2

DEVELOPING THE BOMB, 1939–45

As scientific research into fission continued, the focus was on how many neutrons were released during fission, and how each uranium isotope reacted. In order for a chain reaction to occur, a large number of excess neutrons would have to be produced by fission. Since fission also absorbed neutrons, another critical aspect was ensuring that the ratio between neutrons produced and absorbed was large enough. Another key step was actually creating a controlled chain reaction. This work moved slowly forward, much to the impatience of Leo Szilárd and others, who felt that a desperate race with the Nazis to be the first to develop an atomic bomb was being lost. In fact, the Germans were initially ahead of the American and British efforts, particularly in stockpiling uranium, and the Japanese were also working on solving the problems of uranium refinement and fission to build an atomic bomb.

The fission problem was tackled by Enrico Fermi and a team of other scientists and graduate students. Fermi was now in the United States because his native Italy, allied with Hitler, had adopted the Nazis' racial policies, and Fermi's wife Laura was of Jewish descent. Fleeing Italy, the Fermi family had relocated to America. In March 1939, Fermi, working with Herbert Anderson, was able to determine that on average, two neutrons were produced for every neutron consumed by fission. Experiments found that uranium in water could not produce a chain reaction, but in July 1939, Szilárd wrote to Fermi and suggested that if they suspended the uranium in carbon (graphite) they might be able to produce a chain reaction.

Even as he participated in the discussions over how best to achieve a chain reaction, Szilárd worried, as did many of the refugee scientists, over whether the Nazis had paid attention to Hahn and Strassman's breakthrough and were now pursuing a chain reaction and then an atomic bomb. They were not wrong to think so. The Reich had recently stopped the sale of uranium from recently occupied Czechoslovakia, and there were rumors that a German chain reaction group had been formed. Szilárd decided to enlist Albert Einstein to take action and write to Einstein's close personal friend Elizabeth, the Queen Mother of Belgium. The letter would ask for her help in preventing the world's largest known uranium supply, in the Belgian Congo, from falling into Nazi hands.

Meeting Einstein at the famous scientist's summer home outside New York at Peconic, on Long Island, Szilárd and physicist Eugene Wigner convinced Einstein to write the letter. However, shortly after that meeting, discussions with economist Alexander Sachs, a friend and unofficial advisor to President Franklin D. Roosevelt, led to Sachs's suggestion that Szilárd get Einstein to write to Roosevelt. Sachs would personally deliver the letter and talk with the President. A second meeting with Einstein secured the great man's permission, and after reviewing various drafts, Einstein signed a letter dated August 2, 1939, that Sachs carried by hand into the Oval Office. The letter started by explaining the threat:

> In the course of the last four months it has been made probable – through the work of Joliot in France as well as Fermi and Szilárd in America – that it may become possible to set up a nuclear chain reaction in a large mass of uranium, by which vast amounts of power and large quantities of new radium-like elements would be generated. Now it appears almost certain that this could be achieved in the immediate future. This new phenomenon would also lead to the construction of bombs, and it is conceivable – though much less certain – that extremely powerful bombs of a new type may thus be constructed. A single bomb of this type, carried by boat and exploded in a port, might very well destroy the whole port together with some of the surrounding territory. However, such bombs might very well prove to be too heavy for transportation by air.[1]

The letter went on to suggest that the President "have more permanent contact maintained between the Administration and the group of physicists working on chain reactions in America. One possible way of achieving this might be for you to entrust with this task a person who has your confidence and who could perhaps serve in an inofficial [sic] capacity." That person could "approach Government Departments, keep them informed ... and put forward recommendations for Government action, giving particular attention to the problem of securing a supply of uranium ore for the United States." They could also "speed up the experimental work" on chain reaction, "which is at present being carried on within the limits of the budgets of University laboratories, by providing funds, if such funds be required, through his contacts with private persons who are willing to make contributions for this cause, and perhaps also by obtaining the co-operation of industrial laboratories which have the necessary equipment."

Sachs met with Roosevelt on October 11, 1939. Germany had invaded Poland on September 1, starting World War II, but at that stage the United States was a neutral nation. Roosevelt understood the Nazi threat, but the only action he could, or would take in regard to the potential for the atomic bomb, was to establish a small, secret working committee to meet with Szilárd and other physicists and examine the uranium problem. The initial meeting, on October 21, led to a commitment from National Bureau of Standards (NBS) Director Lyman Briggs to provide $6,000 in funding for Fermi's experiments at Columbia University in New York.

Born in Rome, Enrico Fermi (1901–1954) received his doctorate at the age of 21. After working in Germany, Fermi returned to Italy and in 1927, he was appointed Professor of Theoretical Physics at the University of Rome. Here Fermi became the world's greatest authority on neutrons, building on the work of Joliot-Curies. Fermi and his team discovered slow neutrons, and their results paved the way for Hahn, Meitner and Strassman's discovery of nuclear fission. Fermi received the Nobel Prize in Physics in 1938. A key figure and leader in the Manhattan Project, Fermi relocated to Los Alamos and remained with the project until war's end. (Library of Congress)

BRITAIN TAKES THE LEAD

Despite the steps taken in the United States, official American action was slow, and Szilárd and his compatriots believed, with some justification, that the US government did not understand the seriousness of the situation. Their colleagues in Britain, however, met with a completely different reaction. Otto Robert Fritsch, working with fellow German refugee scientist Rudolf Ernst Peierls, wrote a top secret memorandum in March 1940 that galvanized the British government into action. The same month, after Szilárd had kept badgering Briggs, the US government belatedly released the $6,000 it had promised for Fermi's research.

The Fritsch-Peierls memorandum began with a detailed, and ultimately proven to be accurate, summary of what a uranium-based "super-bomb" would do:

> The energy liberated in the explosion of such a super-bomb is about the same as that produced by the explosion of 1,000 tons of dynamite. This energy is liberated in a small volume, in which it will, for an instant, produce a temperature comparable to that in the interior of the sun. The blast from such an explosion would destroy life

> in a wide area. The size of this area is difficult to estimate, but it will probably cover the centre of a big city. In addition, some part of the energy set free by the bomb goes to produce radioactive substances, and these will emit very powerful and dangerous radiations. The effect of these radiations is greatest immediately after the explosion, but it decays only gradually and even for days after the explosion any person entering the affected area will be killed. Some of this radioactivity will be carried along with the wind and will spread the contamination; several miles downwind this may kill people.

While other scientists had thought that a large amount of uranium was necessary to create a bomb, Fritsch and Peierls estimated that after bombarding uranium to create its light isotope, U-235, only a small amount was needed to make a bomb. The "critical size" was "about one pound. A quantity of the separated uranium isotope that exceeds the critical amount is explosive, yet a quantity less than the critical amount is absolutely safe." This revelation meant that a bomb need not be carried in a ship, but could probably be carried by air.

To reinforce the point, the memorandum starkly reminded readers that:

> as a weapon, the super-bomb would be practically irresistible. There is no material or structure that could be expected to resist the force of the explosion… We have no information that the same idea has also occurred to other scientists but since all the theoretical data bearing on this problem are published, it is quite conceivable that Germany is, in fact, developing this weapon… Hence it is of extreme importance to keep this report secret since any rumour about the connection between uranium separation and a super-bomb may set a German scientist thinking along the right lines.

Fritsch and Peierls strongly recommended a British atomic program:

> If one works on the assumption that Germany is, or will be, in the possession of this weapon, it must be realized that no shelters are available that would be effective and that could be used on a large scale. The most effective reply would be a counter-threat with a similar bomb. Therefore it seems to us important to start production as soon and as rapidly as possible, even if it is not intended to use the bomb as a means of attack. Since the separation of the necessary amount of uranium is, in the most favourable circumstances, a matter of several months, it would obviously be too late to late to start production when such a bomb is known to be in the hands of Germany, and the matter seems, therefore, very urgent.[2]

The British government established its own secret committee in April, and in June the committee asked another German refugee scientist, Franz Simon of the Clarendon Laboratory at Oxford, to look into creating U-235. Simon was able to refine a process of gaseous diffusion to create the enriched uranium isotope for bombs. By turning uranium into a gas, uranium hexafluoride, and then filtering the U-235 out from the heavier U-238 by passing the gas through semi-permeable membranes (barriers that only allowed certain particles to pass through it), U-235 could be condensed and turned into pure metal. By December, Simon had made his report to the committee, explaining the process and providing specifications for a plant to do the work and outlining costs. British physicist James Chadwick, a member of the secret committee, was aghast at the implications, explaining he now "realised that a nuclear bomb was not only possible, it was inevitable. I had then to take sleeping pills. It was the only remedy."[3]

SPURRING THE AMERICANS

In July 1940 a new American committee, the National Defense Research Council (NDRC), headed by Vannevar Bush, who acted as President Roosevelt's science advisor, formed to spur atomic research, albeit with an initial budget of just $40,000. With that money, which was not released until November, the team at Columbia University began construction of a 38-ton uranium oxide and graphite "sub-critical pile" to try to induce a chain reaction. Another group, at the Department of Terrestrial Magnetism at the Carnegie Institution for Science, in Washington, DC (Bush was also its President), turned their attention to determining the "cross section" of U-235 – this work would help establish the probability of a nuclear reaction. American interest in fission, however, was fixed on nuclear power for wartime use, not a bomb. Regardless of final intentions for nuclear energy, the American and British groups shared their research, and in March 1941, armed with the work from the Carnegie Institution, Peierls more accurately recalculated the critical mass for an atomic bomb.

Armed with the new calculations, the British group, codenamed the "MAUD Committee," began work on a series of reports that they shared with their American counterparts. One of the reports, "Use of Uranium for a Bomb," offered a specific plan to build a bomb and estimated the cost at some $25 million. The report urged cooperation between the United States and Britain to develop the infrastructure for a bomb program, and then to build the bomb. The report, although forwarded to the United States in July 1941, went unanswered, and so Marcus Oliphant of Oxford, the initial recipient of the Fritsch-Peierls memorandum, traveled to Washington DC in August to meet with American officials.

To his disbelief, Oliphant discovered that Lyman Briggs, who he called an "inarticulate and unimpressive man,"[4] had not shared the final reports of the MAUD Committee, and had locked them in his office safe. Oliphant then went directly to the American committee. After urging them to action, and demanding an American commitment to building a bomb because Britain, at war, did not have the resources to do so, Oliphant went on to meet with a number of prominent physicists. Inspired by Oliphant's demands, and with a copy of the MAUD Committee report in hand, Vannevar Bush took it to Roosevelt in early October. After a meeting with other key figures later in the month, Bush delivered a report to the President in late November encouraging the US development of a U-235 bomb.

Earlier experiments at Berkeley by physicist Glenn Seaborg, assisted by graduate student Arthur Wahl, had discovered a new element created by bombardment. When a neutron from U-235 hit a U-238 nucleus, it created a short-lived isotope, U-239. As U-239 decayed, it became Pu-239, or "plutonium," the name given to the new element. The possibility of using this element as a material to make a bomb had been encouraged by the British. Despite the fact that calculations showed that the new element would be 170 percent more powerful than U-235, the American team decided on the better-known uranium isotope, which they were then in the process of testing to see what the threshold was for making it go "critical" and start a chain reaction. Fermi and his team's sub-critical experiments at Columbia, ironically, had shown that uranium alone was not sufficiently powerful, and something stronger was needed. That meant processing large amounts of U-235.

As the head of a new "Office of Scientific Research and Development" (OSRD), Bush set into motion a series of projects to continue research under the leadership of Arthur Compton, a Nobel Prize-winning physicist at the University of Chicago. In January 1942, Compton created a new laboratory at the University of Chicago to serve as a consolidated research center. Known as the Metallurgical Laboratory, it would focus on the development of what were then known as "uranium burners" – the nuclear reactors that would generate a chain reaction by "burning" the uranium to create energy. Compton assigned the task of theoretical analysis of fast neutrons to a team led by Gregory Breit, a physicist from the University of Wisconsin.

At the same time, at the University of California, Berkeley, another group, under the leadership of J. Robert Oppenheimer, began the same task. Oppenheimer, a brilliant, unconventional professor, had been invited into the project by Lawrence, who like Szilárd had seen the impending threat of a Nazi nuclear program. The study of neutron behavior was essential – at this early stage, no one was sure that there was not a hitherto undiscovered aspect of atomic behavior that would prevent a chain reaction, and hence a bomb.

J. Robert Oppenheimer (1904–1967). New York-born, Oppenheimer studied at Harvard, switching from chemistry to physics. Earning his doctorate from the University of Göttingen, he returned to the United States, and within a few years held joint professorships at the University of California, Berkeley, and the California Institute of Technology.
A brilliant theoretical physicist, Oppenheimer was at first invited to work on neutron calculations for the Manhattan Project, and soon thereafter was named scientific director in June 1942. Oppenheimer resigned as director of Los Alamos at the end of the war, but remained part of the government's nuclear research until politically motivated and highly controversial hearings stripped him of his security clearance in 1953, some believing the decision had more to do with his concerns over the development of the hydrogen bomb than his political leanings.
(Library of Congress)

By the early spring, Enrico Fermi had relocated to Chicago to continue his work on building a critical mass. At Columbia, Fermi and his team had built successive "exponential piles" of uranium and graphite to measure the release of neutrons. The graphite would absorb the neutrons – and in theory control a runaway reaction. The exponential piles allowed Fermi and his team to increase, slowly and a step at time, the size of the pile.

A successful pile required a great deal of U-235, and that needed refinement. There were various methods proposed to do this. In March 1942, James Bryant Conant, a chemist, President of Harvard University, and chairman of the NRDC, suggested that the best plan of action would be to develop redundant facilities to produce U-235 and plutonium using every known method, which included gaseous diffusion, electromagnetic separation, centrifuges, and, in the case of plutonium, "breeding" by using atomic piles for bombardment. Only by taking this approach, Conant successfully argued, would the material needed to build a bomb be amassed in the quickest possible time. As Conant's argument carried the day, Glenn Seaborg arrived in Chicago to develop the industrial process to manufacture plutonium.

In May, Breit resigned, and went to work in the US Navy's ordnance laboratory. He believed that the work was progressing too slowly, and he was unhappy with what he perceived to be a sufficient lack of secrecy in the project (his research was shared with Oppenheimer, whom Breit felt was not sufficiently secretive). Compton turned to J. Robert Oppenheimer to take over the theoretical physics team. The 38-year-old Oppenheimer, the son of a German immigrant, had earned his doctorate in physics at Göttingen, Germany in 1927. Oppenheimer joined the University of California, Berkeley, in 1929, moving west from his native New York. At odds with some of his colleagues, and socially awkward, Oppenheimer was sharp, witty, caustic, and brilliant. Within a year of joining the project, Oppenheimer would catapult himself to the head of the newly formed laboratory that would build the atomic bomb.

Oppenheimer's skills as the leader of the theoretical physicists came to the forefront in the summer of 1942, as he spearheaded the efforts of a study group he had assembled at Berkeley. Physicists Hans Bethe, a German refugee scientist from Cornell University, Edward Teller, a Hungarian refugee physicist from George Washington University, John van Vleck of Harvard, Robert Serber, from the University of Illinois, Felix Bloch, a Swiss-born refugee scientist from Germany from Stanford University, and Emil Konopinski of the University of Indiana, all worked with Oppenheimer through the summer of 1942. They developed the basic principles of bomb design, and determined how much U-235 was required for a high-yield nuclear detonation.

THE ARMY STEPS IN

After the slow initial start American response to the German atomic threat, the US effort remained under-funded, somewhat disorganized, and disjointed. Steps to rectify the problems began in the summer of 1942. President Roosevelt secretly approved the project and authorized its initial budget of tens of millions of dollars in June.[5]

The same month, the US Army Corps of Engineers (USACE) established an office to commence the government's part of the project. (The mission of the USACE is still expressed as serving the "Armed Forces and the Nation by providing vital engineering services and capabilities, as a public service, across the full spectrum of operations from peace to war in support of national interests."[6]) When Conant issued a report at the end of August summarizing the summer's work by the civilian scientists, Vannevar Bush, in forwarding it to the War Department, suggested that new leadership was needed. In response, the USACE was handed control of the project. It was the only agency of the US government with broad enough authority, facilities, and expertise in design, engineering, project management, and construction to carry out the bomb project. To carry out the work, in August the Corps created a new office.

The USACE North Atlantic Division, headquartered in New York City, was the initial coordinating office, even though the project was nationwide. To disguise the function of the office and its top-secret mission, it was given the innocuous name of the "Manhattan Engineer District," and the effort to build the bomb, as a result, was dubbed the "Manhattan Project." Initially under the command of Colonel James Marshall, in mid-September, the new district received a new commanding officer.

Colonel Leslie R. Groves was hard working, intelligent, and able to complete large projects rapidly (he had recently overseen the construction of the Pentagon, then the world's largest office building). Groves was also an unpopular officer with a reputation for arrogance and ruthlessness. He later wrote that his initial briefing from a superior was "overoptimistic." The basic research and development had been completed, and "you just have to take the rough designs, put them into final shape, build some plants and organize an operating force and your job will be finished and the war will be over."[7] Assuming command on September 17, he immediately went into action, signing a contract to mine for radium in the Canadian Arctic and purchasing 1,250 tons of uranium ore that the United States had managed to ship out of the Belgian Congo one step ahead of the Germans.[8] Groves also bought up property for the construction of the industrial facilities to manufacture U-235 – all in the first two days on the job. A week later, to give Groves the necessary authority to continue his job, the Army promoted him to brigadier general. With Colonel Marshall and another officer, Colonel Kenneth D. Nichol, as his deputies, Groves began to learn more about the task ahead of him.

At the time Groves joined the project, the procedures for refining uranium – separating the small amounts of fissionable U-235 isotope from the more prevalent U-238 isotope in uranium – were still under development in various laboratories. Lab tests were essential before any one process was selected for massive industrial production. There were three methods under consideration. The first, using a powerful centrifuge to pull uranium apart, was least likely to succeed, and Groves soon killed the research. The next was using "electromagnetic separation," a process that Ernest Lawrence was working on at Berkeley. The third was gaseous diffusion, in which the uranium was converted into the highly caustic uranium hexafluoride gas, and then filtered to capture the U-235 particles, which could then be converted back into metal. Industrializing this method was under active study by scientists Harold Urey and John Dunning and their research was promising.

While Groves evaluated the methods and set about creating the plants to refine the U-235, Enrico Fermi and his team at the University of Chicago worked to determine how best to start – and stop – a chain reaction. In late July, the first shipment of U-235 reached the lab, and a month later Fermi's team had built and tested an experimental pile that brought a self-sustaining chain reaction closer. While the pile did not achieve a sufficient reaction to be self-sustaining, it was clear that a larger pile would do the job. A chain reaction was now assured. From September through to November, Fermi and his team received large shipments of graphite and 3 tons of uranium. In an abandoned squash court at the University's Stagg Field, they began construction of the final pile on November 16, working around the clock in a race to finish.

CP-1, as the final pile was codenamed, was built of graphite that the scientists had cut and shaved into bricks, and loaded with lumps of uranium as they stacked it, layer by layer, to reach the proper mass. Boron and cadmium, both of which possess a powerful capacity to absorb neutrons, were laid into the pile to help control the release of energy. Boron steel rods, inserted into the pile, could be slowly slid out and then back in to control neutron release. After 24 long days and nights, by December 1, before the pile was complete, measurements by constantly monitoring Geiger counters showed that the pile could go critical and achieve a self-sustaining chain reaction if the control rods were pulled out.

After calling a break for lunch on December 2, Fermi and his team reassembled in the squash court. Arthur Compton, a witness to the test, recalled that as he entered the room, 20 scientists had gathered on a balcony as the last checks were made. Volunteers (nicknamed the "suicide squad") stood precariously perched over the pile with buckets of liquid cadmium, ready to sacrifice themselves but nonetheless quench the atomic fire by drowning it should the reaction prove unstoppable. Just before 03:20hrs:

> Fermi gave the order to withdraw the control rod another foot. We all knew this was the real test. The Geiger counters … began to click faster and faster, until their sound became a rattle … the reaction grew until there might be danger from the rays coming

> from the pile. "Throw in the safety rods," came Fermi's order... The rattle of the counters fell to a slow series of clicks. For the first time, atomic power had been released, and it had been controlled and stopped.[9]

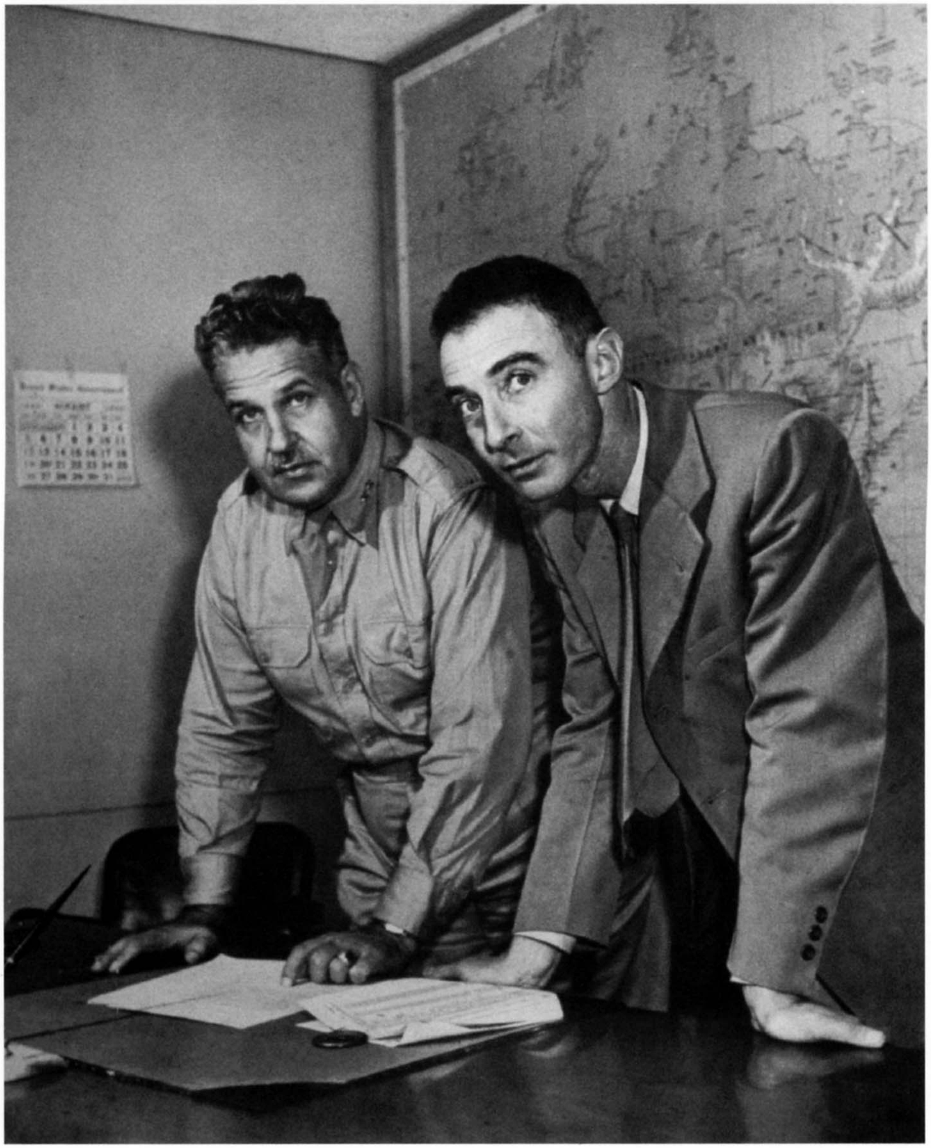
While only enough power to light a small bulb had been generated, the next important step at the dawn of the atomic age had been taken. A series of new facilities, quickly authorized by Groves, began to spring up in isolated spots around the United States to process U-235 and plutonium on a massive scale, and a new, top-secret laboratory rose in the wilderness of New Mexico to house the scientists who would design and build weapons that would use the newly processed material.

PROJECTS W, X, AND Y

Groves selected an isolated, rural community in Tennessee in which to build the electromagnetic and gaseous diffusion plant. Next to the Clinch River, the plant could tap into the tremendous hydroelectric power of America's Tennessee Valley Authority. Enough power to light a city would be required to run the electromagnetic process alone, as Groves intended to build the world's largest magnets to do the job. Codenamed "Project X," the new facility rose on 1,100 acres 18 miles northwest of Knoxville. Officially known as Oak Ridge, but called "Dogpatch" by its 79,000 residents, it was a "secret city" that did not exist on maps. In the Pacific Northwest, along the banks of the Columbia River, the plutonium processing facility codenamed "Project W," the Hanford Engineering Works, rose on a 400,000-acre reservation. Hanford housed 60,000 workers who built it in a year, and who were then replaced by 17,000 people – the technicians who would make plutonium, and their families.

The third facility, "Project Y," was a centralized laboratory that would be "concerned with the development and manufacture of an instrument of war."[10] Oppenheimer, based on his experience with his summer meeting, had come up with the idea of the lab to end the inefficiency of a number of teams at different universities working on the major problems of the project in isolation from one another. Groves not only accepted the principle of the new lab; on October 15, 1942, he selected Oppenheimer to head it, overruling the concerns of his security officers, who believed that the Berkeley scientist posed an unacceptable risk because they feared he was at best a Communist sympathizer and at worst an actual agent.

A site still needed to be selected, facilities built, and a team of scientists selected. The construction of roads, laboratories, homes for the scientists, and the necessary infrastructure of water and power started for what was initially a small community of a few hundred. The number of scientists, technicians and military personnel kept growing, and construction crews continually worked on additional projects as both staff and laboratory facilities expanded. By the time it was completed, the laboratory, built atop an isolated mesa in the New Mexico desert, would be another secret city, home to 5,800 people. At the end of 1942, Vannevar Bush told President Roosevelt that the total cost of the atomic bomb project would be around $400 million. By the time the project ended, it had cost more than five times that – in all, the United States spent over $2 billion on the Manhattan Project.



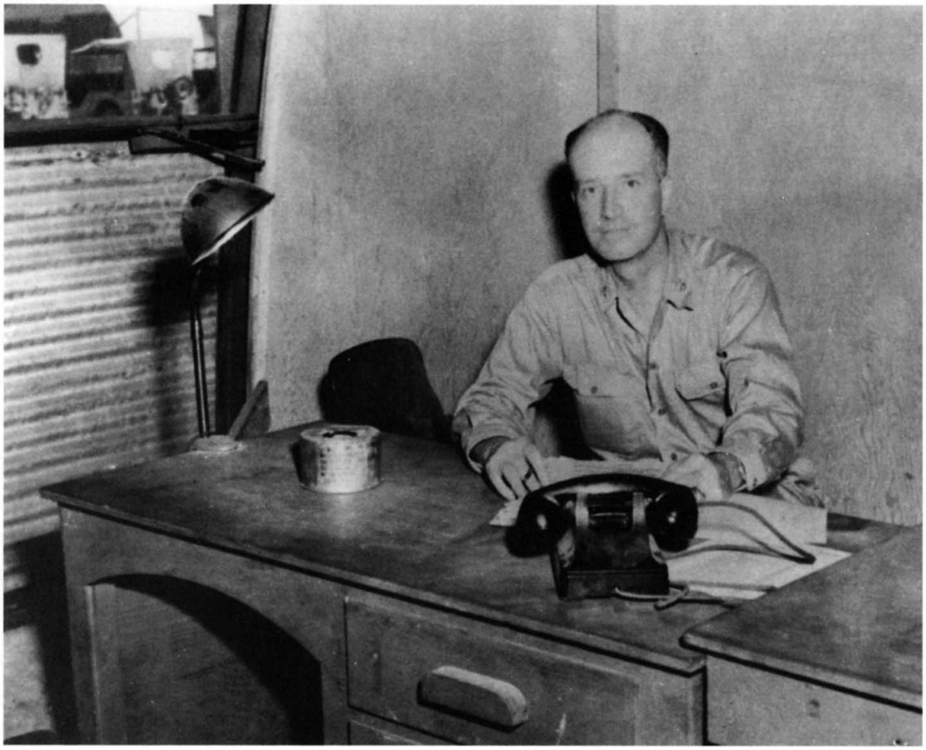
Leslie Groves (1896–1970) and Oppenheimer, pictured here at Los Alamos in August 1945. Groves, a career Army officer, was the US Government's choice to head the Manhattan Project when the American drive to develop an atomic bomb faltered under civilian control and the project was assigned to the US Army Corps of Engineers. His partner on this project was the brilliant, conflicted and controversial Oppenheimer. "Oppie" was a seemingly unlikely choice for the position of scientific director of the Manhattan Project because of his associations with and sympathies for Communism and doubts about his loyalties. Oppenheimer oversaw the development of Los Alamos in the New Mexico desert, assembled and managed a diverse and talented team of brilliant scientists and technicians, and successfully delivered the atomic weapon Groves demanded from him. (Library of Congress)

The lab, built on the site of a boy's ranch school at Los Alamos, was ready for occupancy by the initial staff of scientists and their families at the end of March 1943. Within a short time, Oppenheimer and Groves realized that their original calculations of how many people were needed – a hundred scientists – had been a gross underestimate. From that point, the pace of growth never stopped as more recruits and additional buildings expanded Los Alamos constantly.

Groves had demanded that a workable bomb be ready by the summer of 1945. In a series of initial meetings with his team, Oppenheimer and his senior staff developed the basic outline of how the lab would work, and who was responsible for what. To save time, the lab simultaneously began work on research and the engineering needed to design and build a bomb, with key scientists and technicians given overlapping responsibilities. At the same time, laboratories conducted redundant research to overcome hurdles that might crop up in one lab, but not another. Speculative, imaginative research was encouraged, but if it became clear that the line of research was a dead-end, the lab would quickly drop it. Isolated, locked behind a fence for the rest of the war, the Los Alamos lab staff set to their tasks.

The team at Los Alamos determined that two methods of firing off an atomic bomb were likely. The first was firing a sub-critical pellet of enriched U-235 or plutonium into a larger sub-critical mass to initiate an uncontrolled chain reaction. The second, although it didn't seem likely to succeed, was the "implosion method" of squeezing a mass of U-235 or plutonium by use of a controlled explosion to detonate a bomb. While the scientists understood theory, it became clear that an expert in ordnance – the science and art of weapons – was required, and that an expert was needed from the military. The major problem with the "gun method" was that if the two sub-critical pieces did not hit fast enough, the bomb would fizzle – it would produce enough fission to blow itself apart, but nothing more. A small, powerful gun was needed to deliver a strong enough punch.

The military expert selected for the job was Captain William S. Parsons, a visionary and inspirational naval officer who had started his naval career as a battleship gunnery officer before heading into experimental work at the Naval Research Laboratory (NRL). Under Parsons, who arrived in June 1943 with his wife and two daughters, work began on the gun method of firing the bomb – one aspect of the project that was considered a safe bet. With a newly built laboratory, ordnance range, and a team of 200 ordnance experts, Parsons, with his second-in-command, Commander Frederick L. "Dick" Ashworth, another naval officer, set to work. By mid-September, the team had fired its first shot of many in a series of gun tests to develop a miniature, high-velocity cannon that would fit inside a bomb, itself small



Capt. William S. "Deak" Parsons (1901–1953) was a visionary and inspirational naval officer with a brilliant career in naval gunnery and scientific development. He was selected to join the Manhattan Project to take the fissionable products of the laboratory and construct a working atomic bomb. Parsons and his team developed the first working bomb, the "Little Boy" weapon, which he accompanied to the Pacific and armed for the attack on Hiroshima. After the war, Parsons was the military's top expert on nuclear weapons, and with a small staff helped lead the development of an atomic program not only for the Navy, but also for the other branches of the Armed Forces until his untimely death from a heart attack. (US Naval Institute)

enough to fit into an airplane. To assist in that effort, Parsons assembled a new team in October to work with scientist Norman Ramsay. Its task was to make the necessary preparations to prepare for combat use the bomb that the rest of Los Alamos was racing to develop.

In November, the production of plutonium in its metal form began in the lab. At the same time, British scientists began arriving at Los Alamos. An earlier decision not to inform the British atomic team about the top-secret atomic bomb work in the United States had been reversed. Following a meeting between President Roosevelt and Prime Minister Winston Churchill in Quebec, an agreement to share the work and the results of the bomb program reopened the door closed more than a year earlier. The agreement, signed on August 19, stipulated that "we will never use this agency against each other," that "we will not use it against third parties without each other's consent," and that "we will not either of us communicate any information about Tube Alloys [the codename for the atomic bomb project] to third parties except by mutual consent."[11]

Key figures in the initial breakthrough research – Britain's best – now joined the growing team at Los Alamos. Among them were Otto Fritsch, Rudolf Peierls, James Chadwick, William Penney, and a young German refugee scientist, Klaus Fuchs.

With them came Neils Bohr, who had recently fled the Nazi occupiers of his native Denmark to neutral Sweden. He was subsequently smuggled into Britain. As part of the British Empire, Canada also joined the effort. Canada was already playing a key role as the supplier of a key ingredient – hundreds of tons of Canadian uranium, the product of sub-Arctic radium mines at Port Radium on the shores of the Great Bear Lake. By the time the war ended, the Americans would have ordered more than 1,500 tons of uranium from Canada.[12]

As 1944 began, work on the gun device proceeded, and by July 1944 the design was complete. However, increasing scientific evidence suggested that it would not work with plutonium. Even as this problem was being grappled with, work at Oak Ridge and Hanford was plagued by a series of problems. The electromagnetic separation equipment had faced a problem in the lack of copper to wind the magnets to carry the current to the huge cores, but that problem had been overcome by the ingenious borrowing of 6,000 tons of silver from the United States Mint – to be returned after the war. Faulty design of the magnets, however, forced an expensive rebuild of the system, and a loss of time the project seemingly could not afford.

An even greater problem existed with the gaseous diffusion plant. The uranium gas was so corrosive that most metal was eaten away, and nothing was therefore available to build a barrier of material strong enough to trap the U-235 in an industrial diffusion process. By the fall of 1944, U-235 production, which should have been in the tons, was at less than a few pounds. The problem would not be solved until it was discovered that nickel was strong enough to resist the corrosive gas. When that breakthrough was made, Groves contracted the job to the Chrysler Corporation. Chrysler turned one of its plants over to a massive effort to build the gaseous diffusion units. Learning that the nickel needed would take two years to mine, Carl Heussner, head of Chrysler's plating lab, ingeniously cut costs and saved time when he developed a method for electroplating steel with the nickel. As Chrysler's workers began their task, the stalled industrial gaseous diffusion process seemed close to fruition.

Plutonium production was beginning, however, and the first full-scale pile – now renamed a "reactor" – was fired up under Enrico Fermi's supervision at Hanford on September 26. Then, without warning, the reactor shut down the following day. Analysis of the problem soon discovered that fission was giving off xenon-135, an isotope that absorbed neutrons even better than U-238 or graphite. Another costly delay, another major expense followed. The reactor had to be redesigned and rebuilt to add more "reactivity" to overcome the xenon. On December 17, the changes proved effective, and the full-scale processing of plutonium began at Hanford.

TURNING POINT

By the first months of 1945, the successful resolution of the processing problem and Parson's group's success with the gun problem had convinced Oppenheimer that sufficient U-235 could be developed to build one uranium-gun bomb by the summer of that year. Furthermore, it was also clear that the Nazis had lost the race to build an atomic bomb. The German conquest of Czechoslovakia and Belgium had given the Nazis access to large amounts of radium, and the conquest and occupation of Norway provided a ready source of heavy water, which acted as a neutron absorbent. But incredibly brave acts of sabotage by European resistance movements, including sinking a ferry containing barrels of heavy water, which were being shipped to Germany, in a deep Norwegian lake, had helped stall the German atomic program.

The disinterest of Hitler, who viewed physics as "Jewish science," and an over-extended German effort to develop a wide range of "super weapons," also helped doom the Nazi bomb. In late 1944, a secret team from Los Alamos, commanded by Colonel Boris Pash, one of Groves' security officers, followed victorious troops as they liberated France and drove into Germany. Interviews with Frederick Joliot-Curie led them to the heart of the German program in Strasbourg, where they discovered that the Germans had not beaten the United States to the atomic bomb – and nor would they.

The Manhattan Project was the seeming winner of the race, as the U-235 bomb was to all intents ready once enough fissionable material was manufactured to arm it. The key question that remained was whether a crash program and retooling of Los Alamos to develop a workable plutonium bomb would also succeed.

3

LITTLE BOY AND FAT MAN

A leading hope of the Manhattan Project from the earliest days was that if a U-235 bomb could be built, then so could a plutonium weapon. Since the initial calculations that Pu-239 would probably have an explosive effect 170 times stronger than U-235, planning for a plutonium bomb had proceeded along the same lines as the U-235 bomb. The gun method of firing a small sub-critical mass into a larger sub-critical mass should result in a nuclear detonation, but it would require the uranium slug to be fired at a speed of 3,000ft per second. As research continued through 1944, however, it became clear to the atomic scientists at Los Alamos that the gun method would not work on plutonium.

At the start of the project, in early 1943, plutonium existed only at a microscopic level. To make a weapon, plutonium had to be transformed into a metal, refined to a high level of purity to ensure that it would reach critical mass and simply not melt down (a process known as pre-detonation), and then be produced in large quantities. Chemists assigned to the project examined various methods of manufacturing purified plutonium and eventually settled on a multi-staged process of precipitation, or using a chemical reaction in a liquid solution to form a precipitate of solid metal. As the initial production of plutonium began, Emilio Segre, a former student of Fermi's and a member of Fermi's team in Italy before the war, began experiments to determine the spontaneous fission rate. Segre, a brilliant physicist and former director of the Physics Laboratory of the University of Palermo, was another Jewish refugee who had stayed in the US after the Fascist government banned Jews from university positions in 1938. After working for

Ernest Lawrence and lecturing at the University of California, Segre joined the Manhattan Project to take a leading role in the Metallurgical Lab.

In June 1943, Segre's initial experiments showed that plutonium should detonate inside a gun bomb. More plutonium became available after November when the Metallurgical Lab was finally able to create plutonium in a metallic form. After further experiments in March 1944 demonstrated an even higher rate of fissioning, and potential problems with pre-detonation, further analysis became essential. In April, analysis of the first samples of plutonium produced at Oak Ridge revealed that the plutonium was likely not to work inside a gun bomb. It was not pure enough, and it would fizzle out in a pre-detonation. The results, however, had come from a limited sample, and so Segre and Oppenheimer kept the report quiet. Segre continued to examine additional plutonium as it became available for testing, to make sure that the results were accurate.

By July, it was clear that plutonium would definitely not work in a gun bomb. On the 4th, Oppenheimer told the Los Alamos staff the bad news. The plans for a plutonium gun bomb were immediately scrapped, and a back-burner effort, implosion, was quickly moved into the lead position. While Parsons had favored the gun method, as sufficiently refined U-235 would work in a gun-based bomb, he now agreed to step up implosion research. Oppenheimer and Parsons quickly reorganized Los Alamos to tackle the engineering and development problems of an implosion weapon. One critical aspect of the shift, in addition to research and development, was the need for a test of the bomb to make sure it actually worked.

The shift to implosion was both a vindication for Seth Neddermeyer, the scientist who had first proposed it as a method of detonation at the beginning of the project, and Oppenheimer's management of the lab. A back-burner project had been allowed to continue, which was exactly what Oppenheimer had planned for when he and Groves had established the unique working atmosphere of Los Alamos. The race was now on, with only a year to go before the deadline for a deliverable atomic bomb.

The concept of implosion called for explosives to compress a ball of plutonium from a sub-critical to a critical mass to start the chain reaction and detonate the bomb. During the first meetings of laboratory staff in April 1943, Neddermeyer, a young scientist transferred from the National Bureau of Standards, suggested the concept. It met with cynical reactions from most of the other scientists, who feared that explosive charges could not be made to perform properly to compress simultaneously a plutonium or U-235 hollow core into a solid ball. They feared that all that would result was a fizzle, or the bomb blowing apart and scattering highly radioactive fragments. Nonetheless, Oppenheimer supported Neddermeyer's pursuit of the problem, and assigned him to work under Parson's ordnance group.

Neddermeyer's first experiments began with test explosions in the back canyons of Los Alamos. Rather than try to blast the complex geometry of a sphere, Neddermeyer encased thick steel pipe in explosives and attempted to crush the pipe equally. He quickly discovered that the pipe was always thrown out of the blast as a twisted, badly warped piece of metal. To compress the pipe thoroughly would also require enough explosives that would rip it apart, ruining the experiments.

As Neddermeyer continued to grapple with the problem, Oppenheimer and Parsons began to push for more results, especially as the first inklings of a Pu-239 gun bomb problem began to surface. When visiting mathematician John von Neumann looked at Neddermeyer's results and at calculations by physicist Edward Teller of the pressures generated in the blasts, he quickly determined that there could only be a very narrow margin for error in the symmetry of the shock waves generated by blasts in order to successfully compress plutonium. That narrow margin meant a variation in the symmetry would shatter the plutonium core, and the bomb would fail. Neddermeyer added six more team members to tackle the extra work required to meet such exact specifications.

At the same time, von Neumann's calculations also showed that if the high-velocity shock waves were generated, a plutonium bomb could be made with an even smaller amount of plutonium than originally believed. Groves and Oppenheimer were by now worried that the failure of the gun method for a plutonium bomb meant that the United States would have only one lower-yield U-235 bomb by the summer of 1945. Even if used in combat, a single bomb would be an insufficient demonstration of America's new atomic power, and it might not only not end the war but also actually spur the Japanese, who were known to have their own nuclear program, into a rushed effort to attack with a bomb of their own.

Oppenheimer asked the theoretical physics team, headed by Hans Bethe, to examine implosion physics more closely, and Teller began to work on more calculations. In January 1944, Teller assumed more responsibility as head of a new implosion theory group. However, he was unhappy with his assignment, believing that Oppenheimer was relegating him to a less important task when his research was centered on a fusion bomb. While the implosion concept was sound, and would ultimately lead to the development of the hydrogen bomb, Oppenheimer believed it would not be developed in time to affect the war, and had placed Teller under Bethe to tackle what Teller saw at best as sidetracking and at worst a breach of faith. In time, Oppenheimer would shift Teller entirely into an effort, not completed at war's end, to create his "super-bomb."

DEVELOPING NEW METHODS OF IMPLOSION

Oppenheimer and Parsons were also having problems with Neddermeyer. The young scientist was taking too long, and he needed more help, a fact that he did not seem to realize. In September 1943, Oppenheimer turned to explosives expert George Kistiakowsky, who arrived at Los Alamos in January 1943. By mid-February, Kistiakowsky had replaced Neddermeyer as the head of the implosion team. Under "Kisty," the implosion team, known as the X Division, focused on making implosion work, while Bethe, still in charge of the theoretical group, assisted. Robert Bacher headed the G Division responsible for building the new weapon (G stood for "Gadget," the nickname for the plutonium bomb) and Parsons, while skeptical of the ultimate success of implosion, oversaw the merging of all aspects into a bomb that could be manufactured, sent off to war, and delivered to a target.

To accentuate the push, more supplies and more bodies were needed. With Groves' approval and the US Army's assistance, enlisted personnel with relevant experience were reassigned to Los Alamos. Known as the Special Engineering Detachment (SED), the draftee scientists and technicians eased a critical shortage in people power. The Manhattan Project was now costing the United States $100 million a month. Results were essential, and obstacles were quickly dealt with, no expense spared.

A key shift in the implosion project came through a suggestion from British scientist James Tuck. After arriving in April 1944, Tuck had suggested using an example from British work on shaped explosive charges designed to crack armor. Tuck believed that high-powered, three-dimensionally shaped charges, used to create "explosive lenses," could generate the powerful series of shock waves necessary for successful implosion. A problem that required solving, however, was achieving simultaneous detonation of the charges. The possible solution was the use of exploding wire detonators in the charges, and the first tests of the detonators took place at the end of May.

The detonation sequence of the Little Boy weapon was simpler than a plutonium core implosion. The bomb was essentially a powerful gun that fired a uranium projectile into a "target" of uranium-235, causing a chain reaction and a nuclear explosion.

The development of the new methods did not necessarily mean success. Over the next few months, an exhaustive program of developing molds and casting explosive charges with fragile explosive compounds discarded tens of thousands of imperfect castings. Over 20,000 lenses that passed quality control were detonated in experiments to develop the simultaneous ignition system and to produce sufficient and equal compression of a plutonium core. As theory and practical application continued at a rushed pace in tandem, the work environment was later described as one in which "in their cubicles the theoretical scientists would sit for many hours working with pieces of colored chalk on a blackboard or with pencil on pads of paper. At frequent intervals one would hear the boom of great explosions on the various proving grounds in the distant canyons."This, said the project's official chronicler, *New York Times* reporter William L. Laurence, represented "in the true sense the explosion of ideas in the minds of men."[1]

One of the explosive ideas that proved to be a further breakthrough came when Robert Christy, another of the British scientists, suggested the use of a smaller, solid core approximately the size of a grapefruit. A smaller, solid mass would theoretically be easier to compress, but it would still require a precise burst to achieve criticality. Squeezed to twice its density, the plutonium would react as the nuclei were shoved closer to each other and free neutrons would punch through the nuclei, releasing more neutrons that in turn would strike more nuclei and release the incredible energy of a nuclear explosion. By the end of December, 1944, the tests of the lenses were progressing sufficiently to suggest that success was around the corner.

To test what constituted the critical mass for an explosion in the uranium bomb, other experiments in another "distant canyon" used a device known as the "guillotine." A wooden frame supported two steel rods that were set into two small blocks of "active material." A smaller block, suspended between the rods, was dropped to come into contact with the other blocks, and then slide past them. For a brief moment criticality, measured by neutron flux, would occur. While this test was dangerous because of the release of harmful radiation for that fraction of a second, another test, conducted under the supervision of Otto Frisch, used a small pile, pushing it to the brink of criticality, essentially modeling the "conditions prevailing in the bomb."

These tests showed that without a doubt the uranium gun bomb would work, and 1944 came to an end, it seemed that a successful method of implosion would be developed, even if by trial and error. To ensure success, however, a test of the Gadget was necessary. In March 1944, Kenneth Bainbridge, a member of Kistiakowsky's explosives group, was placed in charge of group X-2 to "make preparations for a field test in which blast, earth shock, neutron and gamma radiation" were to be measured and studied and to also make "complete photographic records ... of the explosion and any atmospheric phenomena connected with the explosion."[2] Bainbridge, a Harvard University physics professor, had previously been in charge of high-explosive development. Described as "quiet and competent" by General Groves,[3] Bainbridge worked closely with the SED and a team of other scientists as he started the massive preparations for the test.

As Bainbridge began his preparations, the issues facing the Manhattan Project other than the questions of implosion were steadily being resolved. The first was both the quantity and the purity of processed plutonium. At the start of the year, Hanford began to produce more plutonium, while at the same time Oak Ridge's gaseous diffusion facilities, built in a rush, went on line. The final tests with U-235 were made, and in February 1945 Oppenheimer ordered the team designing the uranium gun bomb to finalize the design. Parsons turned his focus to planning for the delivery and use of the weapon, which was now codenamed "Little Boy."

At the end of February, Groves and Oppenheimer met with George Kistiakowsky, Hans Bethe, Charles C. Lauritsen, Arthur Conant, and Richard Tolman to examine the best design options for the plutonium weapon. The meeting resulted in a series of decisions. Even through Christy's theory of solid core compression had not yet been proved in a test, the team decided that the use of multiple explosive lenses with a modulated initiator and electric detonators would be used to create simultaneous, converging shock waves to compress the core. With that, all work on other designs for implosion compression was dropped and the design of the plutonium bomb was frozen. The decision was another gamble, because all of the components had problems. Groves had set a deadline of August 1 for a bomb to be ready for combat use, and so the team agreed on a series of deadlines to solve the problems and test an implosion weapon, which was codenamed "Fat Man."

The goals and deadlines were:

March 15–April 15: The detonators were to have their problems resolved and be ready for mass production.
April 2: A full-scale mold for the explosive lenses was to be completed and ready for use to cast the lenses out of the explosive compounds selected for the best results.
April 15: Less than two weeks later, enough lenses were to be ready for multi-point electrical detonation.
April 25: "Hemisphere tests" were to begin and would measure how the shock waves converged.

By 1945, Los Alamos had developed one working weapon design. The weapon was, at the beginning of that year, the only design that was guaranteed to work. The method was essentially simple: explosive charges were designed to fire a hollow U-235 projectile through a long gun barrel built into the heart of the bomb, which would impact into a U-235 target, inducing a chain reaction and nuclear detonation. "Little Boy" performed with deadly effect over Hiroshima. The weapon shown here is a replica displayed at the National Museum of the United States Air Force at Wright Patterson Air Force Base in Dayton, Ohio. (Alamy Ltd.)

May 15:	A full-scale test of implosion would successfully compress a solid core of metal.
May 15–June 15:	Enough plutonium would be on hand and full-scale spheres would be manufactured and tested for criticality.
June 4:	Molding lenses and assembling the detonators for the field test of the bomb would begin.
July 4:	The field test of the bomb would successfully detonate a plutonium-core weapon.

To meet the deadlines, Oppenheimer established a committee to see the various phases through, including delivery of sufficient plutonium from Hanford, the work at Los Alamos, and the construction of a massive new base to test the bomb. Known as the "Cowpuncher Committee" because in western parlance they were to "ride herd" on the various scientists and technicians and their projects, the committee was Captain Parsons, Charles Lauritsen, Samuel K. Allison, Robert Bacher, and George Kistiakowsky. Parsons had advocated the committee, writing to Oppenheimer that "ruthless, brutal people must band together to force the Fat Man components to dovetail in time and space."[4] Allison, a former member of the University of Chicago's Metallurgical Laboratory and a highly respected member of the Los Alamos team, chaired the cowpunchers. With the committee in place, Oppenheimer then moved into what would be the final phases of the Manhattan Project.

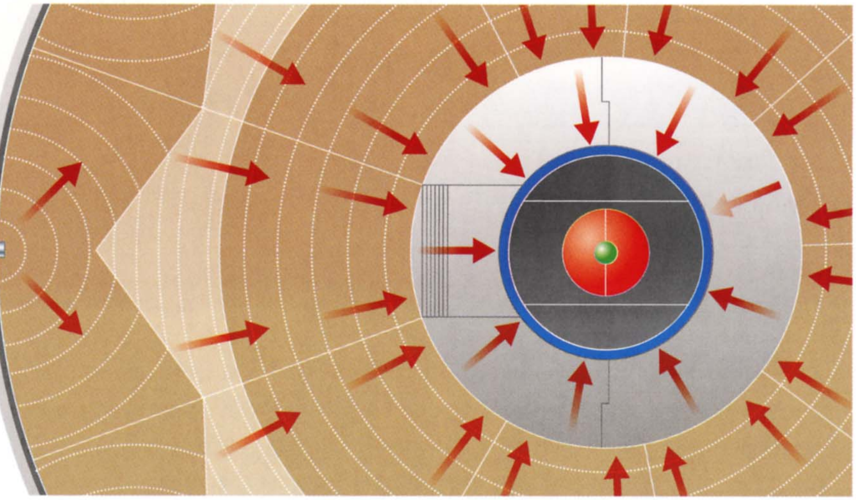
During the first half of 1945, Los Alamos' scientists and technicians raced to complete a workable plutonium core weapon that could be detonated through implosion. The initial weapon, known as "the Gadget," gave rise to the combat version of the bomb, "Fat Man." The "Fat Man" bomb was dropped on Nagasaki, and was later tested at Bikini Atoll in 1946. (Alamy Ltd.)

In March 1945, Oppenheimer split Los Alamos's efforts into two separate projects – "Project Alberta" and "Project Trinity." The same month, another gamble paid off when the first evidence of implosion-produced compression of a solid sphere was observed in a test. By mid-April, Kistiakowsky was sure he had at last achieved optimal results in his sub-scale tests. Another hurdle had passed. To continue the tests with larger-scale cores, in early May the team introduced a Raytheon Mark II X-Unit, protected from the blasts in closely spaced concrete blockhouses, to shoot fast X-rays every ten-millionth of a second to measure the blasts.

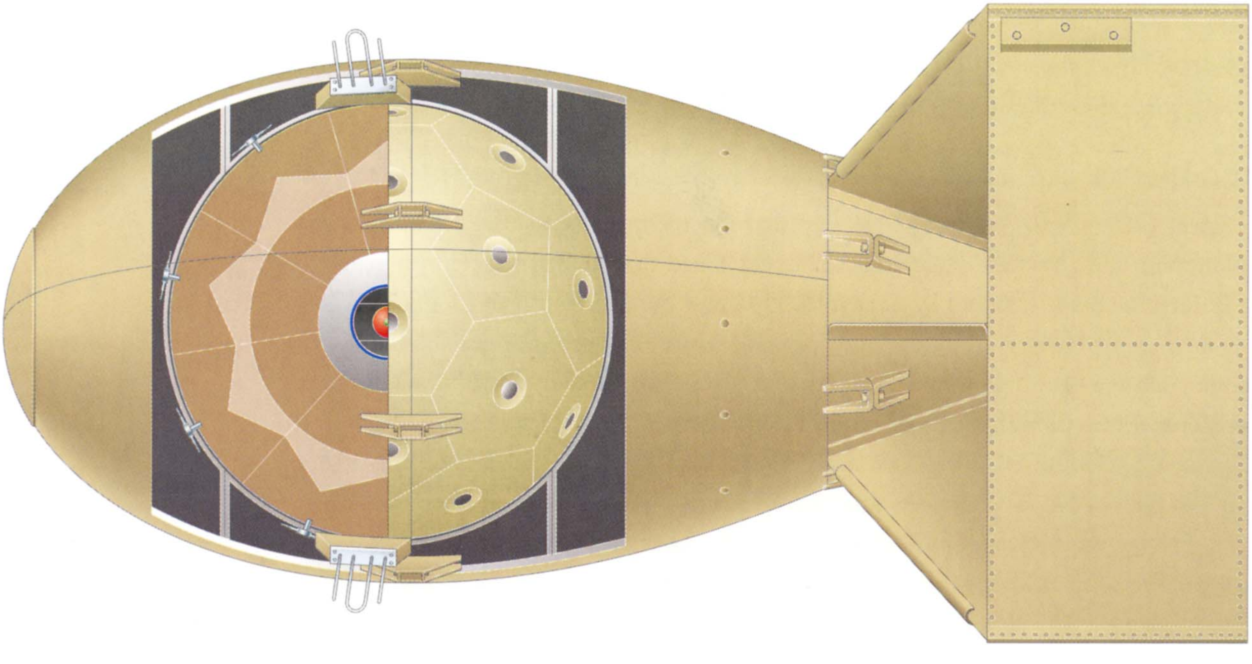
TRINITY

Project Trinity was Bainbridge's all-out drive to ready a site to test the Fat Man plutonium-core bomb. Oppenheimer later explained that he had selected the name "Trinity," a choice inspired by poet John Donne – the fourteenth of Donne's *Holy Sonnets* starts: "Batter my heart, three person'd God." The preparations for the test took place at a site selected by Bainbridge after an exhaustive tour of the New Mexico wilderness and approved by Oppenheimer and Groves in the late fall of 1944. The best site would be within a day's drive of Los Alamos, have good weather, and be in as flat an area as possible. The choice was an isolated spot in an area known since Spanish colonial days as the *Jornada del Muerto* (Journey of Death). The test site was an 18 by 24-mile section inside a bombing range of the 2,000-square-mile Alamagordo Air Base. Located 125 miles south of Albuquerque and 30 miles east of the nearest settlement, Carrizozo, then a town of 1,500 inhabitants, the Trinity Site was some 210 miles from Los Alamos. It would be a long day's drive.

There, as a Los Alamos technical history later recounted, Bainbridge raced to "establish under conditions of extreme secrecy and great pressure a complex scientific laboratory in a barren desert."[5] Preparations for the test had languished in late 1944 and early 1945 until the implosion experiments showed promise and the cowpunchers



To detonate the plutonium core "Fat Man," shaped charges of fast and slow explosives focused a spherical shock wave to compress the inner components - a beryllium–polonium-210 "initiator" known as the "urchin" and a "pit" of plutonium-239/240. As the metals came into contact, they fissioned and a chain reaction that was controlled and focused by a uranium tamper. About 20% of the pit fissioned, and released energy in the form of a nuclear explosion.



had formed. Spurred on in February 1945, Bainbridge had five months to complete his task before the scheduled date of the test on July 4. Fortunately, preparation of the site had started in December 1944 as workers began to build a series of wood and concrete slab bunkers covered by earth to protect test instruments, motor generators, cameras, and test personnel. A base camp, erected 9 miles southwest of the test site, became the administrative center for the Project Trinity team, with labs, maintenance, repair and support facilities, and living quarters for the military personnel and scientists who worked at the site. By July, the base camp's population had grown to 125 souls who contended with the isolation, heat, alkali-laden water (which forced them to shower with Navy-issue saltwater soap), and an even larger population of scorpions. Boots and shoes needed shaking every morning to liberate unwelcome guests who had crawled into them during the night.

At the test site, Bainbridge selected a flat area termed the "Zero Point" to erect a tower on which the bomb would be detonated. Clustered around Zero were various bunkers. The instrument bunkers were erected 800 yards west and 800 yards north of the Zero Point. Three personnel bunkers were built 10,000 yards from Zero to the north, west, and south. Generator bunkers were built alongside them, and camera bunkers were built next to the north and west personnel bunkers. Later, two more instrument bunkers were built 600 yards northwest and 1,000 yards north, and a small firing bunker was built 500 yards west of Zero Point.

Workers strung nearly 500 miles of communications and signal cables on poles or buried them in trenches to link the various bunkers and instruments. The instruments for measuring the blast's heat, flash, radiation, and shock effects were a diverse assembly of equipment, some of it specially developed at Los Alamos. They included condenser gauges, piston gauges, quartz piezo gauges, crusher gauges, excess velocity gauges, impulse meters, ionization chambers, sulfur threshold detectors, gold foil detectors, gamma ray recorders, electron multiplier chambers, oscilloscopes, coil loudspeaker pickups, geophones, seismographs, spectographs, tracking radar, high-speed cameras, motion picture cameras, and cellophane catcher cameras. While many instruments were placed on the ground at the time of the test, others were suspended from weather balloons or dropped by parachute from observer aircraft.

In May, work on the cross-braced, four-legged steel tower to hold the bomb began. When completed in mid-June, it was 100ft high. At the top was a metal shed to keep the bomb out of the weather. A heavy-duty electrical winch to hoist the bomb up was also installed in the shed. Close by, another tower rose, this one to support a massive steel chamber shaped like a jug. When the test was first proposed, Groves had expressed concern that a pre-detonation would lose the only plutonium the United

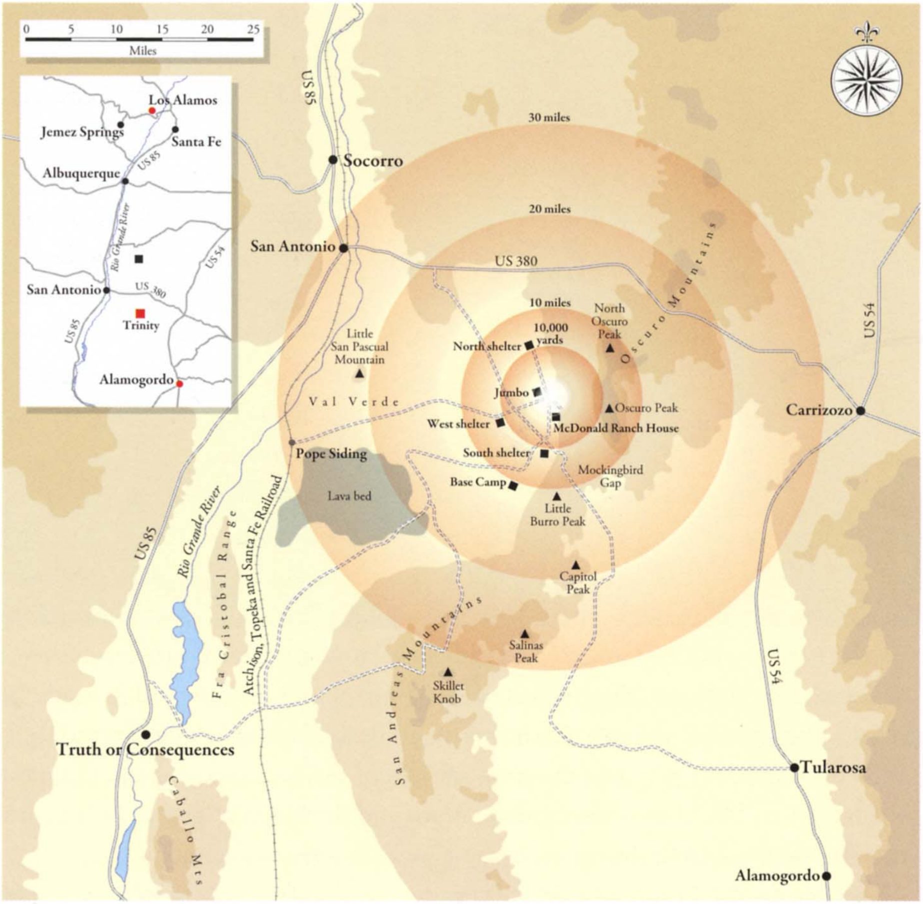
States had on hand. A variety of methods to save the plutonium (itself valued in the hundreds of millions of dollars) were studied, among them testing the bomb in water, or burying it beneath a large mound of sand that could then be mined to recover the precious metal in the event of a fizzle. Ultimately, the idea of a massive steel container to hold in the blast prevailed.

The problem was that a steel container big enough to hold the bomb and withstand the detonation of the 5,300lb of high-explosive charges inside the Gadget had never been built before, and contractors approached declined the job until the boiler-making firm of Babcock and Wilcox, in Baberton, Ohio, agreed to take the job. When completed at a cost of over a half million dollars (some accounts claim the actual cost was $12 million), the huge steel jug, nicknamed "Jumbo," was 25ft long and 12ft in diameter. With 14in.-thick steel walls, it weighed 214 tons. Shipped by rail to Pope, New Mexico, crews loaded Jumbo onto a specially designed, 64-wheel trailer that transported it to the Trinity Site. By the time Jumbo arrived, however, confidence in the Gadget was higher, and fear that the atomic blast would vaporize the jug and add its 214 tons of steel to the cloud of nuclear fallout that would follow the blast led to a decision to sidetrack Jumbo. Hoisted halfway up a steel tower 800ft from the Zero Point, Jumbo would bear silent witness to the test.

A third tower, built 800 yards from the Zero Point, was a heavily reinforced wooden platform 20ft high for a pre-atomic test. Known as the "100-ton test," the experiment was intended to test both the detonation of the Gadget and to calibrate the instruments. It used 100 tons of high explosive, packed in cases and stacked atop the tower. To measure the dispersion of radiation, 1,000 curies of radioactive material, produced from a slug sent from Hanford was dispersed in cylinders laced into the stack. The 100-ton test, at the time the world's most powerful explosion, lit up the predawn sky at 04:37:05hrs on May 7. The fireball expanded into an oval before dissipating, and a mushroom cloud of smoke and dust climbed 15,000ft into the desert sky.

The 100-ton test was successful, especially in pointing out logistical and organizational problems such as the need for more people, better communications, and the improvement of the test site's dirt roads, which bogged down vehicles – and hence progress. As a result, 20 miles of roads were paved with asphalt, additional telephone lines and radios were ordered, additional staff were brought in, and a "town hall" was built to better house meetings as the July 4 deadline for the atomic test approached.

By the end of May, enough plutonium had arrived to allow for the final tests of critical mass. Within three weeks, Frisch was able to report that the implosion design would work, and soon after, the lab decided that the bomb would generate a blast somewhere between 4 and 13 kilotons. (A kiloton is the force generated when a



Trinity, where the Manhattan Project first tested the atomic bomb, is in a relatively isolated spot in the New Mexico desert. This map shows the layout of the test site's landmarks. (Artist info)

thousand metric tons of explosive detonates.) A pool was established to take bets on the actual yield, with some scientists betting zero, and others, like an optimistic Edward Teller, suggesting that the yield would be higher at 45 kilotons.

The pool was one means of dealing with the tension everyone felt as the test approached. At that stage, nearly $2 billion had been spent, and reputations were on the line. The war in Europe was over, but the ongoing struggle with Japan continued. A new president, Harry Truman, was in office following Franklin Roosevelt's death on April 12. This change inspired a satirical bit of doggerel that made the rounds of Los Alamos:

> From this crude lab that spawned a dud.
> Their necks to Truman's ax uncurled
> Lo, the embattled savants stood,
> and fired the flop heard round the world.[6]

By June, it was clear that the initial deadline of July 4 could not be met, and a new date, July 16, was set.

At Trinity, final preparations for the test continued up to the day of the shot. After delays caused by inferior castings of high explosive, mostly caused by air bubbles forming inside the explosive as it set, there were not enough lenses ready by July 9. Kistiakowsky, guided by X-ray images, borrowed a dental drill, bored into the castings, and filled the air voids with "molten explosive slurry" to make them acceptable. Enough castings of high explosive were ready on July 10 for the Los Alamos team to begin assembly of two packages, one of which would be fired in a test with a non-fissionable core to see how it worked.

Lieutenant Commander Norris Bradbury, US Navy, one of Parson's team, took on the task of assembling the charges while the plutonium cores were cast. The charges were nestled into place, but despite the careful attention to detail, none fitted tightly. A suggestion to fill the voids with grease was rejected, and instead Bradbury and a team of SED technicians filled the spaces with facial tissue paper and then used Scotch tape to hold the charges together. Equally ingenious and last-minute thinking was also needed with the cores. Coated with nickel to absorb alpha particles and avoid corrosion, the cores soon blistered because plating solution was trapped beneath the nickel and against the plutonium, which gave off heat. The cores required a perfect fit inside the bomb, but stripping the cores was out of the question, as it would expose the plutonium. The blisters were ground down and the irregular surface of the cores was filled with gold foil, leaving each core a brilliant reflective surface.

The core for the Trinity test left Los Alamos on the afternoon of July 12, nestled in the back seat of a US Army Plymouth sedan with scientist Philip Morrison for the long drive to the test site. On arrival, the core was unloaded into the abandoned ranch house of George McDonald, which had lain vacant since the creation of the bombing range in 1942 and the McDonald family's evacuation. The master bedroom, turned into a "clean room" for the bomb's assembly, had its windows sealed with plastic, and now held the workbenches for the scientists and technicians. At Los Alamos, Bradbury's team finished the assembly of the charges into the hemispherical casing of the Gadget, and then lowered a tamper sphere of uranium (which would act as a neutron reflector) inside to fit, as historian Richard Rhodes would later describe it, into the "cavity like the pit in an avocado."[7]

On July 13, just past midnight, an Army 5-ton truck loaded with the high-explosive assembly for the bomb left Los Alamos and drove for eight hours through the night and into the dawn, arriving at Trinity an hour before Bainbridge's team assembled in the McDonald ranch house to start the final assembly. As the cores were laid out,

Lieutenant Commander Norris Bradbury, USN, atop the Trinity tower with the partially assembled Gadget prior to the first test detonation of the atomic bomb. Bradbury, with a doctorate in physics, was in charge of the team that assembled the non-nuclear components of the Gadget. Anxiety was high, and yet Bradbury maintained a sense of humor, writing in his log, "Look for rabbit's feet and four leaf clovers. Should we have the chaplain down here?" (Corbis)

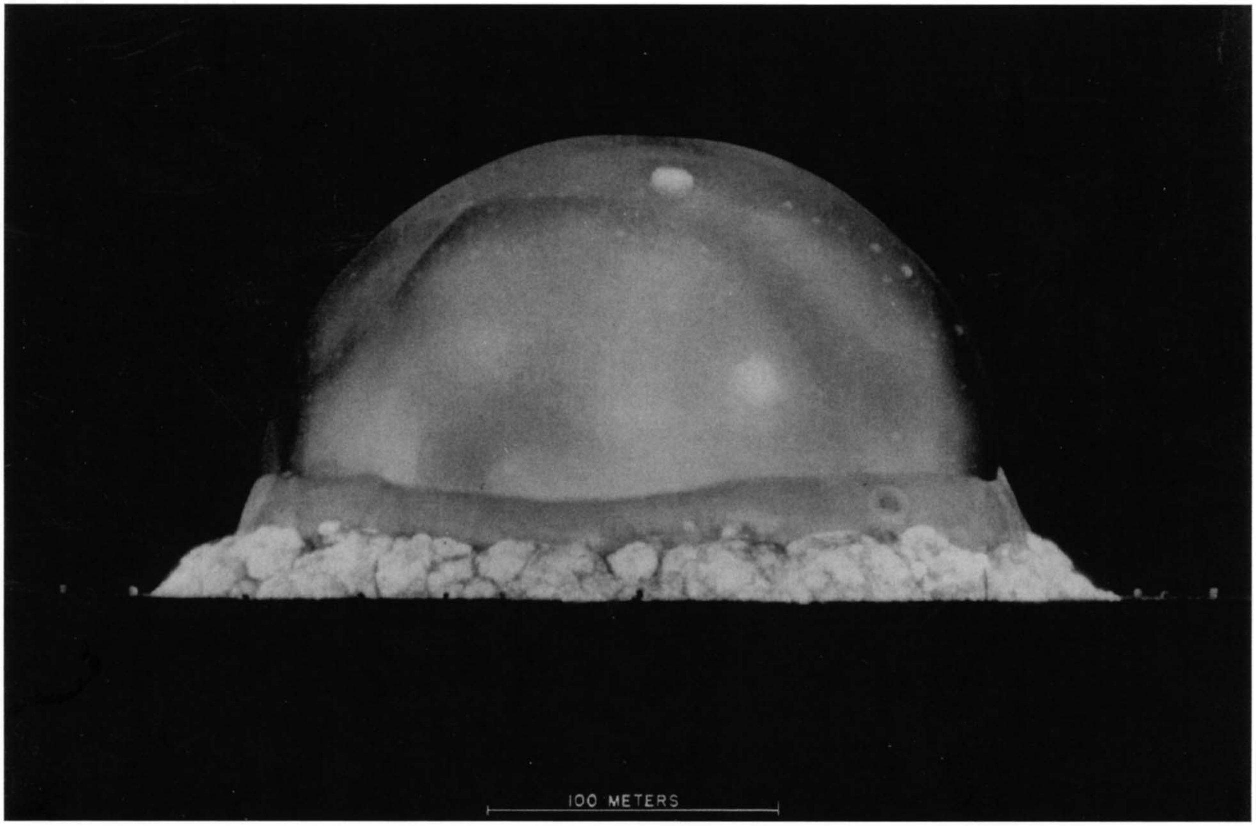
scientist Robert Bacher, the senior advisor, asked the Army for a receipt for the multi-million dollar plutonium that was about to be destroyed. Brigadier General Thomas Farrell, Groves' deputy, signed the receipt:

> I recall that I asked them if I was going to sign for it shouldn't I take it and handle it. So I took this heavy ball in my hand and I felt it growing warm, I got a certain sense of its hidden power. It wasn't a cold piece of metal, but it was really a piece of metal that seemed to be working inside. Then maybe for the first time I began to believe some of the fantastic tales the scientists had told about this nuclear power.[8]

The assembly was ready by the afternoon and the scientists took it by car to the Zero Point, arriving at 03:18hrs to meet up with Bradbury and the rest of the bomb team. Winched off its truck and on skids below the tower, the Gadget was missing one lens, a gap through which the cylindrical plug with the core and its initiator were to fit, tightly, into the heart of the bomb. Everything had been machined to fit perfectly, but as the two assemblies were mated, the plug jammed. As one scientist recalled, consternation reigned until it was pointed out that the core had slightly expanded in the heat of the ranch house overnight, while the rest of the bomb, kept under cover, was cooler. After taking a break to allow the temperatures to equalize, the team found that the pieces fitted together. By late evening, Bradbury had completed the assembly of the bomb, stopping short of inserting the detonators, which would happen the following day after the bomb was winched atop the tower.

On July 14, the team slowly winched the Gadget 100ft up and into the tower, pausing while soldiers piled a stack of mattresses beneath it to cushion the bomb if the winch failed and it fell. Once up, the Gadget's assembly resumed as the detonators were inserted into place, covering the Gadget with an array of wires and plugs. As the assembly progressed, however, bad news came from Los Alamos. The test firing of the other, non-fissionable assembly had produced results that suggested the Trinity bomb would be a dud. Intense discussion, complaints, and several grillings of Kistiakowsky ensued until Hans Bethe reported that a review of the data could not be taken at face value and that a working bomb was still possible if not probable.

By the 15th, everything was at last ready. Tempers were high, tension was perceptible, and Oppenheimer alternately paced, chain-smoked and read as he tried to stay calm. The difficult situation grew worse at 02:00hrs, as a storm hit complete with thunder, lightning, and heavy rain. As the storm continued, Groves postponed



The Gadget detonated at Trinity at 05:29:45hrs on July 15, 1945. A camera captured the world's first atomic explosion at 1/40 seconds. William L. Laurence described it as "a sunrise such as the world had never seen, a great green super-sun climbing in a fraction of a second... lighting up earth and sky all around with a dazzling luminosity." (Los Alamos National Laboratory) the test to 05:30hrs in the morning when his weather forecaster suggested the storm would end. "You'd better be right on this, or I will hang you," Groves barked.[9]

As test personnel made the last-minute preparations, observers gathered in the bunkers and at a VIP lookout atop Compañia Hill, 20 miles northwest of the Zero Point. At Los Alamos, a group of distant observers hiked and spent the night on a mountain, watching in the distance. Aloft, aircraft stood by with instruments and observers, while at distant places, including a Carrizozo motel room, others waited with instruments. The rain finally stopped and as rockets arced into the darkness to signal the impending shot, and a warning siren wailed, the various groups stood waiting, some hastily slathering on sunblock and donning thick dark glasses to shield them.

Then, at 05:29:45hrs, the Gadget detonated. The world's first nuclear explosion was described by William L. Laurence, the only reporter present:

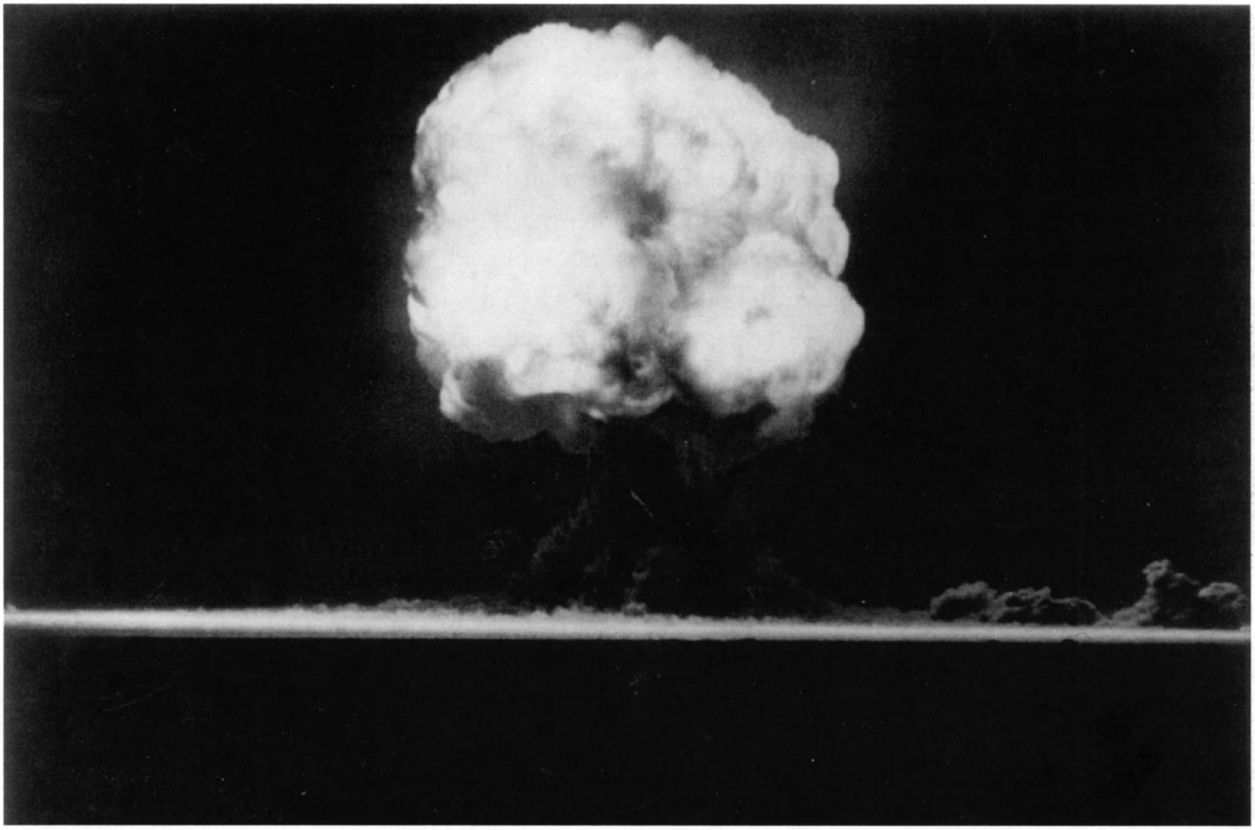
> …there rose from the bowels of the earth a light not of this world, the light of many suns in one. It was a sunrise such as the world had never seen, a great green super-sun climbing in a fraction of a second to a height of more than eight thousand feet, rising even higher until it reached the clouds, lighting up earth and sky all around with a dazzling luminosity.[10]

Hans Bethe described the detonation as looking "like a giant magnesium flare which kept on for what seemed a whole minute but was actually one or two seconds. The white ball grew and after a few seconds became clouded with dust whipped up by the explosion from the ground and rose and left behind a black trail of dust particles."[11]

The fireball continued to expand, changing colors, followed by a cloud that climbed to 41,000ft as it punched through the clouds above. A "mighty thunder," as Laurence termed it, followed, the ground trembled, and a blast of hot wind swept over the desert, and then came silence punctuated by the exclamations of the assembled scientists and military officials who had watched from a safe distance. The flash and the blast were seen and heard hundreds of miles away.

Determining the force of the bomb was a key aspect of the test. Watching the blast, Enrico Fermi decided to try an informal experiment:

> About 40 seconds after the explosion the air blast reached me. I tried to estimate its strength by dropping from about six feet small pieces of paper before, during, and after the passage of the blast wave. Since, at the time, there was no wind, I could observe very distinctly and actually measure the displacement of the pieces of paper that were in the process of falling while the blast wave was passing. The shift was about 2½ meters,



The Trinity detonation at 15 seconds. The fireball is climbing and expanding, while the cloud from the 18.6 kiloton blast would eventually climb to 41,000 feet. Watching the constantly changing colors as the fireball filled the sky, Oppenheimer thought of the Bhagavad-Gita and Vishnu's terrifying aspect as he assumed his multi-armed form and said "Now I am become Death, the destroyer of worlds." (Los Alamos National Laboratory)

> which at the time, I estimated to correspond to the blast that would be produced by ten thousand tons of TNT.[12]

Later, the test instruments showed that the Trinity blast was equivalent to 18.6 kilotons.

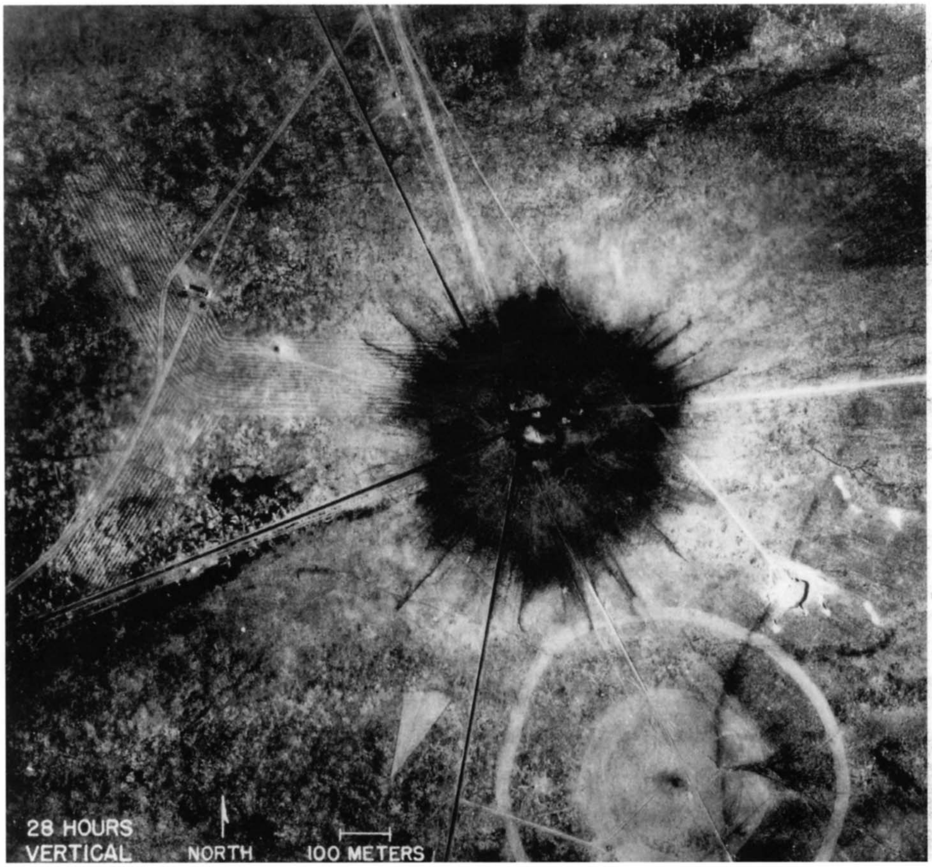
As the blast faded, two lead-lined Sherman tanks rumbled to life and drove into the heart of the test area, finding a mile-wide area devoid of life, scorched and swept clean. The tower was gone, leaving only the stubs of its concrete supports. A crater 400 yards in diameter, 25ft deep at the center and tapering up to a 10ft deep depression at the edges, was lined with melted sand that the heat of the explosion had turned into a greenish-gray, highly radioactive glass. Lifted into the fireball and heated to over 14,710°F (8,430°C), the molten glass had rained back into the depression formed by the blast. Termed "Atomsite" and later "Trinitite," the atomic slag was one of many new phenomena observed that morning.

As the bright light faded and the blast echoed, the tension melted. After the cheers stopped, a grim reality set in. "Now we're all sons of bitches," Bainbridge said.[13]

Oppenheimer later recalled, "we knew the world would not be the same. A few people laughed, a few people cried. Most people were silent." He went on:

> I remembered the line from the Hindu scripture, the Bhagavad-Gita: Vishnu is trying to persuade the Prince that he should do his duty and to impress him he takes on his multi-armed formed and says, "Now I am become Death, the destroyer of worlds." I suppose we all thought of that, one way or another.[14]

The incredible display was not lost on the military. General Farrell approached Groves and said, "The war is over." Groves quickly replied, "Yes, after we drop two bombs on Japan."[15] Two days later, over a meal, President Truman and Prime Minister Churchill discussed the success of the joint American-British effort, and agreed to proceed with the combat deployment of the weapon by the Americans as quickly as possible. The bomb was on its way to Japan.



The Trinity blast crater, photographed from the air 28 hours after the test. Four hundred yards in diameter and 25 feet deep, it is coated in radioactive glass formed from fused sand that rained down as a molten rain. The crater from the 100-ton non-atomic test is visible to the lower right. (Los Alamos National Laboratory)