The Manhattan Project

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Introduction

In a national survey at the turn of the millennium, both journalists and the public ranked the dropping of the atomic bomb and the end of the Second World War as the top news stories of the twentieth-century. The Manhattan Project is the story of some of the most renowned scientists of the century combining with industry, the military, and tens of thousands of ordinary Americans working at sites across the country to translate original scientific discoveries into an entirely new kind of weapon. When the existence of this nationwide, secret project was revealed to the American people following the atomic bombings of Hiroshima and Nagasaki, most were astounded to learn that such a far-flung, government-run, top-secret operation existed, with physical properties, payroll, and a labor force comparable to the automotive industry. At its peak, the project employed 130,000 workers and, by the end of the war, had spent $2.2 billion.

Neutrons, Fission, and Chain Reactions

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

The existence of a third subatomic particle, the neutron, so–named because it had no charge, explained the differences. First identified in 1932 by James Chadwick, Rutherford's colleague at Cambridge, neutrons within the nuclei of atoms of a given element could vary in number. The different types of atoms of the same element but with varying numbers of neutrons were designated isotopes. The isotopes of uranium, for instance, all have ninety–two protons in their nuclei and ninety–two electrons in orbit. But uranium–238, which accounts for over ninety–nine percent of natural uranium, has 146 neutrons in its nucleus, compared with 143 neutrons in the rare uranium–235, making up only seven–tenths of one percent of natural uranium.

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

Fission of the uranium atom, it soon became apparent, had another important characteristic besides the immediate release of enormous amounts of energy. This was the emission of neutrons. The energy released when fission occurred in uranium caused several neutrons to "boil off" the two main fragments as they flew apart. Given the right set of circumstances, physicists speculated, these secondary neutrons might collide with other atoms and release more neutrons, in turn smashing into other atoms and, at the same time, continuously emitting energy. Beginning with a single uranium nucleus, fission could not only produce substantial amounts of energy but also lead to a reaction creating ever–increasing amounts of energy. The possibility of such a "chain reaction" completely altered the prospects for releasing the energy stored in the nucleus. A controlled self–sustaining reaction could make it possible to generate a large amount of energy for heat and power, while an unchecked reaction could create an explosion of huge force.[1]

The Atomic Bomb and the Manhattan Project

The possible military uses that might be derived from the fission of uranium atoms were not lost on the best and brightest of the world's physicists. In August 1939, Einstein, with the help of Hungarian émigré physicist Leo Szilard, wrote a letter to President Roosevelt, informing him that recent research showed that a chain reaction in a large mass of uranium could generate vast amounts of power. This could conceivably lead, Einstein wrote, to the construction of "extremely powerful bombs." A single bomb, the physicist warned, potentially could destroy an entire seaport. Einstein called for government support of uranium research, noting darkly that Germany had stopped the sale of uranium and German physicists were engaged in uranium research.[2]

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

At the same time, a second possible path to a bomb gradually emerged. Researchers studying uranium fission products at the Radiation Laboratory at the University of California in Berkeley discovered another product, a new transuranium, man–made element, named neptunium, with an atomic number of 93, created when uranium–238 captured a neutron and decayed. Neptunium itself decayed to yet another transuranium element. In February 1941, the chemist Glenn T. Seaborg identified this as element 94, which he later named plutonium. By May he had proven that plutonium–239 was 1.7 times as likely as uranium–235 to fission. The finding suggested the possibility of producing large amounts of the fissionable plutonium in a uranium pile, or reactor, using plentiful uranium–238 and then separating it chemically. This might be less expensive and simpler than building isotope separation plants.[3]

Not until 1942, after the Japanese attack on Pearl Harbor had thrust the United States into World War II, was the decision made to proceed with a full-scale program to build an atomic bomb. Security requirements suggested placing the atomic bomb project under the Army Corps of Engineers. The Corps set up the Manhattan Engineer District commanded by Brigadier General Leslie R. Groves. The Manhattan Engineer District operated like a large construction company, but on a massive scale and with an extreme sense of urgency. Unique as well was the investment of hundreds of millions of dollars in unproven processes. By the end of the war, Groves and his staff expended approximately $2.2 billion on production facilities, towns, and research laboratories scattered across the nation. Secrecy and fear of a major accident dictated that the production facilities be located at remote sites. Due to ongoing uncertainties as to which processes would work, two distinct paths were chosen to obtain a bomb.

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

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

Much of the research work on producing plutonium, including design of the piles, took place at the Metallurgical Laboratory (Met Lab) in Chicago. Design and fabrication of the first atomic bombs were the responsibility of the newly established Los Alamos Scientific Laboratory, located at a virtually inaccessible site high on a mesa in northern New Mexico. The laboratory, headed by J. Robert Oppenheimer, attracted a remarkable array of scientists from universities across the United States.[4]

Bomb Design

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

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

Los Alamos, working with the Army Air Force, developed two bomb models by spring 1944 and began testing them, without the fissionable materials, with drops from a B–29 bomber. The plutonium implosion prototype was named Fat Man. The uranium gun prototype became Little Boy. Field tests with the uranium prototype eased remaining doubts about the artillery method. Confidence in the weapon was high enough that a full test prior to combat use was seen as unnecessary. The plutonium device was more problematic. It would have to be tested before use.[5]

The Trinity Test

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

Not so with radiation. Prior to Trinity, scientists were well aware that the blast would create potential radiation hazards. Plutonium in the device would fission into other radionuclides. Neutrons would strike various elements on the ground and turn some into active nuclides. This radioactive debris would be swept with fission products into a growing fireball and lifted high into the air. Once in the atmosphere, they would form a cloud of intense radioactivity. Immediate radiation from the explosion and residual radioactive debris initially caused faint worry because of dilution in the air and the isolation of the site, but as the test drew closer planners realized, with some sense of urgency, that radioactive fallout over local towns posed a real hazard. Groves, in particular, feared legal culpability if things got out of hand. As a result, Army intelligence agents located and mapped everyone within a forty–mile radius. Test planners set up an elaborate offsite monitoring system and prepared evacuation plans if exposure levels became too high.[6]

On July 16, 1945, the Trinity device detonated over the New Mexico desert and released approximately 21 kilotons of explosive yield. The predawn blast, which temporarily blinded the nearest observers 10,000 yards away, created an orange and yellow fireball about 2,000 feet in diameter from which emerged a narrow column that rose and flattened into a mushroom shape. The blast scoured the desert floor, leaving a shallow crater, 10 feet deep and some 400 yards across, in which radioactivity far exceeded pretest estimates. More efficient than expected, the shot dropped little fallout on the test site beyond 1,200 yards of ground zero. Most radioactivity was contained within the dense white mushroom cloud that topped out at 25,000 feet. Within an hour, the cloud had largely dispersed toward the north northeast, all the while dropping a trail of fission products. Offsite fallout was heavy. Several ranch families, missed by the Army survey, received significant exposures in the two weeks following Trinity. The families, nonetheless, evidenced little external injury. Livestock were not as fortunate, suffering skin burns, bleeding, and loss of hair. The test, as Stafford Warren, the Manhattan District's chief medical officer, informed Groves, had been something of a near thing. "While no house area investigated received a dangerous amount," he noted, "the dust outfall from the various portions of the cloud was potentially a very dangerous hazard over a band almost 30 miles wide extending almost 90 miles northeast of the site." The Alamogordo site, Warren concluded, was "too small for a repetition of a similar test of this magnitude except under very special conditions." For any future test, he proposed finding a larger site, "preferably with a radius of at least 150 miles without population."[7]

From the Second World War to the Cold War

Three weeks after the Trinity test, on August 6, 1945, Little Boy, the untested uranium bomb, was dropped at Hiroshima, Japan. The plutonium weapon, Fat Man, followed at Nagasaki on August 9. Use of the bombs helped bring an end to the war in the Pacific, with Japan surrendering on August 14.[8]

The end of the Second World War brought with it a whole new set of issues and problems, not least of which revolved around the dilemma of what to do with the nuclear genie now that he had been let out of the bottle. Certainly, there was no getting him back in. The United States could not now return to a simpler time when atomic bombs, let alone the knowledge of the physics behind atomic bombs, did not exist. The discovery of nuclear energy, as President Harry S. Truman told Congress in October 1945, “began a new era in the history of civilization.” And while this new era held the promise of perhaps limitless energy for peaceful purposes, the prospect of every nation with it own bomb was terrifying, to say the least. Clearly, some sorts of controls over nuclear energy were optimal and necessary. In the immediate aftermath of the war, the United States sought with mixed success to implement regimes for controlling and regulating the atom at both the domestic and international levels.[9]

On the domestic front, Truman called for the establishment of an Atomic Energy Commission to take over the Manhattan Project’s material resources and “to control all sources of atomic energy and all activities connected with its development.” Following often bitter debate over civilian–versus–military control, Congress passed legislation creating the new agency, and Truman signed it into law on August 1, 1946. The Atomic Energy Act of 1946 transferred authority from the Army to the new Atomic Energy Commission (AEC) composed of a five–member civilian board serving full–time. Oppenheimer headed up the General Advisory Committee to assist the Commission on scientific and technical issues. The Military Liaison Committee was organized to assure input by defense officials. The act also created the Joint Committee on Atomic Energy within Congress to exercise control over nuclear affairs. As inheritors of the Manhattan Engineer District’s far–flung scientific and industrial complex, the Atomic Energy Commission continued the government monopoly in the field of atomic research and development.[10]

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

The impasse over international control of the atom was part of the onset of a new global struggle, this time with the Soviet Union. The breathing space between two wars—the Second World War and the Cold War—was very brief. Already in March 1946, Winston Churchill warned of an “iron curtain” that had descended on Eastern Europe as the Soviet Union sought to expand its influence. A year later, President Truman proclaimed the Truman Doctrine and asked for funds for overseas military assistance. On the issue of control of nuclear weapons, the United States, believing that Soviet troops posed a threat to Western Europe and recognizing that American conventional forces had rapidly demobilized, refused to surrender its atomic deterrent without adequate controls. In an atmosphere of mutual suspicion, the Cold War set in.[11]

Nuclear Weapons Testing: Crossroads

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

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

Baker proved much more impressive. Detonated ninety feet underwater on the morning of July 25, Baker produced a spectacular display as it wreaked havoc on a seventy–four–vessel fleet of empty ships and spewed thousands of tons of water into the air. As with Able, the test yielded explosions equivalent to 21,000 tons of TNT. Baker, as one historian notes, “helped restore respect for the power of the bomb.”

Baker also created a major radiation problem. The test produced a radioactive mist that deposited active products on the target fleet in amounts far greater than had been predicted. As the Joint Chiefs of Staff evaluation board later noted, the contaminated ships “became radioactive stoves, and would have burned all living things aboard them with invisible and painless but deadly radiation.” Decontamination presented a significant radiation hazard, and, as a result, over a period of several weeks personnel exposure levels began to climb. A worried Stafford Warren, who headed the testing task force’s radiological safety section, concluded that the task force faced “great risks of harm to personnel engaged in decontamination and survey work unless such work ceases within the very near future.” With exposure data in hand, Warren prevailed and decontamination operations ceased. A planned third shot, to be detonated on the bottom of the lagoon, was canceled.[12]

Legacy

The legacy of the Manhattan Project is immense. The advent of nuclear weapons not only helped bring an end to the Second World War but ushered in the atomic age and determined how the next war, the Cold War, would be fought. In addition, the Manhattan Project became the organizational model behind the remarkable achievements of American "big science" during the second half of the twentieth century.

Endnotes

[1] This overview of early nuclear physics is necessarily brief and simplistic. A fuller treatment of these discoveries and their implications can be found in F.G. Gosling, *The Manhattan Project: Making the Atomic Bomb*, DOE/MA–0001 (Washington: DOE, January 1999 edition), and Richard G. Hewlett and Oscar E. Anderson, Jr., *The New World, 1939–1946*, Volume I, *A History of the United States Atomic Energy Commission* (University Park, PA: Pennsylvania State University Press, 1962).

[2] The Einstein letter is reprinted in Vincent C. Jones, *Manhattan: The Army and the Atomic Bomb* (Washington: GPO, 1985), pp. 609–10.

[3] Gosling, *The Manhattan Project*, pp. 1–17.

[4] *Ibid*., pp. 5–43.

[5] *Ibid*., pp. 38–43; Hewlett and Anderson, *New World*, pp. 234–35, 244–52.

[6] Leslie R. Groves to Henry L. Stimson, July 18, 1945; Barton C. Hacker, *The Dragon's Tail: Radiation Safety in the Manhattan Project, 1942–1946* (Berkeley: University of California Press, 1987), pp. 75–78, 84–86, 89–93.

[7] Hacker, *The Dragon's Tail*, pp. 75–78, 84–86, 89–93 98–108; Gosling, *The Manhattan Project*, pp. 48–49.

[8] Gosling, *The Manhattan Project*, pp. 51–54.

[9] "Special Message to the Congress on Atomic Energy," October 3, 1945, *Public Papers of the Presidents of the United States, Harry S. Truman, 1945* (Washington: GPO, 1961), pp. 362–65.

[10] *Ibid*.; Gosling, *The Manhattan Project*, p. 57; Hewlett and Anderson, *New World*, pp. 482-530.

[11] Gosling, *The Manhattan Project*, pp. 55–57; Hewlett and Anderson, *New World*, pp. 531-79, 582-619.

[12] Hacker, *The Dragon's Tail*, pp. 116–53; Gosling, *The Manhattan Project*, p. 55; Hewlett and Anderson, *New World*, pp. 580–81.