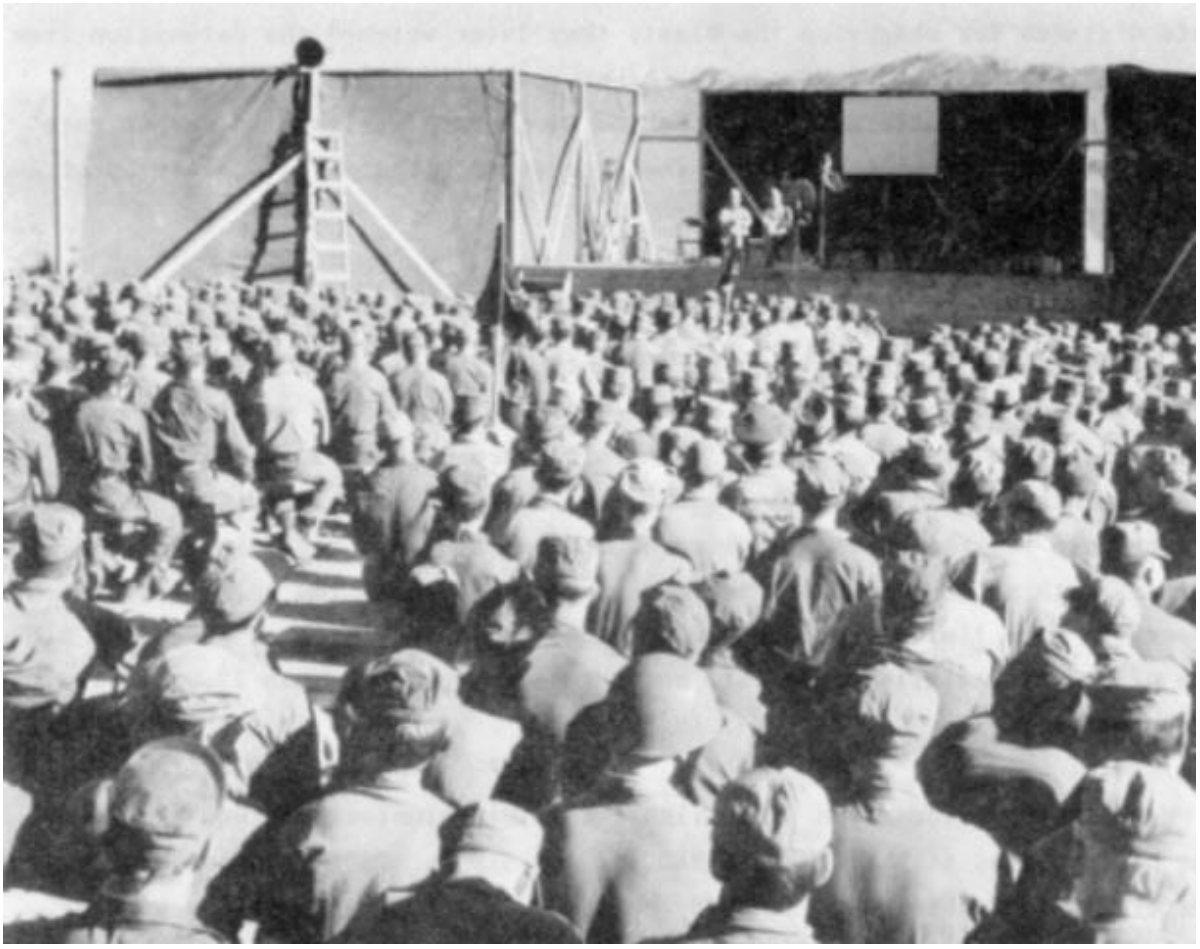


Figure 12. Exercise Desert Rock V troops being briefed on the characteristics and effects of nuclear detonations before the Operation UPSHOT-KNOTHOLE tests.

4.9.2 UPSHOT-KNOTHOLE Test Operations.

An estimated 18,000 DOD personnel participated at UPSHOT-KNOTHOLE in observer programs, tactical maneuvers, scientific studies, and support activities. The largest DOD participation was in Exercise Desert Rock V, which involved members of all four armed

services. Exercise Desert Rock V included troop orientation and training, a volunteer officer observer program, tactical troop maneuvers, operational helicopter tests, and damage effects evaluation. The troop orientation and training included briefings before the detonation on nuclear weapons characteristics and effects and on personal protection; figure 12 is a photograph of one such briefing (E). Troop orientation and training also involved observation of a nuclear detonation, as did the volunteer officer observer program. For the latter, trained staff officers calculated the effects of a nuclear detonation to determine a minimum safe distance for observing the blast; they later watched the detonation from the calculated position. Among the other activities, the operational helicopter tests performed by the Marine Corps were designed to investigate the capability of helicopters and their crews to withstand a nuclear burst and its effects (11: 1).

4.9.3 Dose Summary for Operation UPSHOT-KNOTHOLE.

The maximum permissible dose for participants in the Joint Test Organization, which coordinated UPSHOT-KNOTHOLE, and AFSWC was 3.9 rem of gamma radiation for the series. The limits were higher for Desert Rock V participants, according to the requirements of their missions. Desert Rock V troops were restricted to a maximum of 6.0 rem of gamma radiation for the series, with no more than 3.0 rem of prompt radiation. The volunteer officer observers were limited to 10.0 rem of gamma radiation, with no more than 5.0 rem of prompt radiation per test, and a total of no more than 25.0 rem for the exercise (11: 11).

Dosimetry information is available for the volunteer officer observers, who participated at Shots NANCY, BADGER, and SIMON. The exposures of seven of the eight SIMON observers exceeded the 10.0 rem shot limit, with a high of 17.5 rem. The one volunteer observer who witnessed all three shots had an exposure of 26.6 rem (11: 12).

The calculated mean neutron doses for the volunteer observers have been reconstructed as 0.63 rem for Shot NANCY; 2.4 rem for Shot BADGER; and 28 rem for Shot SIMON (11: 12,15).

Summary of External Doses for Operation UPSHOT-KNOTHOLE as of 1 May 1986
Gamma Dose (rem)

	0-0.5	0.5-1	1-3	3-5	5-10	10+
Army	3,705	3,041	4,459	1,299	20	10
Navy	402	171	96	87	16	1
Air Force	1,125	226	260	45	17	3
Marine Corps	112	205	330	1,611	16	1
Civilian DOD Participants	98	28	28	2	0	0

4.10 OPERATION CASTLE.

CASTLE was conducted at Enewetak and Bikini Atolls during the spring of 1954. The first event of this series, Shot BRAVO, had a yield of 15 megatons and was the largest device ever detonated by the U.S. Government as part of atmospheric nuclear weapons testing. The following table provides specifics on this detonation, shown in figure 13 (F), as well as the other five in the series (13: 1):

Event	Date	Type	Yield
BRAVO	1 March	Surface	15 megatons
ROMEO	27 March	Barge	11 megatons
KOON	7 April	Surface	110 kilotons
UNION	26 April	Barge	6.9 megatons
YANKEE	5 May	Barge	13.5 megatons
NECTAR	14 May	Barge	1.69 megatons

Figure 13. CASTLE BRAVO shot, 1 March 1954.

4.10.1 Background and Objectives of Operation CASTLE.

CASTLE was the culmination in the development of the super, or hydrogen, bomb that began in 1950. Shot GEORGE, a test in the 1951 GREENHOUSE series, had demonstrated the initiation of a sustained thermonuclear reaction by use of a fission reaction. Fusion, or thermonuclear, reactions had been used in 1952 to generate the very powerful detonation of the MIKE device in Operation IVY, but MIKE was not a deliverable nuclear weapon. In BRAVO, the first CASTLE test, a device more powerful than MIKE was exploded that, although not a weapon, was capable of delivery by an aircraft (13: 26).

CASTLE also was the first Pacific series in which the Lawrence Livermore National Laboratory (LLNL) provided a nuclear device for testing, detonated as Shot KOON. All previous nuclear test devices had been designed at the Los Alamos National Laboratory (13: 26).

4.10.2 CASTLE Test Operations.

Numerous technical experiments were carried out in conjunction with each of the six detonations. These experiments measured the yield and efficiency of the devices and attempted to gauge the military effects of the explosions. The approximately 12,700 DOD participants in this series had duty stations at the AEC design laboratories or were members of units performing separate experiments or various support roles. Almost all of the Navy support personnel were at Bikini, where Navy ships provided living quarters for participants who were evacuated from the islands for the first test and then could not return to live there because of the potential radiation exposure (13: 2).

4.10.3 Dose Summary for Operation CASTLE.

Among the CASTLE detonations, only BRAVO produced significant, unexpected personnel radiation exposures. This first shot of the series, which significantly exceeded its expected yield, released large quantities of radioactive materials into the atmosphere. These materials were caught up in winds that spread the particles over a much larger area than had been anticipated. This resulted in contamination and exposure of Marshall Island residents, Japanese fishermen, and U.S. personnel on distant atolls or aboard various vessels. Acute radiation effects were observed among some of these people (13: 3).

Some DOD personnel exceeded the maximum permissible limit of 3.9 rem of gamma radiation within any 13-week period of the operation. BRAVO fallout on some Navy ships resulted in personnel who had doses approaching or exceeding this limit. To allow for completion of the CASTLE tests, it became necessary to issue a number of waiver authorizations permitting doses of as much as 7.8 rem. In a limited number of shipboard cases, even this level was exceeded. Substantial overdoses from BRAVO, the highest for any test series, were accrued by the 28 Air Force and Army personnel on Rongerik Atoll (13: 3-4) and the 92 crew members of USS Patapsco, a Navy gasoline tanker that was overtaken by the nuclear cloud on the day following

the shot while en route from Enewetak Atoll to Pearl Harbor (14). Film badge readings suggest that three members of the U.S. Navy Bikini Boat Pool also may have received substantial overdoses. Thorough investigation at the time failed, however, to indicate reasons for these readings (13: 243-244). As a result of BRAVO, 21 individuals on the USS Philip and 16 on the USS Bairoko sustained lesions that were classified as beta burns, all of which healed without complications (13: 3-4).

Summary of External Doses for Operation CASTLE as of 1 May 1986
Gamma Dose (rem)

	0-0.5	0.5-1	1-3	3-5	5-10	10+
Army	0	0	1,341	47	6	3
Navy	3,940	1,462	2,210	695	211	115
Air Force	984	193	970	62	30	31
Marine Corps	160	8	101	29	5	0
Civilian DOD Participants	30	6	13	0	0	0

4.11 OPERATION TEAPOT.

Conducted from 18 February to 15 May 1955, Operation TEAPOT was the fifth series of CONUS tests. Two of the 14 nuclear detonations in the series, APPLE 1 and WASP PRIME, occurred on the same day although in different parts of the NTS. ESS, the only TEAPOT subsurface detonation (-67 feet), forced tons of earth upward, thereby creating a crater 88 meters wide and 96 feet deep. Figure 14 shows Exercise Desert Rock VI troops observing the ESS detonation (G). They were positioned approximately 8 kilometers from the shot site.

The TEAPOT schedule was continually revised as the AEC waited for appropriate weather conditions for firing the test shots. The delay in one shot often resulted in postponing subsequent shots, regardless of the weather. The many schedule changes, affecting all but the first two shots, caused a 6-week extension of TEAPOT from 1 April to 15 May (15: 29).

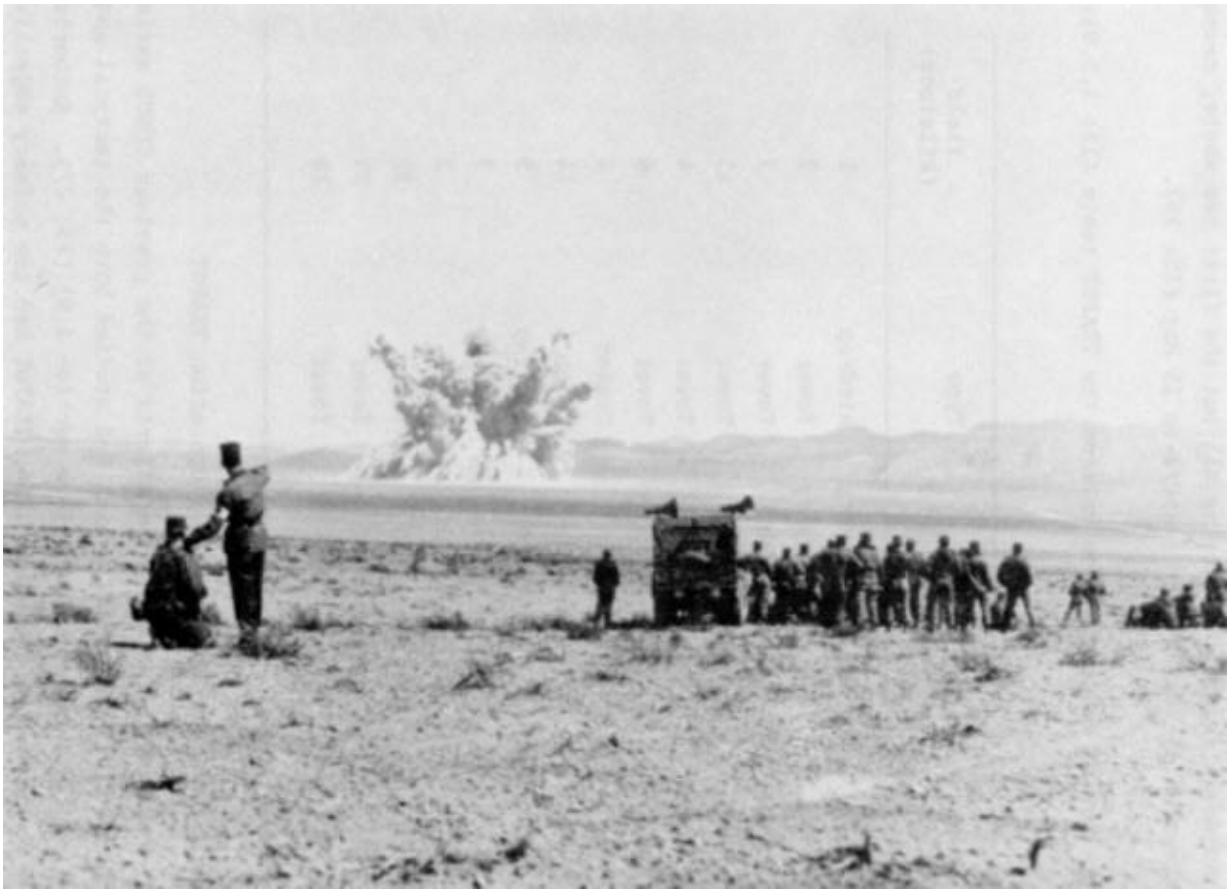


Figure 14. Exercise Desert Rock VI troops observing the detonation of ESS, 23 March 1955.

The following table provides data on the TEAPOT tests (15: 1,5,9):

Event	Date	Type	Yield (kilotons)
WASP	18 February	Airdrop	1
MOTH	22 February	Tower	2
TESLA	1 March	Tower	7
TURK	7 March	Tower	43
HORNET	12 March	Tower	4
BEE	22 March	Tower	8
ESS	23 March	Crater	1
APPLE 1	29 March	Tower	14
WASP PRIME	29 March	Airdrop	3
HA	6 April	Airdrop	3
POST	9 April	Tower	2
MET	15 April	Tower	22
APPLE 2	5 May	Tower	29
ZUCCHINI	15 May	Tower	28

4.11.1 Background and Objectives of Operation TEAPOT.

Operation TEAPOT furthered the efforts of the previous CONUS series, the 1953 Operation UPSHOT-KNOTHOLE, which had studied both the tactical and strategic uses of nuclear weapons (see section 4.9) (15: 27). Authorized by President Eisenhower on 30 August 1954, TEAPOT had two primary objectives:

- To establish military doctrine and tactics for the use of ground forces on a nuclear battlefield
- To improve the nuclear weapons used for strategic bomber delivery and missile delivery and those used for tactical battlefield situations.

The DOD conducted Exercise Desert Rock VI to achieve the first objective, and the AEC fielded scientific experiments to achieve the second (15: 27,28).

4.11.2 TEAPOT Test Operations.

Approximately 8,700 DOD personnel participated in TEAPOT observer programs, tactical maneuvers, scientific studies, and support activities. The largest number, about 8,000, took part in Exercise Desert Rock VI, which included observer programs at Shots WASP, MOTH, TESLA, TURK, BEE, ESS, APPLE 1, and APPLE 2 and troop tests at Shots BEE and APPLE 2. The largest single TEAPOT activity was the Marine Brigade Exercise at BEE, which involved about 300 officers and 1,950 enlisted men. The objective of the exercise was to train personnel and to test the tactics and techniques employed if a nuclear detonation were used to support an air-ground task force. The troop test at APPLE 2, involving about 1,000 troops, was designed to demonstrate the capability of a reinforced tank battalion to seize an objective immediately after a nuclear detonation. In addition to these activities, technical studies were conducted at 10 of the shots (15: 1,5-7).

4.11.3 Dose Summary for Operation TEAPOT.

The maximum dose limit for personnel of the Joint Test Organization, which coordinated Operation TEAPOT, and AFSWC was 3.9 rem of gamma radiation during the series. The limit for Desert Rock troops was 6.0 rem of gamma radiation during the series, with no more than 3.0 rem of prompt radiation. The Desert Rock troops had this higher limit because they, unlike JTO and some AFSWC technical personnel, were not likely to be exposed to radiation after the tests (15: 2,3).

The 10 Desert Rock volunteer officer observers at APPLE 2 were authorized a special limit of 10.0 rem of gamma radiation. Their average film badge readings were 1.3 rem. Pilots for Project 2.8b, Manned Penetrations of Atomic Clouds, were authorized a limit of 15 rem. One participant had a film badge reading of 21.7 rem, and another received 21.8 rem (15: 3).

Summary of External Doses for Operation TEAPOT as of 1 May 1986
Gamma Dose (rem)

	0-0.5	0.5-1	1-3	3-5	5-10	10+
Army	2,280	1,088	1,234	51	5	0
Navy	287	32	197	21	0	4
Air Force	842	73	103	55	5	4
Marine Corps	462	1,450	4	0	0	0
Civilian DOD Participants	128	3	1	0	0	0

4.12 OPERATION WIGWAM.

Operation WIGWAM consisted of only one nuclear detonation, a deep underwater test conducted in the Pacific Ocean approximately 500 miles southwest of San Diego, California. The device was suspended by cable from an unmanned barge and detonated at a depth of 2,000 feet in water 16,000 feet deep. The test, which had a yield of 30 kilotons, occurred on 14 May 1955 at 1300 hours Pacific Daylight Time (16: 9).

The test site was chosen after careful deliberation. AT DOD request, Scripps Institution of Oceanography surveyed various locations in the Pacific, the Caribbean, and the Atlantic. The site had to be deep enough to contain the detonation, yet away from undersea or sea bottom perturbations, such as sea mounts, ridges, and islands. Migratory fishing areas were to be avoided. In addition, the site was to have fairly well-known currents and thermal gradients, a predominance of good weather, and isolation from shipping lanes. The area selected was judged the best to fulfill the requirements (16: 1-11).

4.12.1 Background and Objectives of Operation WIGWAM.

Prior to WIGWAM, nuclear weapons had been tested in the atmosphere, on the surface of the earth or water, or at a shallow underwater depth. Considerable interest developed, particularly within the Navy, in investigating deep underwater effects by detonating a weapon at sufficient depth to contain all the initial energy of the nuclear explosion in the water (16: 1-3).

The Navy needed to know how a deep underwater shot would affect naval forces and, specifically, the answers to two leading questions: (1) What are the characteristics and lethal ranges of the resulting underwater shock wave? and (2) What are the effects of the radioactivity, following the explosion, on naval tactical operations? For example, could a surface vessel use a nuclear depth charge to destroy submerged enemy submarines without endangering itself? Specific answers to these questions were required to plan possible naval use of these weapons (16: 1-3,1-5).

4.12.2 WIGWAM Test Operations.

Approximately 6,800 personnel and 30 ships participated in Operation WIGWAM. They conducted or supported the three scientific programs designed to collect the desired data (16: 9,1-3).

A 6-mile towline connected the fleet tug, USS Tawasa, and the barge from which the nuclear device was suspended. Located at varying distances along this towline were a variety of pressure-measuring instruments, unmanned and specially prepared submerged submarine-like hulls (called squaws), as well as instrumented and also unmanned surface boats (16: 9).

The ships and personnel conducting the test were positioned 5 miles upwind from the barge that suspended the nuclear device. The only exceptions were for USS George Eastman (YAG-39) and USS Granville S. Hall (YAG-40). These two extensively reconfigured ships, equipped with special shielding to prevent radiological exposure, were stationed 5 miles downwind from the barge. Recovery parties later reentered the test area with radiological safety monitors, and after aerial surveys showed the general location and size of the contaminated water area and the radiation levels (16: 9).

4.12.3 Dose Summary for Operation WIGWAM.

The maximum dose limit for WIGWAM was 3.9 rem of gamma radiation for the duration of the operation. The two vessels (YAG-39 and YAG-40) stationed downwind of the detonation were subjected to contamination by water droplets of the base surge. Because of the special shielding, however, none of the YAG personnel exceeded the radiation limit. All doses were low because most of the radioactivity was confined deep under the surface of the water (16: 10,11).

WIGWAM was the first series in which nearly all participants were issued film badges. Personnel whose duties were such that exposure to radiation was possible (such as sampling radioactive water, recovering equipment or instruments) were issued additional film badges on a daily basis. One of the vessels, the USS Wright, contained a film processing center where badges were read and personnel exposures were recorded. Over the period of the operation, approximately 10,000 film badges were issued (16: 10).

Summary of External Doses for Operation WIGWAM as of 1 May 1986
Gamma Dose (rem)

	0-0.5	0.5-1	1-3	3-5	5-10	10+
Army	9	0	0	0	0	0
Navy	6,567	1	0	0	0	0
Air Force	64	0	0	0	0	0
Marine Corps	109	0	1	0	0	0
Civilian DOD Participants	17	0	1	0	0	0

4.13 OPERATION REDWING.

REDWING was conducted in 1956 as the sixth nuclear test series at the Marshall Islands, specifically at Enewetak and Bikini Atolls. The series consisted of the 17 detonations identified in the accompanying table. Figure 15 presents a photograph taken during the ERIE detonation, the fifth shot of the series. It shows a group on Enewetak turned away from the detonation as it breaks the predawn darkness (H).

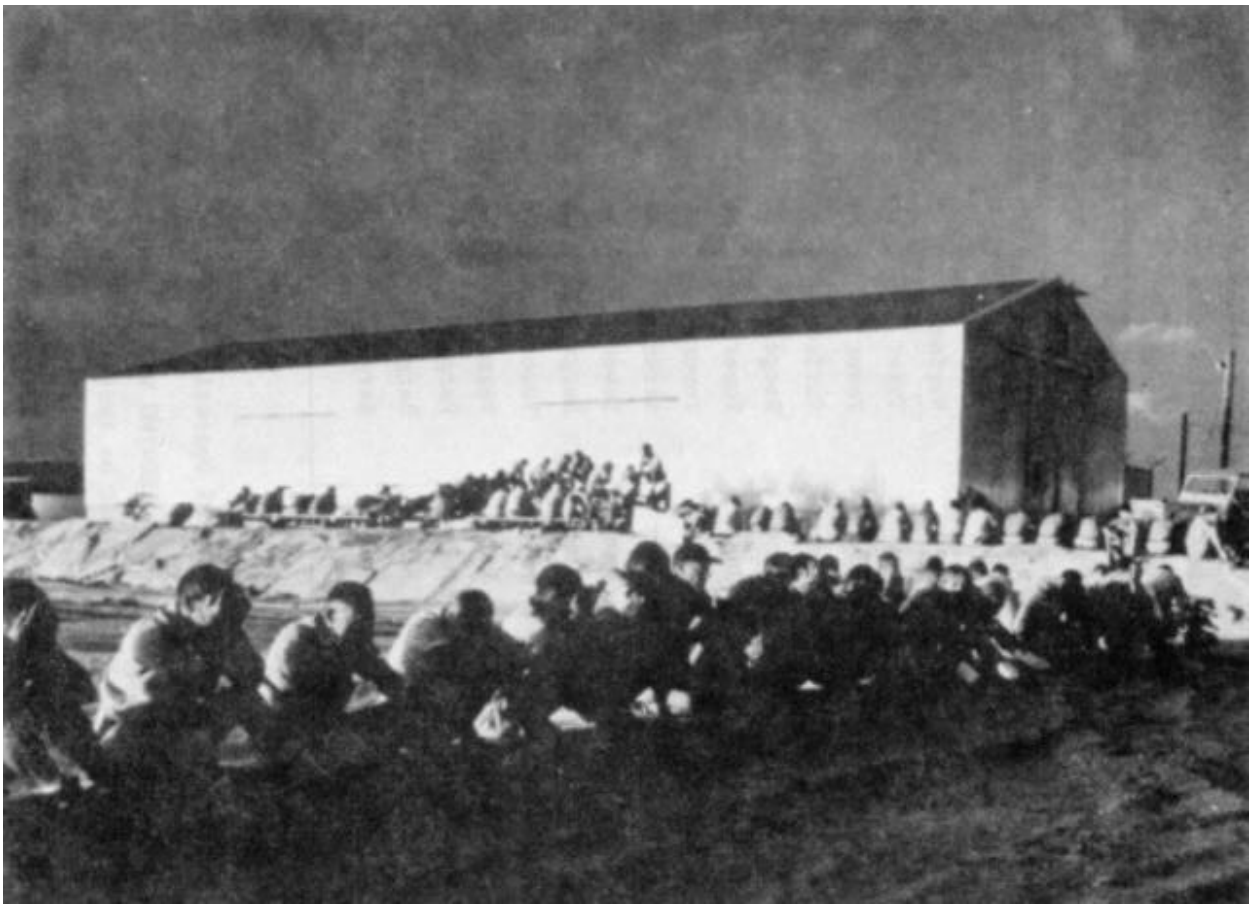


Figure 15. Observers facing away from the detonation of ERIE, 31 May 1956.

Operation REDWING Test Events, 1956

Event	Date	Type	Yield
LACROSSE	5 May	Surface	40 kilotons
CHEROKEE	21 May	Airdrop	3.8 megatons
ZUNI	28 May	Surface	3.5 megatons
YUMA	28 May	Tower	190 tons*

ERIE	31 May	Tower	14.9 kilotons
SEMINOLE	6 June	Surface	13.7 kilotons
FLATHEAD	12 June	Barge	365 kilotons
BLACKFOOT	12 June	Tower	8 kilotons
KICKAPOO	14 June	Tower	1.49 kilotons
OSAGE	16 June	Airdrop	1.7 kilotons
INCA	22 June	Tower	15.2 kilotons
DAKOTA	26 June	Barge	1.1 megatons
MOHAWK	3 July	Tower	360 kilotons
APACHE	9 July	Barge	1.85 megatons
NAVAJO	11 July	Barge	4.5 megatons
TEWA	21 July	Barge	5 megatons
HURON	22 July	Barge	250 kilotons

*Some yields marked "Not announced" in the original report have since been declassified and are included in this online version.

4.13.1 Background and Objectives of Operation REDWING.

The main purpose of Operation REDWING was to test high-yield thermonuclear devices that could not be tested in Nevada. The only shot of the series not expressly for weapons development was CHEROKEE, which was airdropped from a B-52. Its primary purpose was to demonstrate the ability of the U.S. to deliver large-yield nuclear devices. The event was viewed by 15 press observers, the first such group invited to view a Pacific nuclear test since the CROSSROADS detonations of 1946. Seventeen invited civil defense officials also observed the shot (17: 2, 177, 22-23).

During CASTLE, the fifth nuclear test series conducted in the Marshall Islands, a serious fallout contamination incident from Shot BRAVO had affected not only U.S. personnel but Marshall Island residents and Japanese fishermen as well. On 27 April, 8 days before the first REDWING detonation, a joint DOD-AEC press release identified the safety precautions in effect for the series. It described the improved fallout prediction capability available and the extensive monitoring that was to be done both at the Pacific Proving Ground and beyond. It also described programs for surveying marine life in the Pacific. Moreover, the release stated that the yields of the devices to be tested were expected to be lower than the largest of those detonated as part of Operation CASTLE (17: 21,22).

Press observers were invited to view part of the series. Fifteen members of the press, the first to observe oceanic tests since the CROSSROADS detonations of 1946, accordingly witnessed LACROSSE and CHEROKEE. Seventeen invited civil defense officials also observed the shots (17: 22).

4.13.2 REDWING Test Operations.

Numerous technical experiments were carried out in conjunction with each of the 17 detonations. These experiments measured the yield and efficiency of the devices and attempted to gauge the military effects of the explosions. Approximately 11,350 DOD personnel took part in or supported these activities. Also present at the tests were several thousand personnel from the AEC and its contractors, a few from other Government agencies, and some foreign observers as well (17: 2).

Most of the Navy and Marine Corps personnel were on ships operating around Bikini providing supply, evacuation capability, and other support to the tests there. Most of the Army and Air Force personnel were on Enewetak. All the services had personnel assigned to laboratory organizations whose operations were conducted on both atolls as well as other locations in the Pacific (17: 3).

4.13.3 Dose Summary for Operation REDWING.

TEWA, the last REDWING event fired at Bikini, led to an increase in personnel doses. The edge of the TEWA cloud passed over Enewetak causing fallout on the Enewetak base camp. Because the incident occurred toward the end of the series, some personnel had already returned to the U.S. (17: 3,4). The remaining Enewetak personnel, however, received additional doses calculated at 2.0 to 3.3 rem from this incident (17: 3,4).

The personnel limit was 3.9 rem of gamma radiation for the series. The highest doses were received by Air Force flight officers whose missions required them to penetrate the clouds resulting from the nuclear detonations (17: 3,4).

Summary of External Doses for Operation REDWING as of 1 May 1986
Gamma Dose (rem)

	0-0.5	0.5-1	1-3	3-5	5-10	10+
Army	89	262	308	649	144	0
Navy	2,987	1,843	1,581	225	18	0
Air Force	769	289	938	717	86	12
Marine Corps	59	67	118	9	0	0
Civilian DOD Participants	62	5	38	1	0	0

4.14 OPERATION PLUMBBOB.

Conducted at the Nevada Test Site from 28 May to 7 October 1957, Operation PLUMBBOB included the 24 nuclear detonations summarized in the accompanying table. The series also

included six safety experiments, conducted to ensure that no nuclear reaction would occur if the high explosive components of the device were accidentally detonated during storage or transport (18: 1,6,7). These tests are discussed with the subsequent safety experiments in section 4.18.

Operation PLUMBBOB Weapon-Related Events, 1957

Event	Date	Type	Yield
BOLTZMANN	28 May	Tower	12 kilotons
FRANKLIN	2 June	Tower	140 tons
LASSEN	5 June	Balloon	0.5 tons
WILSON	18 June	Balloon	10 kilotons
PRISCILLA	24 June	Balloon	37 kilotons
HOOD	5 July	Balloon	74 kilotons
DIABLO	15 July	Tower	17 kilotons
JOHN	19 July	Air to air missile	about 2 kilotons
KEPLER	24 July	Tower	10 kilotons
OWENS	25 July	Balloon	9.7 kilotons
STOKES	7 August	Balloon	19 kilotons
SHASTA	18 August	Tower	17 kilotons
DOPPLER	23 August	Balloon	11 kilotons
FRANKLIN PRIME	30 August	Balloon	4.7 kilotons
SMOKY	31 August	Tower	44 kilotons
GALILEO	2 September	Tower	11 kilotons
WHEELER	6 September	Balloon	197 tons
LAPLACE	8 September	Balloon	1 kilotons
FIZEAU	14 September	Tower	11 kilotons
NEWTON	16 September	Balloon	12 kilotons
RAINIER	19 September	Tunnel	1.7 kilotons
WHITNEY	23 September	Tower	19 kilotons
CHARLESTON	28 September	Balloon	12 kilotons
MORGAN	7 October	Balloon	8 kilotons

4.14.1 Background and Objectives of Operation PLUMBBOB.

Largely a joint AEC/DOD effort, Operation PLUMBBOB was planned as an integral part of the continuing U.S. program for developing the means to conduct nuclear warfare in defense of the Nation. The AEC wanted to test a number of nuclear devices scheduled for early production for the defense stockpile or those important to the design of improved weapons. The DOD used the series to continue its study of military weapons effects and, with Exercises Desert Rock VII and VIII, its training of personnel in nuclear operations (18: 34).

4.14.2 PLUMBBOB Test Operations.

About 13,300 DOD personnel participated in observer programs, tactical maneuvers, and scientific and diagnostic studies during Operation PLUMBBOB. Exercises Desert Rock VII and VIII, consisting of training programs, tactical maneuvers, and technical service projects, engaged the largest DOD participation. At Shot HOOD, approximately 2,150 Marines took part in a maneuver involving the use of a helicopter-airlift and tactical air support. An estimated 1,144 Army troops (Task Force WARRIOR) participated in an airlift assault at Shot SMOKY, and about 110 Army troops (Task Force BIG BANG) were interviewed at Shot GALILEO to determine their psychological reaction to witnessing a detonation (18: 1,4,5).

4.14.3 Dose Summary for Operation PLUMBBOB.

The maximum dose limit for Desert Rock troops was 5.0 rem of gamma radiation in any 6-month period, with no more than 2.0 rem to be from prompt radiation. Participants in activities of the AEC Nevada Test Organization and AFSWC were limited to 3.0 rem for any 13-week period and 5.0 rem for one calendar year (18: 2,3).

Summary of External Doses for Operation PLUMBBOB as of 1 May 1986
Gamma Dose (rem)

	0-0.5	0.5-1	1-3	3-5	5-10	10+
Army	6,242	737	528	55	22	2
Navy	401	36	130	4	2	1
Air Force	1,678	118	102	22	18	4
Marine Corps	726	1,244	176	1	1	0
Civilian DOD Participants	819	22	22	0	0	0

4.15 OPERATION HARDTACK I.

HARDTACK was the designation for U.S. nuclear testing in both the Pacific and in Nevada during 1958. Phase I, discussed in this section, consisted of 34 Pacific nuclear detonations, which was as many as had been fired in all prior oceanic tests. The series encompassed a wide variety of events, as indicated in the accompanying table (19: 23,24).

All but two of the detonations were at Enewetak and Bikini Atolls in the Marshall Islands. TEAK and ORANGE, high-altitude detonations, occurred 42 and 76 kilometers over Johnston Island, which lies about 700 nautical miles west-southwest of the Hawaiian Islands. A Honolulu resident described the TEAK burst, which took place 10 minutes before midnight, in a front-page story for the 1 August Honolulu Star-Bulletin (19: 1,266):

> I stepped out on the lanai and saw what must have been the reflection of the fireball. It turned from light yellow to dark yellow and from orange to red.

The red spread in a semi-circular manner until it seemed to engulf a large part of the horizon.

A cloud rose in the center of the circle. It was quite large and clearly visible. It remained visible for about a half hour.

It looked much closer than Johnston Island. The elevation of the circle was perhaps 20° above the horizon.

Operation HARDTACK I Nuclear Events, 1958

Event	Date	Type	Yield
YUCCA	28 April	High Altitude (Balloon)	1.7 kilotons*
CACTUS	6 May	Surface	18 kilotons
FIR	12 May	Barge	1.36 megatons
BUTTERNUT	12 May	Barge	81 kilotons
KOA	13 May	Surface	1.37 megatons
WAHOO	16 May	Underwater	9 kilotons
HOLLY	21 May	Barge	5.9 kilotons
NUTMEG	22 May	Barge	25.1 kilotons
YELLOWWOOD	26 May	Barge	330 kilotons
MAGNOLIA	27 May	Barge	57 kilotons
TOBACCO	30 May	Barge	11.6 kilotons
SYCAMORE	31 May	Barge	92 kilotons
ROSE	3 June	Barge	15 kilotons
UMBRELLA	9 June	Underwater	8 kilotons
MAPLE	11 June	Barge	213 kilotons
ASPEN	15 June	Barge	319 kilotons
WALNUT	15 June	Barge	1.45 megatons
LINDEN	18 June	Barge	11 kilotons
REDWOOD	28 June	Barge	412 kilotons
ELDER	28 June	Barge	880 kilotons
OAK	29 June	Barge	8.9 megatons
HICKORY	29 June	Barge	14 kilotons
SEQUOIA	2 July	Barge	5.2 kilotons
CEDAR	3 July	Barge	220 kilotons
DOGWOOD	6 July	Barge	397 kilotons
POPLAR	12 July	Barge	9.3 megatons
PISONIA	18 July	Barge	255 kilotons
JUNIPER	22 July	Barge	65 kilotons
OLIVE	23 July	Barge	202 kilotons
PINE	27 July	Barge	2 megatons

TEAK	31 July	High Altitude (Rocket)	3.8 megatons
QUINCE	6 August	Surface	zero
ORANGE	11 August	High Altitude (Rocket)	3.8 megatons
FIG	18 August	Surface	20 tons

*Some yields marked "Not announced" in the original report have since been declassified and are included in this online version.

4.15.1 Background and Objectives of Operation HARDTACK I.

HARDTACK I consisted of three parts. The first, aimed at the development of nuclear weapons, continued the type of testing that had been conducted at Enewetak and Bikini during the early and mid-1950s. The AEC weapon development laboratories (LANL and LLNL) detonated experimental devices, with the DOD providing support and conducting experiments that did not interfere with AEC activities (19: 1).

The second part, sponsored by DOD, consisted of the underwater test shots, WAHOO and UMBRELLA, the first in open ocean and the second within the lagoon at Enewetak . These tests, which furthered efforts undertaken with the 1946 CROSSROADS and the 1955 WIGWAM series, were designed to gain additional data on the effects of underwater explosions on Navy ships and material (19: 1).

The third part, sponsored by DOD, addressed a military problem that was newer: nuclear weapons in air and ballistic missile defense. Shots YUCCA, TEAK, and ORANGE, also called Operation NEWSREEL by DOD, were directed to this concern (19: 3).

4.15.2 HARDTACK I Test Operations.

The HARDTACK experimental program incorporated two aspects, one being the development of the weapons and the second being the measurement of the explosive and radiation effects. The AEC was primarily interested in weapons development, and the DOD focused on weapons effects, specifically concerning the military application of the weapons (19: 3).

Approximately 16,000 DOD personnel took part in HARDTACK I. They participated in the weapons development experiments by providing cloud-sampling aircraft and crews, along with ship patrols, instrument placement and recovery, and radioactive sample return. Their primary participation, however, was in the effects experiments associated with the underwater and the high-altitude shots (19: 105).

4.15.3 Dose Summary for Operation HARDTACK I.

The maximum permissible dose for HARDTACK I personnel was 3.75 rem of gamma radiation per consecutive 13-week period, with a maximum of 5.0 rem for the operation. The crew of air-sampling aircraft were authorized a special limit of 10.0 rem. In case of operational error or emergency, an additional dose of 10.0 rem would be accepted (19: 3,4).

During the series, one incident involved the exposure of participants to significantly elevated radiation levels. On 14 May, the base islands of Enewetak and Parry at Enewetak Atoll received fallout from a test shot detonated at Bikini 2 days earlier (19: 4,5). According to current calculations, the period of fallout, which lasted about 60 hours, could have contributed as much as 1.7 rem through 31 May 1958, 2.2 rem through 30 June 1958, and 2.5 rem through 31 July 1958 to personnel on the Enewetak Atoll.

Summary of External Doses for Operation HARDTACK I as of 1 May 1986
Gamma Dose (rem)

	0-0.5	0.5-1	1-3	3-5	5-10	10+
Army	249	258	1,011	54	2	0
Navy	5,307	2,746	1,656	26	1	0
Air Force	1,561	474	1,825	183	73	7
Marine Corps	60	99	56	4	0	0
Civilian DOD Participants	65	34	66	3	0	0

4.16 OPERATION ARGUS.

ARGUS, the code name for the only atmospheric nuclear test operation in the Atlantic Ocean, consisted of the three high-altitude, low-yield detonations identified below. The nuclear devices were lifted to about a 300-mile altitude by rockets fired from the missile trials ship USS Norton Sound (AVM-1), one of the nine ships participating in the series (20: 1).

The operation was based in the Atlantic at about 45 deg south latitude. The location placed the task force outside regular shipping lanes but kept the launch well within the range of U.S. military forces required for support of ARGUS scientific projects (20: 19).

Event	Date	Type	Yield (kilotons)
ARGUS I	27 August	Rocket	1-2
ARGUS II	30 August	Rocket	1-2
ARGUS III	6 September	Rocket	1-2

4.16.1 Background and Objectives of Operation ARGUS.

ARGUS was unique among U.S. atmospheric nuclear test operations in a number of respects. It was one of the most expeditiously planned and executed of all U.S. nuclear tests, requiring just 5 months from inception to execution, in contrast to the normal period of 1 or more years. Besides TRINITY, it consisted of the only clandestine tests conducted during the 18-year period of atmospheric testing. The intentions of all phases of the ARGUS operation were concealed not only from other nations but also from the majority of DOD participants in the tests. In addition, ARGUS was the first shipboard launch of a ballistic missile with a nuclear warhead (20: 11, 18).

Most significant of all, the purpose of ARGUS did not fit the usual categories: the ARGUS shots, strictly speaking, involved neither diagnostic tests of a weapon design nor effects tests on military systems. The objective was to establish the practicability of a theory, postulated by Nicholas Christofilos, a physicist at LLNL, that a very-high-altitude nuclear detonation of proper yield would produce phenomena of potentially significant military importance by interfering with communications and weapon performance. When the Eisenhower Administration officially announced the occurrence of the tests on 19 March 1959, the New York Times headlined ARGUS as the "Greatest Scientific Experiment Ever Conducted" (20: 11,12).

The operation proved the validity of the Christofilos theory. It not only provided data on military considerations, but also produced a great mass of geophysical information (20: 2).

4.16.2 ARGUS Test Operations.

The series was conducted by Task Force 88, a naval organization consisting of nine ships and approximately 4,500 men. Coordinated measurement programs using satellite, rocket, aircraft, and surface stations were carried out by the services and other Government agencies and contractors throughout the world. The ships of Task Force 88, in addition to the USS Norton Sound, were the antisubmarine carrier USS Tarawa, the destroyers USS Bearss and USS Warrington, the destroyer escorts USS Courtney and USS Hammerberg, the fleet oilers USS Neosho and USS Salamonie, and the seaplane tender USS Albemarle (20: 1).

4.16.3 Dose Summary for Operation ARGUS.

The detonations occurred at such distances above the earth that the possibilities of personnel exposures to ionizing radiation were considered remote. The recorded doses were, in fact, so low as to be negligible. The highest level recorded by the 264 film badges distributed to the task force was 0.010 rem. The highest level recorded, 0.025 rem, was by a control film badge, which was not issued to personnel but remained in storage in a radiation-free area within a ship. Another control badge read 0.020 rem. These readings were so low that they probably were spurious and the result of environmental effects on film emulsions (20: 1,2).

4.17 OPERATION HARDTACK II.

HARDTACK II was the continental phase of Operation HARDTACK. The oceanic phase, HARDTACK I, was conducted in the Pacific from 28 April through 18 August 1958, as noted in section 4.15. Phase II, conducted at the Nevada Test Site from 12 September through 31 October 1958, consisted of 19 nuclear weapons tests and 18 safety experiments (21: 1). The next section, 4.18, discusses the safety experiments. This section concentrates on the weapons-related tests, identified in the accompanying table.

Operation HARDTACK II Nuclear Events, 1958

Event	Date	Type	Yield (kilotons)
EDDY	19 September	Balloon	0.083
MORA	29 September	Balloon	2
TAMALPAIS	8 October	Tunnel	0.072
QUAY	10 October	Tower	0.079
LEA	13 October	Balloon	1.4
HAMILTON	15 October	Tower	0.0012
LOGAN	16 October	Tunnel	5
DONA ANA	16 October	Balloon	0.037
RIO ARRIBA	18 October	Tower	0.090
SOCORRO	22 October	Balloon	6
WRANGELL	22 October	Balloon	0.115
RUSHMORE	22 October	Balloon	0.188
SANFORD	26 October	Balloon	4.9
DE BACA	26 October	Balloon	2.2
EVANS	29 October	Tunnel	0.055
MAZAMA	29 October	Tower	NMY*
HUMBOLDT	29 October	Tower	0.0078
SANTA FE	30 October	Balloon	1.3
BLANCA	30 October	Tunnel	22

*No measurable yield

4.17.1 Background and Objectives of Operation HARDTACK II.

HARDTACK II was the last nuclear test series before the United States adopted a nuclear test moratorium, which had originally been intended to last 1 year but continued until 1961. The nuclear weapons tests were conducted to evaluate the yield and efficiency of newly developed nuclear devices (21: 1,7).

Concern about nuclear weapon proliferation intensified throughout the 1950s, particularly after the BRAVO test of Operation CASTLE and the heavy fallout resulting from this shot. At that

time, Prime Minister Nehru of India proposed a cessation of tests. The call for a test ban figured repeatedly in disarmament discussions, most importantly, those of the Disarmament Subcommittee of the U.N. Disarmament Commission, in session from 18 March to 6 September 1957. Continuing pressure on the nuclear powers to reach an agreement on limiting testing resulted in the Conference on Discontinuance of Nuclear Weapons Tests, which began in Geneva on 31 October 1958 and was attended by U.S., British, and Soviet delegates. On 1 November 1958, the U.S. unilaterally announced a test moratorium to begin on 1 November 1958, declaring a cessation in nuclear testing if the Soviet Union also refrained (21: 28).

Because the testing and improvement of various nuclear weapons was crucial to American defense policy, a number of tests needed to be conducted before the moratorium began. On 28 August 1958, President Eisenhower approved an accelerated series of nuclear tests code named Operation MILLRACE to be completed at the NTS before the start of the moratorium. On 29 August 1958, by AEC directive, the name of the series was changed to Operation HARDTACK, Phase II (21: 28,29).

4.17.2 HARDTACK II Test Operations.

An estimated 1,650 DOD personnel took part in HARDTACK II. This participation was relatively small compared with previous nuclear weapons testing series because of the weapons development emphasis of the program and because of the substantial DOD involvement (about 16,000 personnel) in HARDTACK I. The primary DOD involvement in HARDTACK II was at Shots HAMILTON and HUMBOLDT, the two weapons effects tests cosponsored by the DOD and the Lawrence Livermore National Laboratory. Projects at these tests were planned to develop delivery systems for small nuclear devices, to design military equipment that could withstand the effects of a nuclear detonation, and to determine the military requirements for future nuclear device designs. In addition to participation in these projects, DOD personnel at HARDTACK II provided air and ground support, including radiological safety monitoring, and administrative staff support (21: 1,29,2).

4.17.3 Dose Summary for Operation HARDTACK II.

HARDTACK II participants, with the exception of AFSWC personnel on cloud-sampling missions, were limited to a gamma plus neutron dose of 3.0 rem per calendar quarter or a total of 5.0 rem per year. The AFSWC personnel involved in cloud sampling were permitted to receive up to 10.0 rem during the series. Individuals who participated in cloud sampling at HARDTACK II who were also at HARDTACK I were authorized to receive 15 rem for the total operation (21: 5,74). The table below summarizes doses for both the weapons-related events and the safety experiments:

Summary of External Doses for Operation HARDTACK II as of 1 May 1986
Gamma Dose (rem)

	0-0.5	0.5-1	1-3	3-5	5-10	10+
Army	45	64	200	15	5	1
Navy	31	0	1	1	0	0
Air Force	204	19	27	5	2	0
Marine Corps	2	0	0	0	0	0
Civilian DOD Participants	952	35	20	2	0	0

4.18 SAFETY EXPERIMENTS.

The nuclear weapons testing program included 33 safety experiments, conducted at the NTS from 1955 to 1958 (22: 8,9,11,12; 17: 9):

- Four experiments called PROJECT 56 and conducted in November 1955 and January 1956, after Operation TEAPOT
- Six experiments called PROJECT 57 and conducted in April, July, August, and September 1957 before and during Operation PLUMBBOB
- Four experiments identified as PROJECT 58 and conducted in December 1957 and February and March 1958, after Operation PLUMBBOB
- Nineteen experiments conducted from July to October 1958 during Operations HARDTACK I and II.

Eleven of the tests were surface detonations, while nine occurred in shafts, six in tunnels, and one on a barge. Of the remaining safety experiments, five were tower detonations and one was a balloon test. Ten of the experiments had no measurable yield while one, COULOMB C, had 0.5 kiloton, which was the highest yield of any safety experiment.

4.18.1 Objectives of the Safety Experiments.

Except for one PROJECT 57 test, the safety experiments were conducted for the same purpose: to determine the weapons' susceptibility to nuclear detonation during accidents in storage and transportation. High-explosive portions of these devices were fired to simulate accidental detonation and to determine the potential for such firings to result in a significant nuclear yield. The test results were used to develop devices that could withstand shock, blast, fire, and accidents without initiating a nuclear chain reaction and producing a nuclear detonation. The initial PROJECT 57 test was conducted to spread alpha-emitting material (plutonium) in a defined area to study the biological effects of alpha radiation and to test monitoring and decontamination procedures (22: 23,8).

4.18.2 Test Operations at the Safety Experiments.

DOD personnel participation during these experiments is difficult to determine. Although most of the employees of LANL and LLNL were civilians, some DOD personnel also were assigned to these organizations. In addition, some of the project activities engaged DOD participation. Eight AFSWC personnel and two participants from the 50th Chemical Service Platoon performed field work for one of the programs during PROJECT 57, the alpha-dispersion experiment. Moreover, a DOD effects project was conducted at four of the safety experiments. Other DOD participation involved cloud-tracking and cloud-sampling missions (22: 12; 17: 184,185).

4.18.3 Dose Summary for the Safety Experiments.

Section 4.17 presents information on personnel doses at the 18 HARDTACK II safety experiments. The limited dosimetry information on the other safety experiments indicates four doses exceeding the 3.9 rem limit at Experiment 4 of PROJECT 56. The readings, which may have resulted from the participants' having handled hot instrumentation cable, were 28, 18.5, 13.7, and 4.3 rem (22: 21).

4.19 OPERATION DOMINIC I.

Operation DOMINIC, like Operation HARDTACK, consisted of two phases: DOMINIC I, the oceanic nuclear tests discussed in this section; and DOMINIC II, the continental tests considered in section 4.20. The DOMINIC shots, also named Operation SUNBEAM by DOD, were the last atmospheric nuclear weapons tests conducted by the United States (23: 1).

DOMINIC I consisted of the 36 nuclear tests identified in the accompanying table. Most of the shots were detonated in the air after having been dropped from B-52 bombers. Twenty-four of the airdrops took place from 25 April through 11 July over the ocean just south of Christmas Island, United Kingdom territory 1,200 nautical miles south of Honolulu. Five more airdrops were detonated in October over the open ocean in the vicinity of Johnston Island, U.S. territory 780 nautical miles west-southwest of Honolulu. The five rocket shots, designated FISHBOWL events, were launched from Johnston Island and detonated at high altitudes, up to 400 kilometers. The Navy conducted the other two shots: FRIGATE BIRD, launched by a Polaris missile from the submarine USS Ethan Allen and detonated east of Christmas Island; and SWORDFISH, a rocket-launched antisubmarine nuclear depth charge detonated 400 miles west of San Diego (23: 1,2). Figure 16 shows the SWORDFISH spray dome and the USS Agerholm (DD-286), from which the rocket was fired (I).

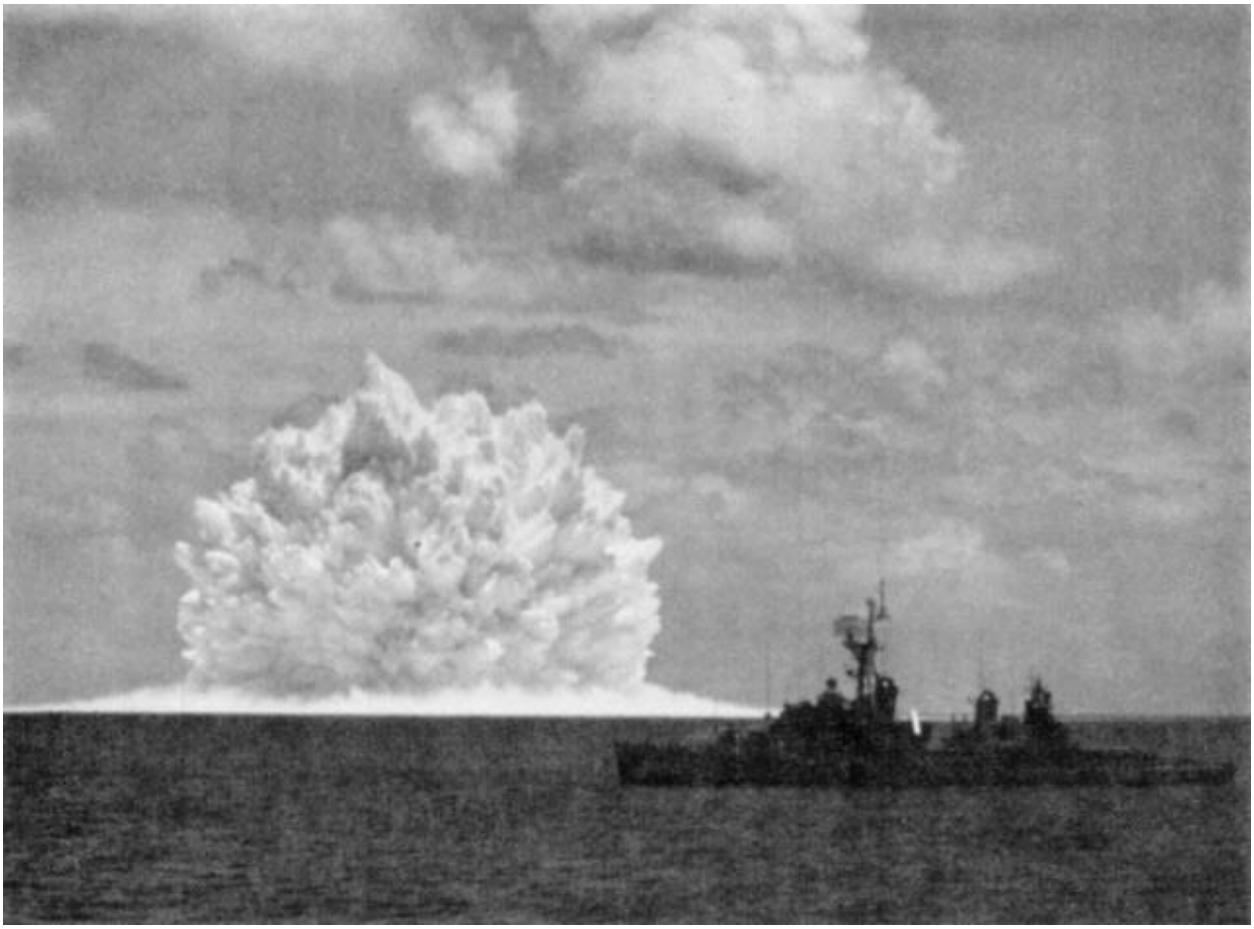


Figure 16. SWORDFISH spray done with USS Agerholm (DD-826) in the foreground, 11 May 1962.

4.19.1 Background and Objectives of Operation DOMINIC I.

The U.S. did not conduct any nuclear tests from 30 October 1958, the date of the last HARDTACK II test, to 15 September 1961, when the U.S. resumed underground nuclear testing at the NTS. On 1 November 1958, the U.S. initiated its 1-year suspension of nuclear testing, which was later extended throughout 1959. On 29 December 1959, the U.S. announced an end to its moratorium, effective 31 December, but with a promise not to resume testing without advance public notice (23: 25).

On 3 January 1960, the Soviet Premier pledged that the Soviet Union would not conduct nuclear tests unless the Western nations resumed their testing. On 31 August 1961, however, the U.S.S.R. abruptly announced plans to resume atmospheric testing and then detonated a nuclear device at the Semipalatinsk test range in Central Asia the next day. This began an extensive Soviet series that continued into November and included more than 30 nuclear shots, among which were a 58-megaton detonation (the largest ever) and high-altitude tests. U.S. testing recommenced with a tunnel shot at the NTS, 15 September 1961, followed by a series of

underground tests. The President approved planning for atmospheric tests on 10 October 1961 but did not approve DOMINIC until 2 March 1962 (23: 25).

Operation DOMINIC I was conducted with four primary objectives: to develop nuclear weapons (the 29 airdrops); to study the effects of nuclear detonations (the five high-altitude bursts); to test the Polaris weapon system (the FRIGATE BIRD event); and to test the Navy nuclear antisubmarine rocket (Shot SWORDFISH) (23: 1).

Operation DOMINIC I Test Events, 1962

Event	Date	Type	Yield*
ADOBE	25 April	Airdrop	190 kilotons
AZTEC	27 April	Airdrop	410 kilotons
ARKANSAS	2 May	Airdrop	1.09 megatons
QUESTA	4 May	Airdrop	670 kilotons
FRIGATE BIRD	6 May	Rocket	NA**
YUKON	8 May	Airdrop	100 kilotons
MESILLA	9 May	Airdrop	100 kilotons
MUSKEGON	11 May	Airdrop	50 kilotons
SWORDFISH	11 May	Underwater	Low
ENCINO	12 May	Airdrop	500 kilotons
SWANEE	14 May	Airdrop	97 kilotons
CHETCO	19 May	Airdrop	73 kilotons
TANANA	25 May	Airdrop	2.6 kilotons
NAMBE	27 May	Airdrop	43 kilotons
ALMA	8 June	Airdrop	782 kilotons
TRUCKEE	9 June	Airdrop	210 kilotons
YESO	10 June	Airdrop	3 megatons
HARLEM	12 June	Airdrop	1.2 megatons
RINCONADA	15 June	Airdrop	800 kilotons
DULCE	17 June	Airdrop	52 kilotons
PETIT	19 June	Airdrop	2.2 kilotons
OTOWI	22 June	Airdrop	81.5 kilotons
BIGHORN	27 June	Airdrop	7.65 megatons
BLUESTONE	30 June	Airdrop	1.27 megatons
STARFISH PRIME	8 July	Rocket	1.4 megatons
SUNSET	10 July	Airdrop	1 megaton
PAMLICO	11 July	Airdrop	3.88 megatons
ANDROSCOGGIN	2 October	Airdrop	75 kilotons
BUMPING	6 October	Airdrop	11.3 kilotons
CHAMA	18 October	Airdrop	1.59 megatons
CHECKMATE	19 October	Rocket	Low
BLUEGILL 3 PRIME	25 October	Rocket	Submegaton
CALAMITY	27 October	Airdrop	800 kilotons
HOUSATONIC	30 October	Airdrop	8.3 megatons

KINGFISH	1 November	Rocket	Submegaton
TIGHTROPE	3 November	Rocket	Low

*Low yield is less than 20 kilotons, and intermediate yield is 20-1,000 kilotons.
**Not announced.

4.19.2 DOMINIC I Test Operations.

The estimated 22,600 participants in DOMINIC I were from all four military services, as well as from DOD agencies, AEC organizations, DOD and AEC contractors, and various Federal agencies. The DOD participation was extensive in all parts of the DOMINIC I experimental program: weapons development, weapons effects, and operational tests. Even the experimental program for the weapon development shots at Christmas Island and later at Johnston Island, conducted by AEC laboratories, involved DOD personnel and units for device placement, cloud sampling, operation of airborne data recording stations, and general support. The weapons effects and operational tests were DOD programs, the former involving a number of experimental projects (23: 11).

4.19.3 Dose Summary for Operation DOMINIC I.

With exceptions for specified Navy and Air Force participants, the maximum permissible dose for Operation DOMINIC I personnel was 3.0 rem of gamma radiation for the series. Navy personnel who were to collect samples of weapon debris from the radioactive pool of water created by SWORDFISH were authorized a maximum limit of 7.0 rem. Air Force personnel associated with cloud sampling (crew, maintenance, sample removal, or decontamination) could receive up to 20 rem of gamma radiation (23: 3).

The table below summarizes available dosimetry information for DOMINIC I participants. Existing evidence indicates that some of the film badges had been defectively sealed or damaged by the environment and that they gave higher readings than the dose actually received. Nevertheless, all personnel have been assigned the readings recorded in Navy records (23: 3,4).

Summary of External Doses for Operation DOMINIC I as of 1 May 1986
Gamma Dose (rem)

	0-0.5	0.5-1	1-3	3-5	5-10	10+
Army	587	8	19	2	0	0
Navy	17,604	205	344	9	1	0
Air Force	2,557	83	98	11	19	21
Marine Corps	653	1	5	0	0	0
Civilian DOD Participants	190	2	1	0	0	0

4.20 OPERATION DOMINIC II.

Also known by the DOD code name of Operation SUNBEAM, DOMINIC II was the continental phase of the DOMINIC nuclear tests. The four shots of this series were conducted at the NTS from 7 July through 17 July 1962, during the period of DOMINIC I, the nuclear test series conducted at the Pacific Proving Ground from 25 April through 3 November 1962 (24: 1).

DOMINIC II consisted of the four low-yield shots identified below.

LITTLE FELLER I, one of the surface shots, was part of Exercise IVY FLATS, the only military training exercise conducted at DOMINIC II (24: 1,5).

Event	Date	Type	Yield (kilotons)
LITTLE FELLER II	7 July	Surface	Low
JOHNIE BOY	11 July	Crater	0.5
SMALL BOY	14 July	Tower	Low
LITTLE FELLER I	17 July	Surface	Low

4.20.1 Background and Objectives of Operation DOMINIC II.

The United States resumed nuclear weapons testing on 15 September 1961 with a series of underground tests conducted at the NTS: Operation NOUGAT, 15 September 1961 to 30 June 1962. This was followed by another underground series: Operation STORAX, 6 July 1962 to 25 June 1963. Operation DOMINIC II was conducted during the period of Operation STORAX but was not a part of STORAX (24: 19,20).

Operation DOMINIC II, designed to provide information on weapons effects, originally comprised only Shot SMALL BOY. Subsequent plans were to include three Little Feller shots, one 3 feet above ground, another 40 feet above ground, and the third also at a height of 40 feet, having been launched tactically as part of a military exercise. The third shot was, however, canceled, and the second, which became LITTLE FELLER I, was changed to a 3-foot shot to be launched in connection with a tactical maneuver (24: 1,114,73).

Plans for JOHNIE BOY, the last shot added to the series, were not made until May 1962. Detonated 2 months later, JOHNIE BOY was designed to explore the cratering effects of a subkiloton nuclear device fired in a shallow emplacement (24: 94).

4.20.2 DOMINIC II Test Operations.

An estimated 2,900 DOD military and civilian personnel participated at Operation DOMINIC II in Exercise IVY FLATS (Shot LITTLE FELLER I), scientific and diagnostic tests, and air support or administrative support activities. Approximately 1,000 of these participants were Sixth Army military personnel who took part in Exercise IVY FLATS, which consisted of an observer program and a troop maneuver. The observers, who wore protective goggles, witnessed the detonation from bleachers about 3.5 kilometers southwest of ground zero. Five participants from the IVY FLATS maneuver task force launched the weapon from a rocket launcher mounted on an armored personnel carrier. After the initial radiological surveys were completed, the IVY FLATS troops entered their vehicles and moved into the shot area, where they spent about 50 minutes conducting maneuvers (24: 1,3).

4.20.3 Dose Summary for Operation DOMINIC II.

Most DOMINIC II participants were subject to a quarterly dose limit of 3.0 rem (gamma plus neutron) and an annual limit of 5 rem (gamma plus neutron). Cloud-sampling pilots were authorized to receive up to 3.9 rem per 13-week period because their mission sometimes required them to penetrate the clouds (24: 3,7).

The following table summarizes the dosimetry data available for DOMINIC II, as well as for the first two events of the PLOWSHARE Program, GNOME and SEDAN, which are discussed in section 4.21. GNOME was conducted on 10 December 1961 and SEDAN on 6 July 1962. A number of DOD participants in these two events also took part in DOMINIC II. In many cases, their recorded doses were cumulative, covering their participation in both DOMINIC II and the PLOWSHARE events. For this reason, the combined totals are provided for DOMINIC II, GNOME, and SEDAN, as is shown below:

Summary of External Doses for Operation DOMINIC II and for GNOME and SEDAN of the PLOWSHARE Program as of 1 May 1986
Gamma Dose (rem)

	0-0.5	0.5-1	1-3	3-5	5-10	10+
Army	1,184	163	101	2	0	0
Navy	61	19	32	0	1	0
Air Force	235	28	14	1	0	0
Marine Corps	37	8	16	1	0	0
Civilian DOD Participants	638	21	10	0	0	0

4.21 PLOWSHARE PROGRAM.

Conducted from 1961 to 1973, the PLOWSHARE Program consisted of 27 nuclear detonations, four of which occurred before the signing of the 1963 limited test ban treaty. The detonations,

all of which had yields of no more than 200 kilotons, were staged at the NTS and other sites in Colorado and New Mexico. The tests were all subsurface, being either shaft or cratering shots (25: 1).

As indicated by the following table, this section discusses only Projects GNOME and SEDAN, the first two PLOWSHARE events. These two shots were selected for consideration because they were conducted during the period of U.S. atmospheric testing and they had documented, although limited, DOD participation. In addition, the extant sources were sufficient in number and detail to enable a summation of the events (25: 1).

Event	Date	Type	Yield (kilotons)
GNOME	10 December 1961	Shaft	3
SEDAN	6 July 1962	Crater	104

4.21.1 Background and Objectives of the PLOWSHARE Program.

From the earliest days of nuclear research and nuclear weapons testing, scientists were aware of the potential for peaceful applications of nuclear energy, including nuclear detonations. This recognition became U.S. policy in the Atomic Energy Act of 1946, which stated that "atomic energy is capable of application for peaceful as well as military purposes." The opportunity for American scientists to apply nuclear detonations to peaceful ends was delayed, however, by several factors, including the greater priority of developing efficient weapons applications, concern over radioactive contamination, and international suspicion of the intent of the research. Nevertheless, the AEC ultimately succeeded in initiating the PLOWSHARE Program, which had been planned in the late 1950s (25: 19,17,18).

The PLOWSHARE detonations were designed to determine nonmilitary applications of nuclear explosives. The primary potential use envisioned was in large-scale geographic engineering, in such projects as canal, harbor, and dam construction, the stimulation of oil and gas wells, and mining. GNOME was planned in part to provide information on the characteristics of an underground nuclear detonation in a salt medium, while SEDAN was to extend knowledge on cratering effects from detonations with yields of 100 to 200 kilotons. Considering the peaceful objectives of PLOWSHARE, the AEC took the name of the program from the Bible: "And they shall beat their swords into plowshares" (Isaiah 2:4) (25: 1-3).

The ultimate goal of PLOWSHARE, the peaceful applications of nuclear explosives, was never realized. The limited test ban treaty, signed on 5 August 1963 in Moscow, ended nuclear testing in the atmosphere, on land, and underwater, although not underground. Hence, a number of the PLOWSHARE experiments had to be canceled. Other contributing factors were changes in national priorities, Government and industry disinterest in the program, public concern over the health and safety aspects of using nuclear detonations for civil applications, and shortages of funding (25: 26).

4.21.2 PLOWSHARE Test Operations.

The Lawrence Livermore National Laboratory, which provided technical direction for the PLOWSHARE Program, conducted an extensive series of scientific projects at GNOME and SEDAN. Given the objectives of PLOWSHARE, the DOD did not stage military exercises during the program and had limited involvement in the shots. The primary role of the military was to provide logistical support. DOD personnel did, however, participate at GNOME and SEDAN in the VELA UNIFORM program, conducted by the DOD to develop U.S. capabilities in detecting and identifying underground nuclear detonations. In addition, the Air Force Special Weapons Center performed cloud-sampling, cloud-tracking, and support missions at the shots (25: 1-3).

4.21.3 Dose Summary for the PLOWSHARE Program.
PLOWSHARE participants were limited to 3.0 rem of gamma and neutron radiation per calendar year and not more than 5.0 rem annually. The dosimetry information available for GNOME and SEDAN participants is included in the dose summary table given in section 4.20.

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See Availability Information page in Appendix E.
*Available from NTIS; price code and order number appear before the asterisk.
**Available at CIC.
