Project Y

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Dedicatation

This book is dedicated to Dr. Robles.

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Introduction

The Los Alamos Laboratory, also known as "Project Y", was a secret laboratory established by the Manhattan Project and operated by the University of California (UC) during World War II (WWII). Its mission was to design and build the first atomic bombs. Robert Oppenheimer directed it from 1943 to 1945, succeeded by Norris Bradbury. Project Y operated in a remote part of New Mexico so that scientists could freely discuss their work while preserving security.

Development initially concentrated on making a nuclear fission weapon using plutonium called "Thin Man". In 1944, Oppenheimer reorganized the laboratory and orchestrated a successful effort on an alternative design proposed by John von Neumann: a nuclear weapon they called "Fat Man". They developed a variant of the Thin Man design called "Little Boy", using the isotope uranium-235.

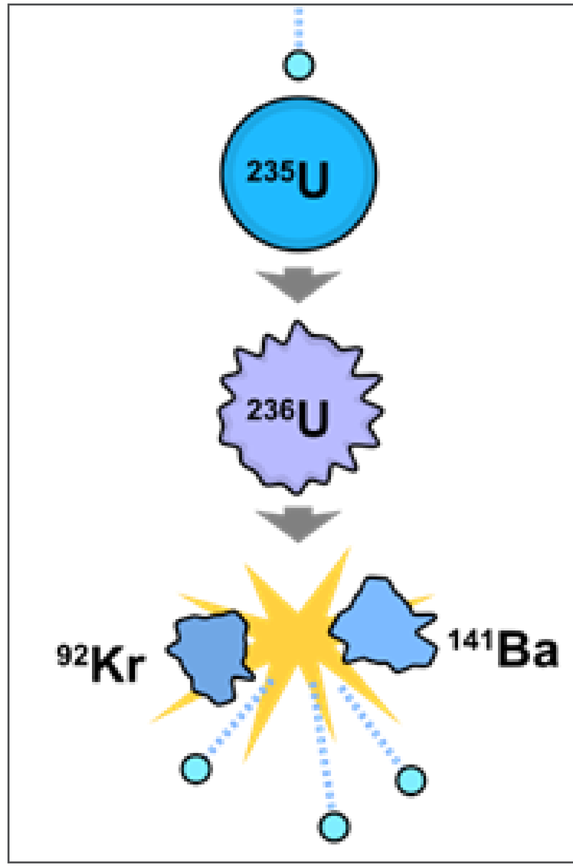
Chemists at the Los Alamos Laboratory developed methods of purifying the elements uranium and plutonium, the latter an uncommon metal when Project Y began. Its metallurgists found that plutonium had unexpected properties; they managed to cast the element into metal spheres. The laboratory also designed, built, and operated the third aqueous homogeneous reactor in the world.

The scientists tested Fat Man during the Trinity nuclear test in July 1945. Project Y personnel formed pit crews and assembly teams for the atomic bombings of Hiroshima and Nagasaki, helping with supplies and observation. After the war ended, the laboratory supported nuclear tests at Bikini Atoll. They formed a new division to control testing, stockpiling, and bomb assembly, all concentrated at Sandia Base. The Los Alamos Laboratory became Los Alamos Scientific Laboratory in 1947.

Origins

Nuclear Fission and Atomic Bombs

Multiple scientific discoveries opened up the viability of a controlled nuclear chain reaction using uranium. James Chadwick discovered the neutron in 1932 (Compton 1956, 14). Soon after, German chemists Otto Hahn and Fritz Strassmann discovered nuclear fission in 1938 (Rhodes 1986, 251-254). At the time, few scientists in the United States thought that an atomic bomb was practical, but the possibility that Nazi Germany would develop atomic weapons sufficiently concerned scientists who had fled Europe (Hewlett & Anderson 1962, 29). These scientists drafted a letter to warn President Franklin D. Roosevelt, prompting preliminary research in the United States starting in late 1939 (Jones 1985, 12).



In nuclear fission, the atomic nucleus of a heavy element splits into two or more light ones when a neutron is captured. If more neutrons are emitted, a nuclear chain reaction becomes possible.

Progress was slow in the United States, but in Britain, Otto Frisch and Rudolf Peierls, refugee German physicists, examined theoretical issues involved in developing, producing, and using atomic bombs. They considered what would happen to a sphere of pure uranium-235, and found that a chain reaction could occur using as little as 1 kilogram (2.2 lb.) of uranium-235 to unleash the energy of hundreds of tons of TNT. Their superior, Mark Oliphant, took Frisch and Peierls' work to the Committee for the Scientific Survey of Air Warfare (CSSAW) (Gowing 1964, 39-43). CSSAW created the MAUD Committee to investigate (Gowing 1964, 43-45). In its final report in July 1941, the MAUD Committee concluded that an atomic bomb was not only feasible, but possible to produce as early as 1943 (Gowing 1964, 107-109).

Unlike Britain, the United States hadn't formally entered World War II and lacked the urgency for researching nuclear weaponry. Oliphant flew there in late August 1941 and spoke to American scientists, including his friend Ernest Lawrence at UC (Rhodes 1986, 372). Oliphant managed to convince them that an atomic bomb was feasible (Hewlett & Anderson 1962, 43-44). In turn, Lawrence brought in his friend and colleague Robert Oppenheimer to review the MAUD Committee report, which they discussed on 21 October 1941 (Hewlett & Anderson 1962, 46-47).

In December 1941, the S 1 Section of the United States' Office of Scientific Research and Development (OSRD) placed physicist Arthur H. Compton in charge of the bomb's design (Hewlett & Anderson 1962, 50-51; Compont 1956, 86). He delegated tasks of bomb design and research to Gregory Breit while Oppenheimer assisted. But Breit disagreed over security arrangements with other scientists working at the connected Metallurgical Laboratory, particularly Enrico Fermi, and Breit resigned on 18 May 1942 (Monk 2012, 312-315; Hewlett & Anderson 1962, 103). Compton then appointed Oppenheimer to replace him (Compton 1956, 125-127). John Manley, a Metallurgical Laboratory physicist, also joined to aid Oppenheimer by contacting and coordinating experimental physics groups scattered across the country (Hewlett & Anderson 1962, 103). Oppenheimer and Robert Serber of the University of Illinois examined the problems of neutron diffusion—how neutrons moved in a nuclear chain reaction—and hydrodynamics—how the explosion produced by a chain reaction might behave (Monk 2012, 315-316).

Bomb Design Concepts

To review observations and theories of fission reactions, Oppenheimer and Fermi convened meetings at the University of Chicago in June 1942 and UC Berkeley in July 1942 with leading theoretical physicists. Among them numbered Oppenheimer's former students and John Manley. They tentatively confirmed that a fission bomb was theoretically possible (Hoddeson et al. 1993, 42–44).

There remained other factors and options:

- properties of pure uranium-235 compared to slight knowledge of the recently-discovered element plutonium
- possibilities of breeding plutonium in reactors using uranium-238 atoms which absorbed neutrons via fissioned uranium-235 atoms
- arranging fissile material into critical mass with a future reactor and newly-produced plutonium (Hewlett & Anderson 1962, 33-35)
- engineering a nuclear reaction to detonate via implosion using neutrons propelled into critical mass

Putting ideas for fission bombs aside—at least until more experimental data was available—the Berkeley conference then turned in a different direction. Edward Teller advocated for a more powerful bomb: the "Super", usually known today as a hydrogen bomb, which would use the explosive force of a detonating fission bomb to ignite a nuclear fusion reaction between the elements deuterium and tritium (Rhodes 1986, 417). Teller proposed scheme after scheme, but Hans Bethe rejected each one. They skipped fusion in order to concentrate on producing fission bombs (Hoddeson et al. 1993, 44–45). Teller also speculated the possibility that an atomic bomb might "ignite" the atmosphere because of a hypothetical fusion reaction, but Bethe calculated that this could not happen, and a report co-authored with Teller showed that "no self-propagating chain of nuclear reactions is likely to be started" (Bethe 1991, 30; Rhodes 1986, 419; Konopinski et al. 1946).

Bomb Laboratory Concept

Oppenheimer's deft handling of the July conference impressed his colleagues: his insight and ability to organize everyone came as a surprise even to those who knew him well (Monk 2012, 312). Following the conference, Oppenheimer saw that despite knowing the physics, they still needed to work on the engineering, chemistry, metallurgy, and ordnance aspects of building a bomb. He realized they would need an environment of free discussion to reduce duplicated effort. He reasoned that this could best reconcile with security if they established a central laboratory in an isolated location (Monk 2012, 325; Jones 1985, 82-83).

Brigadier General Leslie R. Groves Jr. became director of the Manhattan Project, the overall United States nuclear program, on 23 September 1942 (Jones 1985, 77). He visited Berkeley to meet with Lawrence and Oppenheimer, who gave him a report on bomb design on 8 October (Groves 1962, 60-61). Groves took interest in Oppenheimer's proposal for a separate laboratory. Upon meeting a week later in Chicago, Groves had to catch a train to New York, so he asked Oppenheimer to accompany him so that they could continue the discussion. Groves, Oppenheimer, and two colonels squeezed into a single compartment where they talked about making a bomb laboratory and how it would function (Monk 2012, 325). Groves subsequently invited Oppenheimer to Washington, D.C., where they discussed the matter with Vannevar Bush, the director of the OSRD, and James B. Conant, the chairman of the National Defense Research Committee. On 19 October, Groves approved the laboratory project (Jones 1985, 82-83).

While Oppenheimer seemed the logical candidate to direct the new laboratory, which became known as Project Y, he had little administrative experience. Bush, Conant, Lawrence, and Harold Urey all expressed reservations about this (Jones 1985, 87). Moreover, unlike other project leaders—Lawrence at the Berkeley Radiation Laboratory, Compton at the Metallurgical Project in Chicago, and Urey at the SAM Laboratories in New York—Oppenheimer did not have a Nobel Prize. This raised concerns that he might not have the prestige to deal with distinguished scientists. Meanwhile, many of Oppenheimer's closest associates belonged to the Communist Party, including his wife Kitty (Groves 1962, 61-63; Monk 2012, 234-236). Ultimately, Groves personally issued clearance for Oppenheimer on 20 July 1943 (Groves 1962, 61-63).

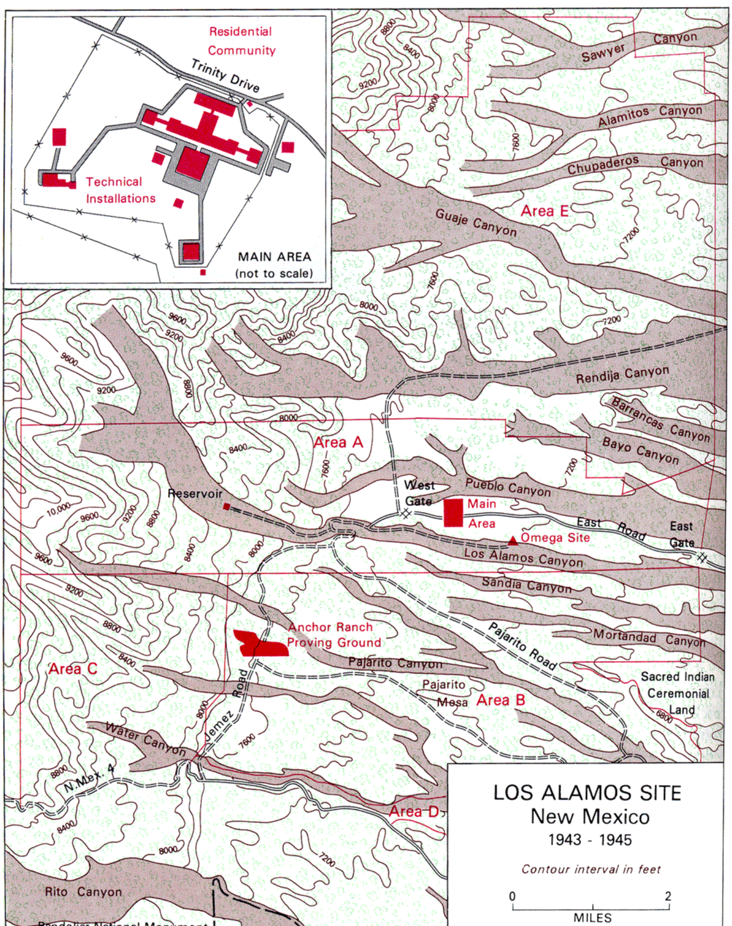
Site Selection

After considering locating Project Y at the Metallurgical Laboratory in Chicago, or at the Clinton Engineer Works in Oak Ridge, Tennessee, they decided that a remote location would be best (Jones 1985, 83-84). A site in the vicinity of Los Angeles was rejected on security grounds, and one near Reno, Nevada was too inaccessible. On Oppenheimer's recommendation, they narrowed the search to the vicinity of Albuquerque, New Mexico, where Oppenheimer owned a ranch in the Sangre de Cristo Range (Groves 1962, 64-65). The climate was mild, the site was accessible via air and rail, the possibility of Japanese attacks coming from across the Pacific Ocean was minimal, and the population density was low (Jones 1985, 83-84).

The United States approved the site's acquisition on 25 November 1942, authorizing purchase of the site's 54,000 acres, all but 8,900 acres of which the government already owned (Jones 1985, 328-331). The Secretary of Agriculture granted use of some 45,100 acres of United States Forest Service land to the War Department "for so long as the military necessity continues" (Los Alamos National Laboratory 1943). Required land for a new road, followed by a 25-mile (40 km) power line, eventually brought wartime land purchases to 45,737 acres; only $414,971 had been spent (Jones 1985, 328-331).

Costly items included the Los Alamos Ranch School, which cost $350,000, and the Anchor Ranch, which cost $25,000 (Manhattan District 1947a, 3.6). Both buildings served to house the laboratory. The school and the ranch hired lawyers to negotiate deals with the government, but Hispanic homesteaders received as little as seven dollars an acre (Yardley 2001). Grazing permits were withdrawn, and the United States purchased or condemned private land through eminent domain (Manhattan District 1947a, S3). The United States worded petitions of condemnation to cover all mineral, water, timber and other rights, so that private individuals would have no reason to intrude (Manhattan District 1947a, 3.3).

Oppenheimer initially estimated that the work could be performed by fifty scientists and fifty technicians; Groves tripled this number to three hundred. (Hunner 2004, 31-32) The actual population, including family members, was about 3,500 by the end of 1943, 5,700 by the end of 1944, 8,200 by the end of 1945, and 10,000 by the close of 1946 (Manhattan District 1947a, S19).



Map of Los Alamos site, New Mexico, 1943–1945

Organization

Military

Post Commander

Colonel John M. Harman was the first post commander at Los Alamos. He joined the Santa Fe office as a lieutenant colonel on January 19, 1943, and became colonel on February 15, 1943 (Manhattan District 1947, 7.1-7.2). After Los Alamos officially became a military establishment on April 1, 1943, he moved to Los Alamos on April 19, 1943 (Manhattan District 1947, 7.1-7.2; Jones 1985, 86). He was succeeded by Lieutenant Colonel C. Whitney Ashbridge, a graduate of the Los Alamos Ranch School, in May 1943 (Hunner 2004, 16). In turn, Ashbridge was succeeded by Lieutenant Colonel Gerald R. Tyler in October 1944, Colonel Lyle E. Seaman in November 1945, and Colonel Herb C. Gee in September 1946 (Manhattan District 1947 7.1-7.2; Hunner 2004, 16). The post commander was answerable directly to Groves, and was responsible for the township, government property and the military personnel (Groves 1962, 153-154).

The Main Gate at Los Alamos

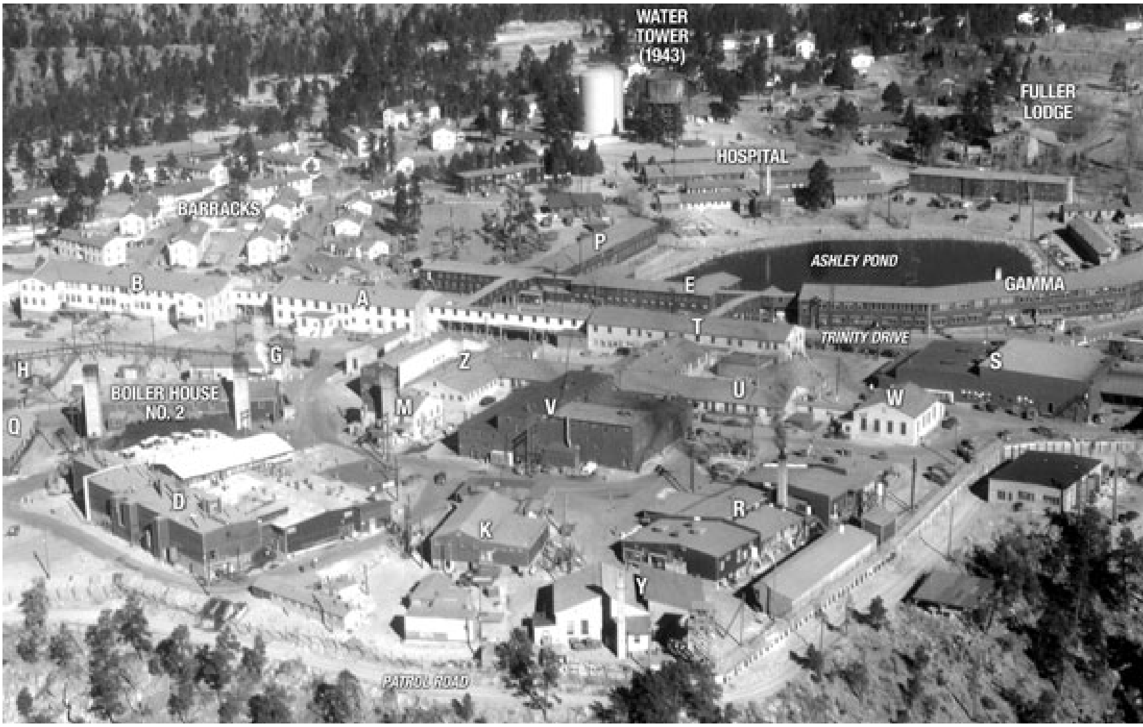
Military Units Assigned to the Post

- The MP Detachment, 4817th Service Command Unit

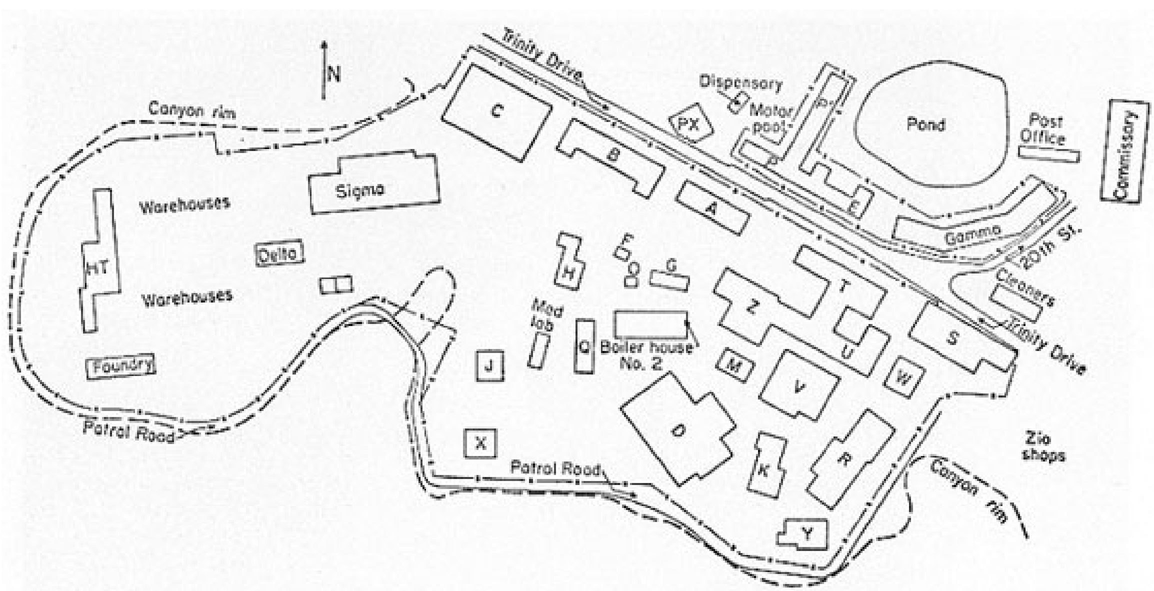
  It arrived from Fort Riley, Kansas, in April 1943. Its initial strength included seven officers and 196 enlisted men; by December 1946, it had nine officers and 486 men, and maintained forty-four guard posts twenty-four hours a day (Manhattan District 1947, 6.33-6.34).

- The Provisional Engineer Detachment (PED), 4817th Service Command Unit

  It was activated at Camp Claiborne, Louisiana, on April 10, 1943. These men performed jobs around the post such as working in the boiler plant,



Picture of the Technical Area



Map of the Technical Area

the motor pool and the mess halls. They also maintained the buildings and roads. It reached a peak strength of 465 men, and was disbanded on July 1, 1946 (Manhattan District 1947, 7.2-7.5).

- The 1st Provisional Women's Army Auxiliary Corps (WAAC) Detachment

  It was activated at Fort Sill, Oklahoma, on April 17, 1943. Its initial strength had just one officer and seven auxiliaries. The WAAC became the Women's Army Corps (WAC) on August 24, 1943.Then, WACs became part of the 4817th Service Command Unit, with a strength of two officers and forty-three enlisted women. Ashbridge emerged WACs into the United States Army later. It reached a peak strength of about 260 women in August 1945. The WACs did a wider variety of jobs than the PED; some served as cooks, drivers and telephone operators, while others served as librarians, clerks and hospital technicians. Some performed highly specialized scientific research inside the Technical Area[1] (Manhattan District 1947, 7.2-7.5).

- The Special Engineer Detachment (SED)

  It was activated in October 1943 as part of the 9812th Technical Service Unit. It made up of men with technical skills or adced education mostly drawn from the defunct Army Specialized Training Prog. (Manhattan District 1947, 7.2-7.5). War Department policy forbade giving deferments from the draft to men under twenty-two, so they were assigned to the SED (Hawkins 1961, 43). It reached a peak strength of 1,823 men in August 1945. SED personnel worked in all areas of the Los Alamos Laboratory (Manhattan District 1947, 7.2-7.5).

Civilian

Scientists

As director of the Los Alamos Laboratory, Oppenheimer reported directly to Groves, instead of Compton, who directed designing the bomb (Jones 1985, 86). Oppenheimer had the responsibility for the technical and scientific aspects of Project Y (Groves 1962, 153-154). He assembled the nucleus of his staff from the groups that worked for him on neutron calculations (Hawkins 1961, 5-6). His staff included scientists from various universities and other laboratories as well as their own research groups.

1 Images on p. 20 show the Technical Area at the Los Alamos Laboratory.

Staff	University/Laboratory
Priscilla Greene	(Oppenheimer's sectary)
Robert Serber	Oppenheimer's group
Edwin McMillan	Oppenheimer's group
Emilio Segrè	The University of California
Joseph W. Kennedy	The University of California
J. H. Williams	The University of Minnesota
Joe McKibben	The University of Wisconsin
Felix Bloch	Stanford University
Marshall Holloway	Purdue University
Hans Bethe	The Radiation Laboratory at MIT
Robert Bacher	The Radiation Laboratory at MIT
Edward Teller	Manhattan Project's Metallurgical Laboratory
Robert F. Christy	Manhattan Project's Metallurgical Laboratory
Darol K. Froman	Manhattan Project's Metallurgical Laboratory
Alvin C. Graves	Manhattan Project's Metallurgical Laboratory
John H. Manley	Manhattan Project's Metallurgical Laboratory
Robert R. Wilson	Manhattan Project's Metallurgical Laboratory
Richard Feynman	Manhattan Project research at Princeton University

Oppenheimer's staff

For the research at Los Alamos Laboratory, these scientists brought valuable scientific equipment. For example, Wilson's group dismantled the cyclotron at Harvard University and had it shipped to Los Alamos; McKibben's brought two Van de Graaff generators[1] from Wisconsin; and Manley's brought the Cockcroft–Walton accelerator[2] from the University of Illinois (Hawkins 1961, 5-6).

1 The Van de Graaff generator is an electrostatic generator, which uses a moving belt to accumulate electric charge on a hollow metal globe on the top of an insulated column, creating very high electric potentials. It produces very high voltage direct current (DC) electricity at low current levels.

2 The Cockcroft–Walton accelerator is an electric circuit that generates a high DC voltage from a low-voltage alternating current (AC) or pulsing DC input.

WACs

Women at Los Alamos were encouraged to work, due to the shortage of labor and security concerns over bringing in local workers. About sixty wives of scientists worked in Technical Area by September 1943. Women took about 200 of the 670 workers in the laboratory, hospital and school in October 1944. Most of them worked in administration, but many women such as Lilli Hornig, Jane Hamilton Hall, and Peggy Titterton worked as scientists and technicians (Hoddeson, et al. 1993, 99-100; Howes and Herzenberg 1999, 43-45; Macdonald 1995). Charlotte Serber headed the A-5 (Library) Group (Hawkins 1961, 180). A large group of women worked on numerical calculations in the T-5 (Computations) Group (Hoddeson, et al. 1993, 99-100). Dorothy McKibbin ran the Santa Fe office, which opened at 109 East Palace Avenue on March 27, 1943 (Steeper 2003, 1-3).

Organization

A governing board at the Los Alamos Laboratory included:

- Robert Oppenheimer,
- Robert Bacher,
- Hans Bethe,
- Joseph W. Kennedy,
- D. L. Hughes (Personnel Director),
- D. P. Mitchell (Procurement Director), and
- Deak Parsons.

Later, the governing board added Edwin McMillan, George Kistiakowsky and Kenneth Bainbridge (Hawkins 1961, 32, 36). The laboratory was organized into five divisions (Hoddeson, et al. 1993, 92; Hawkins 1961, 84, 101, 124, 148):

- Administration (A)
- Theoretical (T) under Bethe
- Experimental Physics (P) under Bacher

- Chemistry and Metallurgy (CM) under Kennedy
- Ordnance and Engineering (E) under Parsons

All the divisions expanded during 1943 and 1944, but T Division, despite trebling in size, remained the smallest, while E Division grew to be the largest. The laboratory faced the difficulty of security clearance. Scientists (including, at first, Oppenheimer) had to obtain access to the Technical Area without proper clearance. In the interest of efficiency, Groves approved an abbreviated process by which Oppenheimer vouched for senior scientists, and three other employees were sufficient to vouch for a junior scientist or technician (Hoddeson, et al. 1993, 93-94).

The British Mission

A British Mission under James Chadwick reinforced the Los Alamos Laboratory. Otto Frisch and Ernest Titterton arrived first; later arrivals included Niels Bohr and his son Aage Bohr, and Sir Geoffrey Taylor, an expert on hydrodynamics who contributed to the understanding of the Rayleigh–Taylor instability[1] (Hawkins 1961, 27-30). The original idea of the British Mission, favored by Groves, included that the British scientists would work as a group under Chadwick, who would farm out the work to them. A favor of having the British Mission fully integrated into the laboratory disregarded the original idea soon. British scientists worked in most of its divisions, only except plutonium chemistry and metallurgy (Szasz 1992, 18-19; Hawkins 1961, 27-30). With the passage of the Atomic Energy Act of 1946[2], known as the McMahon Act, all British government employees had to leave. All had left by the end of 1946, except for Titterton, who was granted a special dispensation, and remained until April 12, 1947. The British Mission ended when he departed (Szasz 1992, 46-49; Truslow and Smith 1961, 3).

1 This instability at the interface between two fluids of different densities occurs when the lighter fluid is pushing the heavier (Sharp 1984, 12:3-18), and when it was vital to the interpretation of experiments with explosives in order to predict the effects of an explosion, the design of the neutron initiators, and the design of the atomic bomb itself.

2 This act ruled that nuclear weapon development and nuclear power management would be under civilian, rather than military control, and established the United States Atomic Energy Commission for this purpose.

Gun-type weapon design

Research

Names of the Bomb Design Projects

In 1943, development efforts focused on a gun-type fission weapon using plutonium called Thin Man (Hoddeson, et al. 1993, 111-114; Hawkins 1961, 74-75). Serber named all three atomic bomb design projects, based on their shapes—Fat Man, Thin Man, and Little Boy. Thin Man was a long device, and its name came from the Dashiell Hammett detective novel and series of movies of the same name. The Fat Man was round and fat, and was named after Sydney Greenstreet's "Kasper Gutman" character in *The Maltese Falcon*. Little Boy came last, and was named after Elisha Cook, Jr.'s character in the same film, as referred to by Humphrey Bogart (Serber and Crease 1998, 104).

Assumptions

A series of conferences in April and May 1943 laid out the laboratory's plan for the year. Oppenheimer estimated the critical mass of a uranium-235 gadget with a formula based on diffusion theory derived at Berkeley by Stan Frankel and E. C. Nelson. This gave a value for a uranium-235 gadget with a perfect tamper of 25 kg; but this was only an approximation. It was based on simplifying assumptions including:

- all neutrons had the same speed;
- all collisions were elastic;
- they were scattered in an isotropic manner; and
- the mean free path of neutrons in the core and tamper were the same.

Bethe's T Division, particularly Serber's T-2 (Diffusion Theory) Group and Feynman's T-4 (Diffusion Problems) Groups, would spend the next few months working on improved models (Hoddeson, et al. 1993, 75-78; Hawkins 1961, 85-88). Bethe and Feynman also developed a formula for the efficiency of the reaction (Hoddeson, et al. 199, 183-184).

Testing

The laboratory could not confirm the values based on the estimates for the cross sections and had not yet determined for plutonium. They prioritized the measurement of these values, but they possessed just 1g of uranium-235, and only a few microg. of plutonium (Hoddeson, et al. 1993, 75-78). This task fell to Bacher's P Division. Williams P-2 (Electrostatic Generator) Group carried out the first experiment in July 1943, when it used the larger of the two Van de Graaff generators to measure the ratio of the neutron per fission in plutonium against the ratio of uranium-235 (Hawkins 1961, 103-104). This involved some negotiation with the Metallurgical Laboratory to obtain 165 µg of plutonium, which the Los Alamos Laboratory received on July 10, 1943.

Bacher could report that the number of neutrons per fission of plutonium-239 was 2.64 ± 0.2, about 1.2 times as much as uranium-235 (Hoddeson, et al. 1993, 78-80). Titterton and Boyce McDaniel of Wilson's P-1 (Cyclotron) Group attempted to measure the time it took for prompt neutrons to be emitted from a uranium-235 nucleus when it fissions (Newton 1992). They calculated that most were emitted in less than 1 nanosecond. Subsequent experiments demonstrated that fission took less than a nanosecond too. In the autumn of 1944, the laboratory confirmed the theorists' contention that the number of neutrons emitted per fission was the same for both fast and slow neutrons, although it took longer than they expected (Hawkins 1961, 103-104).

John von Neumann visited the Los Alamos Laboratory in September 1943, and participated in discussions of the damage that an atomic bomb would do. He explained that while the impulse (the average pressure of the explosion times its duration) determines the damage done by a small explosion, the peak pressure, which depends on the cube root of its energy, determines the damage from large explosions such as an atomic bomb. Bethe then calculated that a 10 kilotonnes of TNT (42 TJ) explosion would result in an overpressure of 0.1 standard atmospheres (10 kPa) at 3.5km (2.2 mi), and therefore result in severe damage within that radius. Von Neumann also suggested that, because pressure increases when shock waves bounce off solid objects, the damage could increase if the bomb was detonated at an altitude comparable to the damage radius, approximately 1 to 2km (3,300 to 6,600 ft) (Hoddeson, et al. 1993, 183-184; Hawkins 1961, 98-99).

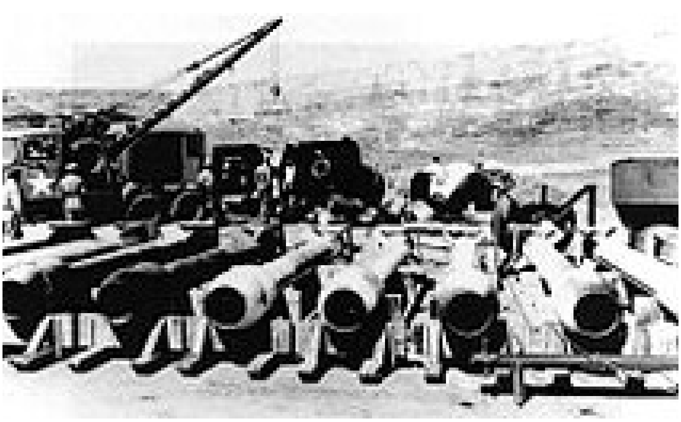
Development

Ordnance and Engineering Division

Parsons took up the head of Ordnance and Engineering Division in June 1943 on the recommendation of Bush and Conant (Hawkins 1961, 124-125). To staff the division, Tolman, who acted as a coordinator of the gun development effort, brought in John Streib, Charles Critchfield and Seth Neddermeyer from the National Bureau of Standards[1] (Hoddeson, et al. 1993, 82-85). The division was initially organized into five groups and later into seven groups under the original group leaders.

Group	Code Name	Director
Proving Ground Group	E-1	Edwin McMillan
Instrumentation Group	E-2	Kenneth Bainbridge
Fuse Development Group	E-3	Robert Brode
Projectile, Target, and Source Group	E-4	Charles Critchfield
Implosion Group	E-5	Seth Neddermeyer
Delivery Group	E-7	Norman Ramsey
Interior Ballistics Group	E-8	Joseph O. Hirschfelder

Groups of the Ordnance and Engineering Division



A Row of Thin Man Casings

1 In 1901, the National Bureau of Standards was founded with the mandate to provide standard weights and measures, and to serve as the national physical laboratory for the United States. In 1988, its name changed to the National Institute of Standards and Technology.

Gun Design

The Los Alamos Laboratory established a proving ground at the Anchor Ranch. The scientists needed to design an unusual gun without crucial data about critical mass. The design criteria included:

- the gun would have a muzzle velocity of 3,000 ft. per second (910 m/s);
- the tube would weigh only 1 short ton (0.91 t) instead of the conventional 5 short tons (4.5 t) for a tube with that energy;
- it would be made of alloyed steel as a consequence;
- it should have a maximum breech pressure of 75,000 pounds per square inch (520,000 kPa); and
- it should have three independent primers.

Because the gun needs to be fired only once, the barrel could be made lighter than the conventional gun. It did not require rifling or recoil mechanisms. Hirschfelder computed pressure curves at the Geophysical Laboratory prior to his joining the Los Alamos Laboratory (Hawkins 1961, 127-128).

While they waited for the guns to be fabricated by the Naval Gun Factory, various propellants were tested. Hirschfelder sent John L. Magee to the Bureau of Mines' Experimental Mine at Bruceton, Pennsylvania to test the propellant and ignition system (Hoddeson, et al. 1993, 114-115). Test firing was conducted at the Anchor Ranch with a 3 in. (76 mm)/50 caliber gun. This allowed the fine-tuning of the testing instrumentation. After the first two tubes arrived at Los Alamos on March 10, 1944, test firing began at the Anchor Ranch under the direction of Thomas H. Olmstead, who had experience in such work at the Naval Proving Ground in Dahlgren, Virginia. They tested the primers and found that the primers work at pressures up to 80,000 pounds per square inch (550,000 kPa). Brode's group investigated the fusing systems, testing radar altimeters, proximity fuses and barometric altimeter fuses (Hawkins 1961, 129-134).

The laboratory conducted tests with a frequency modulated type radar altimeter known as AYD and a pulse type known as 718. The Norden Laboratories Corporation under an Office of Scientific Research and Development (OSRD) contract created the AYD modifications. A new tail warning radar, AN/APS-

13, known as *Archie*, emerged to production, which could be used as a radar altimeter, when the laboratory contracted the manufacturer of 718, RCA. In May, they tested the third unit delivered to Los Alamos in April 1944, by diving an AT-11[1]. After the test, full-scale drop testing was conducted in June and July. Archie was adopted due to the successful tests, although the scarcity of units in August 1944 precluded wholescale destructive testing (Hawkins 1961, 129-134). Testing of Silverplate Boeing B-29 Superfortress aircraft with Thin Man bomb-shapes was carried out at Muroc Army Air Field in March and June 1944 (Ramsey 2002, 344-345).

Plutonium

At a meeting of the S-1 Executive Committee on November 14, 1942, James Chadwick expressed his fear that the alpha particles emitted by plutonium could cause a pre-detonation. Oppenheimer and Seaborg had considered pre-detonation months before, and Seaborg calculated that neutron emitters like boron had to be reduced to one part per hundred billion to prevent a premature explosion. Many doubted that a process that would ensure a safe level of purity could be developed. On November 18, several scientists, including Oppenheimer, reported to Conant, the head of the S-1 section[2] that they were confident that the purity requirement could be met (Hewlett & Anderson 1962, 109).

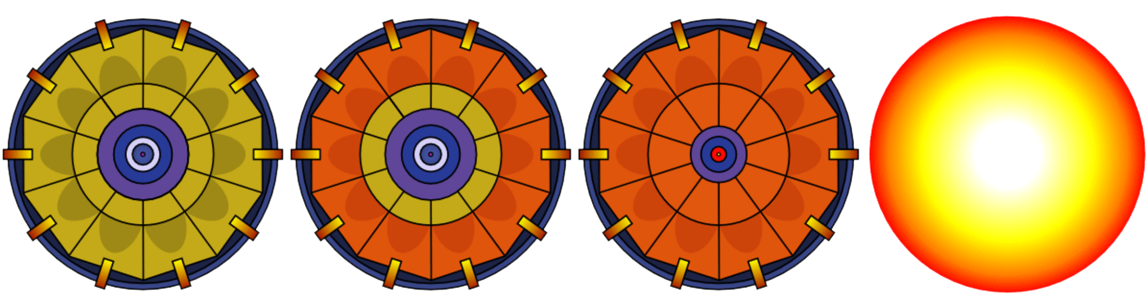
However, purity wasn't the only problem. Plutonium was a rare commodity, with only microscopic quantities available. Even after the X-10 Graphite Reactor (a plutonium producing nuclear reactor) was running, the scientists at the Metallurgical Laboratory were faced with a strange issue: the discoloration of the plutonium fluoride they produced. The scientists could produce the required amount of plutonium fluoride, but the color was sometimes light, and sometimes dark. Even worse, when they finally managed to reduce the plutonium fluoride to plutonium it was 6 g/cm^3 less dense than the predicted density of 19 g/cm^3. If these figures were correct, far more plutonium would be needed for a bomb. Eventually, Joseph Kennedy and Arthur Wahl were able to produce a sample which the Metallurgical Laboratory used to determine that there were two different varieties of fluoride being used: a light, and a dark. Chemists soon discovered how to make them selectively, and learned that the darker fluoride made the reduction process simpler.

1 AT-11 refers to World War II training aircrafts of the Unites States Army Air Force (USAAF).

2 Part of the National Defense Research Committee that focuses on Uranium and the atomic bomb.

At the Los Alamos Laboratory, Emilio Segrè's P-5 (Radioactivity) group set out to measure the fissions per g. per hour of uranium−234, −235 and −238, as well as plutonium, polonium, protactinium and thorium (American Physical Society). Segrè and his group of physicists set up their experiment in an old Forest Service log cabin in Pajarito Canyon. They chose this location because it was about 23 km (14 mi) from the Technical Area at Los Alamos, which meant that no background radiation emanating for other research at the laboratory would affect their results (Hoddeson et al. 1993, 229−233). By August 1943, they had determined values for all the elements tested except for plutonium, which they were unable to measure accurately because they only had five 20 μg (microg.) samples (Hoddeson et al. 1993, 233−237). The small samples that they were able to test indicated a spontaneous fission rate of 40 fissions per g. per hour, which was higher than expected. In April 1944 they received a sample of plutonium from the X-10 Graphite Reactor. Tests soon indicated 180 fissions per g. per hour, which was very high. Supposedly, when one of the researchers, Arthur Compton, learned of the potential power of the fission rate he was visibly shaken (Hoddeson et al. 1993, 233−239).

Next, Segrè's group began trying to test plutonium-240, an isotope that had not yet been discovered, but whose existence had been suspected. What had not been suspected was its high spontaneous fission rate. Segrè's group measured it at 1.6 million fissions per g. per hour, compared with just 40 per g. per hour originally tested for plutonium-239 (Hoddeson et al. 1993, 243−245). This meant that reactor-bred plutonium was unsuitable for the gun-type weapon that the Los Alamos team theorized. The plutonium-240 would react to quickly, causing a pre-detonation that would release the bombs mass before most of the plutonium reacted. A faster gun was suggested, but determined impractical. In July 1944, Oppenheimer concluded that plutonium could not be used in a gun design, and opted for an implosion-type design.



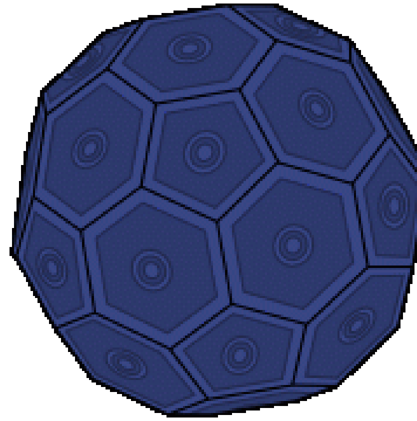
Explosive lenses are used to compress a fissile core inside an implosion-type nuclear weapon.

Implosion-type Weapon Design and Fat Man

Throughout 1943, implosion was considered a backup project in case the gun-type proved impractical (Hawkins 1961, 73). Theoretical physicists like Bethe, Oppenheimer, and Teller were intrigued by the idea of a design of an atomic bomb that made more efficient use of fissile material, and permitted the use of material of lower purity. These were big advantages to Brigadier General Groves, who was concerned with time and cost. However, while Seth Neddermeyer's research into implosion showed promise, it was clear that creating the implosion weapon would be much more difficult than the gun design. In July 1994 the gun-type design was proven impractical, and Oppenheimer reorganized the entire facility to focus on an implosion weapon, codenamed: Fat Man (Hoddeson et al. 1993, 245–248). In addition, Oppenheimer recruited John von Neumann and George Kistiakowsky, who were both military-trained ordnance experts, and created the G (for gadget) division for weapon physics under Robert Bacher (Hoddeson et al. 1993, 245) (Hewlett & Anderson 1962, 311). The implosion-type weapon was led by Neddermeyer and his E-5 (Implosion) group. Neddermeyer had the idea to use explosives to crush a subcritical amount of fissile material into a smaller and denser form (figure 1). When the fissile atoms were packed closer together they would form a critical mass, and detonate. Since the material needs to travel a very short distance, the critical mass could be assembled in much less time than it would take with the gun method (Hewlett & Anderson 1962, 312–313). To facilitate the work, a small plant was established at the Anchor Ranch for casting explosive shapes (Hoddeson et al. 1993, 86–90).


A ring of plutonium ready to be placed in a bomb.

The new design that von Neumann and T Division devised used explosive lenses to focus the explosion onto a spherical shape using a combination of high explosives (Hoddeson et al. 1993, 294–296). A visit by Sir Geoffrey Taylor in May 1944 raised questions about the stability of the bomb, and, as a result, the design was made more conservative. The ultimate expression of this was the adoption of the proposal to make the core solid instead of hollow (Hoddeson et al. 1993, 270–271, 307–308). The design of lenses that detonated with the proper shape and velocity turned out to be slow, difficult, and frustrating (Hoddeson et al. 1993, 294–296). Various explosives were tested before settling on the final design, which resembled a soccer ball (figure 2), with 20 hexagonal and 12 pentagonal lenses, each weighing about 36 kg (80 lb.). Getting the detonation right required fast, reliable and safe electrical detonators, therefore they decided to use exploding-bridgewire detonators (a new invention developed at Los Alamos by a group led by Luis Alvarez). Inside the explosive material there was a 4.5-inch (110 mm) thick aluminum pusher, which provided a smooth transition from the relatively low-density explosive to the next layer: the 76 mm (3 in) thick tamper of natural uranium. Its main job was to hold the critical mass together if possible, but it would also reflect neutrons back into the core. To prevent pre-detonation by an external neutron, the tamper was coated in a thin layer of boron (Hassen 1995, V-123).



An implosion-type nuclear bomb.

A polonium-beryllium modulated neutron initiator, known as an "urchin" because its shape resembled a sea urchin (Hassen 1995, I-298), was developed to start the chain reaction at precisely the right moment (Hewlett & Anderson 1962, 235). This work with the chemistry and metallurgy of radioactive polonium was directed by Charles Allen Thomas of the Monsanto Company and became known as the Dayton Project (Gilbert 1969, 3–4). Testing required up to 500 curies[1] per month of polonium, which Monsanto was able to deliver (Hoddeson et al. 1993, 308–310). The whole assembly was encased in a duralumin bomb casing to protect it from bullets and flak (Hansen 1995, V-123).

The ultimate task of the metallurgists was to determine how to cast plutonium into a sphere. The brittle α phase that exists at room temperature changes to the plastic β phase at higher temperatures. Attention then shifted to the even more malleable δ phase that normally exists in the 300 to 450 °C (572 to 842

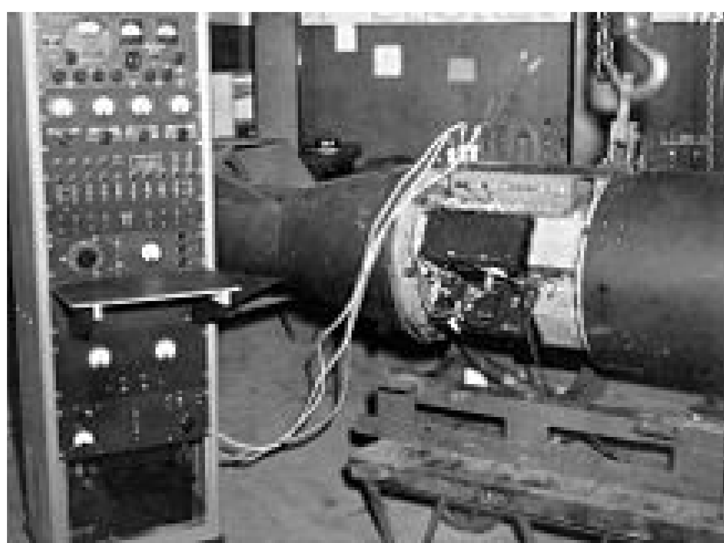
1 Measure of radiation named after Marie Curie: 3.7×1010 Bq.

°F) range. It was found that this was stable at room temperature when alloyed with aluminum, but aluminum emits neutrons when bombarded with alpha particles, which would exacerbate the pre-ignition problem. The metallurgists then learned of a plutonium–gallium alloy, which stabilized the δ phase and could be hot pressed into the desired spherical shape.

Little Boy

Following Oppenheimer's reorganization of the Los Alamos Laboratory in July 1944, the work on the uranium gun type weapon was concentrated in Francis Birch's O-1 (Gun) Group (Hoddeson et al. 1993, 250) (Hawkins 1961, 221). The O-1 Group continued to work on the gun type weapon in case the implosion design failed, but had to work with enriched uranium only (Hawkins 1961, 223). This meant that the Thin Man design could be greatly simplified. A high-velocity gun was no longer required, and a simpler weapon could be substituted, one short enough to fit into a B-29 bomb bay. The new design was called Little Boy (Rhodes 1986, 541) (figure 3).

Shipments of highly enriched uranium commenced in June 1944, but because the gun type had been moved to a lower priority the metallurgists did not receive any until August. In the meantime, the CM Division experimented with uranium hydride, which was considered a prospective active material. The idea was that the hydrogen's ability as a neutron moderator would compensate for the loss of efficiency, but, as Bethe later recalled, its efficiency was "negligible or less, as Feynman would say", and the idea was dropped in August 1944 (Hoddeson et al. 1993, 181).



A Little Boy unit on Tinian connected to test equipment

Frank Spedding's Ames Project had developed the Ames process, a method of producing uranium metal on an industrial scale, but Cyril Stanley Smith, the CM Division's associate leader in charge of metallurgy, (Hoddeson et al. 1993, 210–213) was concerned about using it with highly enriched uranium due to the danger of forming a critical mass (Hawkins 1981, 178). Highly enriched uranium was also far more valuable than natural uranium, and he wanted to avoid the loss of even a millig.. He recruited Richard D. Baker, a chemist who had worked with Spedding, and together they adapted the Ames Process for use at the Los Alamos laboratory (Hoddeson et al. 1993, 210–213). In February, Baker and his group made twenty 360 g reductions and twenty-seven 500 g reductions with highly enriched uranium tetrafluoride (Hoddeson et al. 1993, 252).

Two types of gun design were produced: Type A was of high alloy steel, and Type B of more ordinary steel. Type B was chosen for production because it was lighter. The primers and propellant were the same as those previously chosen for Thin Man (Hawkins 1961, 224–225). Scale test firing of the hollow projectile and target insert were conducted with the 3-inch/50 caliber gun and a 20 mm (0.79 in) Hispano cannon. Starting in December, test firing was done full-scale. Amazingly, the first test case that was produced turned out to be the best made. It was used in four test firings at the Anchor Ranch, and ultimately in the Little Boy used in the bombing of Hiroshima. The design specifications were completed in February 1945, and contractors were allowed to build the components. Three different plants were used so that no one would have a copy of the complete design. The gun and breech were made by the Naval Gun Factory in Washington, D.C.; the target, case and some other components were by the Naval Ordnance Plant in Center Line, Michigan; and the tail fairing and mounting brackets by the Expert Tool and Die Company in Detroit, Michigan (Hoddeson et al. 1993, 257) (Hawkins 1961, 224–225).

Birch's tidy schedule was disrupted in December by Groves, who ordered Oppenheimer to give priority to the gun type over implosion, so that the weapon would be ready by July 1, 1945 (Hoddeson et al. 1993, 255–256). The bomb, except for the uranium payload, was ready at the beginning of May 1945 (Hoddeson et al. 1993, 262). The uranium-235 projectile was completed on June 15, and the target on July 24 (Hoddeson et al. 1993, 265). The target and bomb pre-assemblies (partly assembled bombs without the fissile components) left Hunters Point Naval Shipyard, California, on July 16 aboard the cruiser USS Indianapolis, arriving July 26 (Coster-Mullen 2012, 39). The target inserts followed by air on July 30 (Hoddeson et al. 1993, 265).

Although all its components had been tested in target and drop tests (Hoddeson et al. 1993, 265), no full test of a gun-type nuclear weapon occurred before Hiroshima. There were several reasons for not testing a Little Boy type of device. Primarily, there was insufficient uranium-235 (Hansen 1995, 111–112). Additionally, the weapon design was simple enough that it was only deemed necessary to do laboratory tests with the gun type assembly. Unlike the implosion design, which required sophisticated coordination of shaped explosive charges, the gun type design was considered almost certain to work (Hoddeson et al. 1993, 293). Thirty-two drop tests were conducted at Wendover, and only once did the bomb fail to fire. One last-minute modification was made, to place the powder bags of propellant that fired the gun to be loaded in the bomb bay (Hawkins 1961, 224–225).

The danger of accidental detonation was a safety concern. Little Boy incorporated basic safety mechanisms, but an accidental detonation could still occur. Tests were conducted to see whether a crash could drive the hollow “bullet” onto the “target” cylinder resulting in a massive release of radiation, or possibly nuclear detonation. These showed that this required an impact of 500 times that of gravity, which made it highly unlikely (Hansen 1995, 113). However, there was still concern that a crash and a fire could trigger the explosives (Hoddeson et al. 1993, 333). In addition, if immersed in water, the uranium halves were subject to a neutron moderator effect. While this would not have caused an explosion, it could have created widespread radioactive contamination. For this reason, pilots were advised to crash on land rather than at sea (Hansen 1995, 113).

Water Boiler

The Water Boiler

The Water Boiler was an aqueous homogeneous reactor[1], which is a type of nuclear reactor that dissolves nuclear fuel (in the form of soluble uranium sulfate) in water (Los Alamos Laboratory 1983). Scientists chose uranium sulfate instead of uranium nitrate because sulfur's neutron capture cross section[2] is less than nitrogen's (Hawkins 2014, 165–166).

Originally, Robert Bacher proposed Project Y in April 1943 as part of an ongoing prog. where scientists measured critical masses in chain-reacting systems. Bacher also saw it as a way to test various materials in critical mass[3] systems. T Division disapproved of Project Y, as it could distract from studies on how chain reactions form in an atomic bomb. However, Bacher prevailed on this point—he felt that Project Y should test critical mass systems through the creation of a reactor (Hoddeson, et al. 1993, 199–203). As a result, in 1943 Theoretical Division began its calculations on the Water Boiler (Hawkins 2014, 116–120).

At this time, little was known about building reactors. Donald Kerst created and led a group in Bacher's P Division, the P-7 (Water Boiler) Group, which included Charles P. Baker, Gerhart Friedlander, Lindsay Helmholtz, Marshall Holloway, and Raemer Schreiber (Hawkins 2014, 101). Robert F. Christy from the T-1 Group helped create theoretical calculations for the Water Boiler, most notably for the critical mass calculation. He calculated that 600 g. of

1 Reactors create a nuclear chain reaction to produce energy.

2 A nuclear reaction in which an atomic nucleus and one or more neutrons collide and merge to form a heavier nucleus.

3 The minimum amount of fissile material needed to maintain a nuclear chain reaction.

uranium-235 would form a critical mass in a tamper of infinite size. Scientists initially planned to operate the Water Boiler at 10 kW, but in September 1943 Enrico Fermi and Samuel K. Allison visited the site to review the proposed design. They recommended heavier shielding to prevent the dangerous effects (radioactivity) of decomposing uranium salt. The scientists noted that the Water Boiler would create radioactive fission products, which someone would have to chemically remove. Consequently, Fermi and Allison decided that the Water Boiler would only run at 1 kW until the group gained more operating experience. For the time being, they postponed features that needed high power operation (Hoddeson, et al. 1993, 199–203).

First, Robert F. Christy calculated the area that an accidental explosion would contaminate, then the P-7 Group selected a site in Los Alamos Canyon located a safe distance from the township and outside of Christy's calculation, and downstream from the water supply. The Governing Board approved the site, nicknamed "Omega," on August 19, 1943.

The Water Boiler proved difficult to construct. The halves of the reactor, two stainless steel spheres about 12 in. long (306.39 mm), had to be arc welded [4]because uranium salt would corrode the solder[5]. The CM-7 (Miscellaneous Metallurgy) Group produced beryllia[6] bricks for the Water Boiler's tamper[7] in December 1943 and January 1944. These bricks were hot pressed in graphite at 1,000 °C (1,830 °F) at 100 lb. per square inch (690 kPa) for 5 to 20 minutes. Fifty-three beryllia bricks fit around the boiler.

The Water Boiler was only the third reactor in the world to go critical. The building at Omega Site was ready by February 1 and the Water Boiler was fully assembled by April 1. Sufficient enriched uranium[8] arrived in May to start the

4 Arc-welding joins metal objects by using electricity to create heat. As the metals cool, they bind together.

5 Solder is a fusible metal alloy used to create a permanent bond between metal work pieces.

6 Beryllia acts as an electrical insulator and has a high melting point.

7 A tamper's inertia delays the expansion of reacting material. A tamper creates a longer-lasting, more energetic, and more efficient explosion.

8 Enriched uranium is the only nuclide existing in nature that is fissile (able to create a nuclear reaction) with thermal neutrons.

reactor, and it went critical[1] on May 9, 1944 (Hawkins 2014). Improved cross-section measurements allowed Christy to refine his criticality estimate to 575 g.. In fact, he only needed 565 g.. The accuracy of his prediction surprised Christy more than anyone (Hoddeson, et al. 1993).

In September 1944, the P-7 (Water Boiler) Group became the F-2 (Water Boiler) Group, part of Fermi's F Division (Hawkins 2014, 213). Once the group completed the planned series of experiments in June 1944, they decided to rebuild the Water Boiler as a more powerful reactor.

The group made the following changes to the new model:

- The original goal of 10 kW power changed to 5 kW power, making the cooling requirements simpler and making the reactor stronger.
- The group estimated the Water Boiler's neutron flux[2] at 5 x 10^{10} neutrons per square centimeter per second.
- Then F-2 Group installed a water cooling system, along with additional control rods.
- The group used uranium nitrate instead of uranium sulfate, due to its resistance to contamination.
- Graphite blocks surrounded the tamper of beryllia bricks, since beryllia was hard to get.

With these changes implemented, the reactor commenced operation in December 1944 (Hawkins 2014, 218–219).

Super

Teller directed research into a hydrogen bomb named *Super* that used a fission bomb to ignite a nuclear fusion[3] reaction. Although scientists considered Super

1 To go critical means that the nuclear fission chain has reached a state of self-sustainment.

2 Neutron flux is a quantity corresponding to the total length neutrons travel per unit time and volume. The flow of neutrons initiates the fission of unstable large nuclei.

3 Nuclear fusion is a reaction where two or more atomic nuclei come close enough to form one or more different atomic nuclei and subatomic particles (neutrons or protons). The difference in mass between the reactants and products releases large amounts of energy.

The April 1946 colloquium on the Super. In the front row are (left to right) Norris Bradbury, John Manley, Enrico Fermi and J. M. B. Kellogg. Robert Oppenheimer, in dark coat, is behind Manley; to Oppenheimer's left is Richard Feynman. The Army officer on the left is Colonel Oliver Haywood

research secondary to the development of a fission bomb, the prospect of creating more powerful bombs kept it going—and Teller was its most enthusiastic proponent. The Berkeley summer conference convinced Teller that the Super was technologically feasible. Emil Konopinski, a theoretical physicist involved in the project, suggested that deuterium could more easily ignite if mixed with tritium. Hans Bethe, a nuclear physicist, noted that a tritium-deuterium (T-D) reaction releases five times as much energy as a deuterium-deuterium (D-D) reaction; however, because tritium was hard to obtain and scientists hoped that a fission bomb could ignite deuterium, Manley's group in Chicago and Holloway's group at Purdue proceeded to measure the cross sections of T-D and D-D (Hawkins 2014, 95–98).

[The April 1946 colloquium on the Super. In the front row are (left to right) Norris Bradbury, John Manley, Enrico Fermi and J. M. B. Kellogg. Robert Oppenheimer, in dark coat, is behind Manley; to Oppenheimer's left is Richard Feynman. The Army officer on the left is Colonel Oliver Haywood.]

By September 1943, scientists had revised the values of the D-D and T-D—the numbers rose, raising hopes that lower temperatures could create a fusion reaction. The group calculated that burning 1 cubic meter (35 cu ft) of liquid deuterium would release the energy of 1 megaton of TNT (4.2 PJ), enough to devastate 1,000 square mi. (2,600 km^2) (Hawkins 2014, 214–216). Teller was optimistic about the Super, but concerned about reports that the Germans showed interest in deuterium. Teller asked the governing Board to prioritize the Super. The board agreed to some extent, relenting only one person to work on it full-time. Robert Oppenheimer designated Emil Konopinski as a transfer to the Super, who would spend the rest of the war working on it. By February 1944, Teller had added Stanislaw Ulam, Jane Roberg, Geoffrey Chew, and Harold and Mary Argo to his T-1 (Implosion and Super) Group. Ulam calculated the inverse Compton cooling[1], while Roberg worked out the ignition temperature of T-D mixtures (Hoddeson, et al. 1993, 203–204). Progress with the Super necessitated Maria Goeppert to join the group in February 1945 (Dash 1973).

Super research became far more difficult than anticipated, leading Teller to request an increase in resources. The board declined Teller's request, believing that the research would be incomplete by the time the war ended. For some months, Teller and Bethe argued about the priority of the Super research. In June 1944, Oppenheimer moved Teller and his Super Group from Bethe's T Division to directly under himself. In September, it became the F-1 (Super) Group in Fermi's F Division (Hawkins 2014, 95–98). Over the following months, Super research continued, then the Super Group transferred back to T Division on November 14, 1945 (Truslow and Smith 1961).

In April 1946, the Los Alamos Laboratory held a colloquium on the Super to review the work done during the war. Teller gave an outline of his "Classic Super" concept—the original idea—and Nicholas Metropolis and Anthony L. Turkevich presented calculation results concerning thermonuclear reactions. Later in June, Teller prepared and issued the final report on the Super, remaining upbeat about the prospect of a successful development (Ott 1988). However, Teller's optimism failed to impress everyone present at the colloquium—in June 1946, the loss of staff curtailed work on the Super (Anderson 1962). By 1950, calculations showed that the Classic Super was unable to sustain thermonuclear burning in the deuterium fuel, and was unable ignite in the first place (Ott 1988).

1 Inverse Compton scattering occurs when a charged particle transfers part of its energy to a photon.

Trinity

The group decided that they should conduct an initial test due to the complexity of an implosion-style weapon, despite the waste of fissile material that testing causes. Leslie Groves, the director the Manhattan Project, approved the test, subject to the recovery of active material[2]. The group then considered creating a controlled fizzle explosion, but Oppenheimer opted instead for a full-scale nuclear test that he codenamed "Trinity" (Jones 1985, 465). Kenneth Bainbridge, a physics professor at Harvard, planned the test in March 1944, working under Kistiakowsky.

Herbert Lehr and Harry Daghlian loading the assembled tamper plug containing the plutonium pit and initiator into a sedan for transport from the McDonald Ranch House to the Trinity shot tower.

Jumbo

Bainbridge selected the bombing range near Alamogordo Army Airfield as the site for the test (Anderson 1962, 218–219). Bainbridge worked with Captain Samuel P. Davalos on the construction of the Trinity Base Camp and its facilities, which included barracks, warehouses, workshops, an explosive magazine, and a commissary (Jones 1985, 478–481). Groves disliked the prospect of explaining the loss of a billion dollars' worth of plutonium to a Senate committee, so he constructed a cylindrical containment vessel codenamed "Jumbo" to recover the active material if the test failed.

Measuring 25 ft. (7.6 m) long and 12 ft. (3.7 m) wide, Jumbo needed 214 long tons (217 t) of iron and steel by Babcock & Wilcox, a power generation company in Barberton, Ohio. Brought in by a special railroad car to a siding in Pope, New Mexico, a tractor pulled Jumbo the last 25 mi. (40 km) to the test site (Hoddeson, et al. 1993, 174–175). By the time it arrived, Oppenheimer felt confident enough in the implosion method and the availability of plutonium that he decided to forego Jumbo at the site. Instead, Jumbo rested atop a steel tower

2 Active material refers to radioactive material that releases with the explosive.

The group raising the gadget's explosives to the top of the tower.

800 yards (730 m) from the weapon as a rough measure of the explosion's power. Jumbo survived the test, but its tower did not. This confirmed the belief that Jumbo would have successfully contained a fizzled explosion (Hoddeson, et al. 1993, 365–367).

A pre-test explosion, conducted May 7, 1945, calibrated the instruments. First, the group built a wooden test platform 800 yards (730 m) from Ground Zero[1]. Then, they piled the platform with 108 short tons (98 t) of TNT, spiked with nuclear fission products in the form of an irradiated uranium slug[2] from the Hanford Site, which was dissolved and poured into tubing inside of the explosive. Oppenheimer's and Groves's new deputy commander, Brigadier General Thomas Farrell, observed the explosion. His observations of the pre-test produced data that proved vital for the Trinity test (Jones 1985, 512).

The group then began the actual test on the device, nicknamed "the gadget." The gadget was hoisted to the top of a 100-foot (30 m) steel tower to better indicate how the weapon would behave when dropped from a bomber. The group chose to detonate the weapon in the air, maximizing the amount of energy applied to the target and causing less nuclear fallout.

Norris Bradbury supervised the assembly of the gadget at the nearby McDonald Ranch House on July 13, and precariously winched[3] up the tower the following

1 Ground Zero refers to the point on the earth's surface directly above or below an exploding nuclear bomb.

2 Uranium fuel in short metal cylinders are often referred to as "slugs."

3 A winch is a mechanical device that adjusts the tension of a wire rope to pull in or let out, typically made of a spool and an attached hand crank.

day (Hoddeson, et al. 1993, 360–362). At 5:30 AM on July 16, 1945 the gadget exploded with an energy equivalent of around 20 kilotons of TNT, leaving a crater of Trinitite (radioactive glass) in the desert 250 ft. (76 m) wide. Scientists who observed the explosion included Vannevar Bush, James Chadwick, James B. Conant, Thomas Farrell, Enrico Fermi, Leslie Groves, Ernest Lawrence, Robert Oppenheimer, and Richard C. Tolman; however, the shock wave was felt over 100 mi. (160 km) away, and the mushroom cloud reached 7.5 mi. (12.1 km) in height. People as far away as El Paso, Texas heard the explosion, so Groves issued a cover story about an ammunition magazine explosion at Alamogordo Field (Hoddeson, et al. 1993, 372–374).

Project Alberta

In March 1945, Project Alberta, also known as Project A formed, absorbing existing groups of Deak Parsons's O Division to work on bomb preparation and delivery, and therefore support the bomb delivery effort (Ramsey 2012, 340).

Group	Code Name	Director
Delivery group	O-2	Norman Ramsey
Gun group	O-1	Francis Birch
Development, engineering, and tests group	X-2	Kenneth Bainbridge
Fuse development group	O-3	Robert Brode
Engineering group	O-4	George Galloway

Groups Absorbed into Project Alberta (The Manhattan Project and predecessor organizations n.d.)

Deak Parsons, a naval officer and ordnance expert, became the head of Project A with the physicist Norman Ramsey as his scientific and technical deputy and the naval officer Frederick Ashworth as his operations officer and military alternate (Ramsey 2012, 346). Project A also consisted of fifty-one Army, Navy, and civilian personnel (Campbell 2005). Lieutenant Colonel Peer de Silva commanded the personnel of Project Alberta, assigning them to 1st Technical Service Detachment. All members of Project Alberta volunteered for the mission (Russ 1990, 30–52).

Teams	Members
Fat Man Assembly Team	Commander Norris Bradbury and Roger Warner
Little Boy Assembly Team	Francis Burch
Pit Crew	Philip Morrison
Aerial Observation Team	Bernard Waldman and Luis Alvarez
Aircraft Ordnance Team	Sheldon Dike
Special consultants	Robert Serber, William Penney, and James F. Nolan

Project Alberta Teams and Members

The team readies the Fat Man bomb, sprayed with liquid sealant on the casing's seams, on one of the Northern Mariana Islands, Tinian.

Project Alberta proceeded with the plan to have the Little Boy ready for use by August 1, and the first Fat Man ready for use as soon as possible after that. Between July 20 and July 29, twelve combat missions flew in retaliation against targets in Japan using high-explosive pumpkin bombs, versions of the Fat Man with explosives but without a fissile core (Campbell 2005, 27). Project Alberta's Sheldon Dike and Milo Bolstead flew on some of these missions, as did the British observer Group Captain Leonard Cheshire (Campbell 2005, 50).

The Little Boy team used four pre-assemblies referred to as L-1, L-2, L-5, and L-6 as test drops (Coster-Mullen 2012, 101). The test drops allowed for the final assembly of the live bomb on July 31—Little Boy was ready for an order of attack. General Thomas T. Handy, the acting Chief of Staff of the United States Army, issued the orders of attack to General Carl Spaatz on July 25, since General of the Army George C. Marshall was attending the Potsdam Conference with President Harry S. Truman at the time and was therefore unable to issue the order himself (Rhodes 1986, 691). Handy's order designated four targets: Hiroshima, Kokura, Niigata, and Nagasaki, and ordered the attack to be made "as soon as weather will permit after about 3 August" (Campbell 2005).

Personnel from the High Explosive, Pit, Fusing, and Firing teams assembled the Fat Man unit in a complex operation. During the operation, Parsons limited the numbers allowed inside the assembly building at any time to prevent overcrowding. The Fat Man team assembled the first pre-assembly, known as F13, on July 31 and drop tested it the next day. Assembly for F18 followed on August 4, and also dropped the next day (Russ 1990, 56–57). Three sets of Fat Man pre-assemblies, designated F31, F32, and F33, arrived on B-29s of the 509th Composite Group and 216th Army Air Forces Base Unit on August 2. An inspection of Fat Man revealed that the high explosive blocks of F32 were badly cracked and unserviceable. The Fat Man team assembled the other two, earmarking F33 for a rehearsal and F31 for operational use.

Parsons commanded the Hiroshima mission and inserted the Little Boy's powder bags in the *Enola Gay*'s bomb bay[1] in flight, along with Second Lieutenant Morris R. Jeppson of the 1st Ordnance Squadron. First, Jeppson needed to arm the bomb, which would give the bomb consent to explode, before climbing to altitude and while approaching the target. To arm the bomb, he switched the three safety plugs located between the electrical connectors of the internal battery and the firing mechanism from greed to red. After arming the bomb, Jeppson monitored its circuits (Coster-Mullen 2012, 34–35).

Deak Parsons (right) supervises loading the Little Boy bomb into the B-29 Enola Gay. Norman Ramsey is on his left, with his back to the camera.

Four other members of Project Alberta flew on the Hiroshima mission: Luis Alvarez, Harold Agnew, and Lawrence H. Johnston. They flew on the instrument plane *The Great Artiste* and dropped "Bangometer" canisters that measure the force of the blast (Hoddeson, et al. 1993, 393). Bernard Waldman, a member of the Aerial Observation Team, operated the camera on the observation aircraft to record the Bangometer drops. He equipped himself with a special

1 Enola Gay is a Boeing B-29 Superfortress bomber, and was the first aircraft to drop an atomic bomb.

high-speed Fastax movie camera with six seconds of film to record the blast. Unfortunately, Waldman forgot to open the camera shutter, failing to capture the explosion (McLellan 2003) (Alvarez and Trower 1987).

The day after the Hiroshima attack, Purnell, Parsons, Tibbets, Spaatz, and LeMay met in Guam on August 7 to discuss next steps. Parsons maintained that Project Alberta would have a Fat Man bomb ready by August 11; however, weather reports indicated poor flying conditions from an incoming storm, so Tibbets asked if it could be readied by August 9. Parsons agreed to the advance.

Teams	Members
Bockscar Weaponeer	Commander Frederick Ashworth
Bockscar Assistant Weaponeer	Lieutenant Philip M. Barnes
The Great Artiste Aircraft Flyers	Walter Goodman and Lawrence H. Johnson
Big Stink Aerial Observation	Leonard Cheshire and William Penney
Aircraft Ordnance Team	Sheldon Dike

Nagasaki Mission Teams and Members (Laurence 1945)

Health and Safety

Captain James F. Nolan of the United States Army Medical Corps commanded the medical prog. at Los Alamos.[239][240] Initially, civilians could use a small five-bed infirmary and military personnel could use a three-bed infirmary for less serious medical cases. The Army's Bruns General Hospital in Santa Fe handled more serious cases, but the long trip and security risks made the hospital unsafe for transfers. In response to this security threat, Nolan recommended expansion of the infirmaries into a sixty-bed hospital. Nolan opened a fifty-four-bed hospital in 1944, staffed by Army personnel. A dentist arrived in March 1944, and a Veterinary Corps officer, Captain J. Stevenson, provided medical attention to the guard dogs (Warren 1966, 424–426).

With the medical prog. came more laboratory facilities for medical research, especially research into the effects of radiation and accidental absorption and toxic effects of metals—particularly plutonium and beryllium (Warren 1966, 881). The Health Group began conducting urine tests of laboratory workers in early 1945, many of them revealing dangerous levels of plutonium (Hacker

1987). Work on the Water Boiler also occasionally exposed workers to dangerous fission products and radioactivity.[244] Other exposure to radioactivity occurred through twenty-four fatal accidents at Los Alamos between its opening in 1943 and September 1946. These accidents mostly involved construction workers, but also killed four scientists including Harry Daghlian and Louis Slotin in criticality[1] accidents involving the demon core[2] (Wellerstein 2015).

Remote handling of a kilocurie source of radiolanthanum for a RaLa (Radioactive Lanthanum) Experiment at Los Alamos.

Security

On March 10, 1945, a Japanese fire balloon struck a power line and the resulting power surge disconnected the Manhattan Project's reactors at the Hanford Site (Jones 1985, 267). This concerned Los Alamos personnel—what if the Hanford site was attacked while they were defenseless? Another night, those at the sight were disturbed by a strange light in the sky. Oppenheimer later recalled that this demonstrated how "even a group of scientists is not proof against the errors of suggestion and hysteria," but with these incidences, further security measures became necessary for the site (Conant 2005, 253).

With so many people involved, security was difficult to achieve. The United States Army formed a special Counter Intelligence Corps (CIC) detachment to handle the Manhattan Project's security issues (Jones 1985, 258–260). The Soviet Union's attempts to penetrate the CIC became obvious by 1943 through its use of Soviet spies (Jones 1985, 261–265). The most successful Soviet spy was Klaus Fuchs of the British Mission, and the revelation of his espionage in 1950 damage the United States' nuclear cooperation with Britain and Canada

1 Criticality is the state of a nuclear chain reacting medium when the chain reaction is just self-sustaining (or critical), that is, when the reactivity is zero.

2 The demon core was a 6.2-kg. (14 lb) subcritical mass of plutonium measuring 89 millimeters (3.5 in) in diameter for use in a nuclear bomb.

(Groves 1962, 142–145) (Hewlett and Duncan 1969, 312–314). Subsequently, the CIC uncovered other instances of espionage, leading to the arrest of Harry Gold, David Greenglass, and Ethel and Julius Rosenberg. Other spies remained undetected for decades, like Theodore Hall (Broad 2011).

Post-war

After the war ended on August 14, 1945, Robert Oppenheimer informed Leslie Groves of his intention to resign as director of the Los Alamos Laboratory, but agreed to remain until Groves could find a suitable replacement. Groves wanted someone with both a solid academic background and a high standing to replace Oppenheimer. Oppenheimer recommended the naval officer Norris Bradbury; as a naval officer, he was both a military man and a scientist, which Groves found agreeable. Bradbury accepted the offer on a six-month trial basis. Groves announced Oppenheimer's replacement at a meeting of division leaders on September 18 (Hoddeson, et al. 1993, 625–626). Parsons arranged for Bradbury to be quickly discharged from the Navy, which awarded him the Legion of Merit for his wartime services (Agnew and Shreiber 1998, 9). Bradbury remained in the Naval Reserve, ultimately retiring in 1961 with the rank of captain (Ebinger 2006, 98).

Bradbury (left) examines plans for new laboratory sites and permanent housing with Leslie Groves of the Armed Forces Special Weapons Project (center) and Eric Jette (right) in April 1947; Colonel Lyle E. Seeman stands behind Bradbury, second from left.

On October 16, 1945 at a Los Alamos ceremony, Groves presented the laboratory with the Army-Navy "E" Award and presented Oppenheimer with a certificate of appreciation. Bradbury became the laboratory's second director the following day (Agnew and Shreiber 1998).

The first months of Bradbury's directorship were particularly trying. He had hoped that the Atomic Energy Act of 1946 would quickly pass through Congress and a new, permanent organization could supersede the wartime Manhattan Project. Bradbury soon realized that a permanent organization would take more than six months. President Harry S. Truman signed the act creating the Atomic Energy Commission into law almost a year later on August 1, 1946, and it became active five months later on January 1, 1947. In the meantime, Groves had limited legal authority (Agnew and Shreiber 1998, 4).

Most of the scientists at Los Alamos were eager to return to their laboratories and universities. By February 1946 all of the wartime division heads had left, but a talented core remained.

Teams	Leaders
G Division, renamed M Division	Darol Froman
Chemistry and Metallurgy	Eric Jette
Physics	John H. Manley
Theory	George Placzek
Explosives	Max Roy
Ordnance	Roger Wagner

Remaining Los Alamos Teams and Leaders (Hoddeson, et al. 1993, 398–402)

Z Division

Jerrold R. Zacharias created Z Division in July 1945 to control testing, stock piling, and bomb assembly activities. Zacharias led the division until October 17, 1945 to return to MIT; Roger S. Warner succeeded him. Z Division moved to Sandia Base1 between March and July 1946, except for the Z-4 (Mechanical Engineering) Group, which followed in February 1947 (Truslow and Smith 1961, 95–96).

Operation Crossroads

The number of personnel at the Los Alamos Laboratory plummeted from its wartime peak of over three-thousand to around one-thousand, but many still lived in substandard temporary wartime accommodations (Agnew and Shreiber 1998). Despite the reduced staff, Bradbury still had to provide support for

1 Sandia Base was the principal nuclear weapons installation of the United States Department of Defense from 1946 to 1971.

Operation Crossroads, the nuclear tests in the Pacific. Ralph A. Sawyer became the Technical Director of Operation Crossroads, with Marshall Holloway from B Division and Roger Warner from Z Division as associate directors. Los Alamos Laboratory personnel used two ships: the USS *Cumberland Sound* and *Albemarle*. Operation Crossroads cost the Los Alamos Laboratory over one million dollars, and the services of 150 personnel (about one-eighth of its staff) for nine months (Truslow and Smith 1961). With only ten atomic bombs left at the time, the United States had expended about one-fifth of the stockpile (Wellerstein, Operation Crossroads at 70 2016).

The University of California terminated the 1943 contract with the Los Alamos Laboratory three months after the end of hostilities. The termination raised concerns about the university operating a laboratory outside the state of California. The university rescinded its notice after some persuading, and the operating contract extended until July 1948 (Hewlett and Duncan 1969, 43). Bradbury would remain director until 1970 (Agnew and Shreiber 1998, 3). The total cost of Project Y up to the end of 1946 was $57.88 million (equivalent to $710 million in 2016) (Manhattan District History 1947). The Los Alamos Laboratory became the Los Alamos Scientific Laboratory in January 1947 (Truslow and Smith 1961, v).

Project Y

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