Additional Historical Context

World War II officially began on September 1, 1939 in Europe when Nazi Germany invaded Poland. Soon countries from around the world were fighting the largest war the world has ever seen. There were two main groups of countries that fought in World War II: the Allied Powers and the Axis Powers. The United States joined the Allied Powers after Pearl Harbor, Hawaii was attacked by Imperial Japan on December 7, 1941. These two groups were fighting the war on two main fronts referred to as the Pacific Theater and the European Theater.

World War II in Europe ended when Germany surrendered to the Allies on May 2, 1945, but Germany's Axis ally Imperial Japan did not surrender, and war continued in the Pacific Theater. President Harry S. Truman gave the order to drop the Little Boy atomic bomb over Hiroshima, Japan, on August 6, 1945 and then demanded the unconditional surrender of Japan. Japan answered with only silence, refusing to surrender. Three days later, on August 9, 1945, the U.S. dropped a second atomic bomb, Fat Man, over Nagasaki, Japan. On September 2, 1945, Emperor Hirohito and the Japanese government officially surrendered to the Allies, ending World War II.

Learn more:

Overview of the Manhattan Project

Los Alamos, NM and the Manhattan Project

Oak Ridge, TN and the Manhattan Project

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Early Science at Chicago, Illinois

Begun by the need to determine whether a nuclear chain reaction could be created and controlled, Manhattan Project administrators selected the University of Chicago as the site of the Metallurgical Laboratory (Met Lab), a code-named facility that would bring together dozens of top scientists to research whether a controlled nuclear reaction, a key step in atomic bomb creation, could be achieved.

Led by Arthur Compton, the Met Lab assembled a team of scientists that included Enrico Fermi, Leo Szilard, Eugene Wigner, and Leona Woods Marshall Libby, the youngest member and only female member of the team. On a squash court underneath the university's unused Stagg Field football stands, the scientists and workers built a 20-foot-tall (6 meter) stack of graphite and uranium blocks over a two-week period, creating space for control rods and purifying the graphite and uranium.

Unlike other nuclear reactors that would come later, the Met Lab's experiment had no safety features- no shielding from radiation and no way to cool the reactor. Fermi assured Compton that the likelihood of a catastrophic failure (on the campus of one of the country's most populous cities no less) was slim, but the outcome was never certain.

On December 2, 1942 at 3:53 pm CST, with the control rods carefully removed, their creation, dubbed the Chicago Pile (CP-1), reached criticality. It was the first time in history that a self-sustaining nuclear reaction had been achieved. The scientists celebrated with a bottle of Chianti, as a vital step toward the nuclear age had proved successful.

The outcome of CP-1's success led to the construction a few months later of Oak Ridge's X-10 Graphite Reactor, the world's first full-scale experimental reactor that served as the basis for the massive plutonium-producing reactors at Hanford. Though CP-1 was disassembled shortly after the experiment, the site of its construction was dedicated a National Historic Landmark in 1967.

Learn more about Chicago, IL and the Manhattan Project.

Overview of Manhattan Project Science at Hanford

The Manhattan Project, America's wartime effort to build an atomic bomb, was so promising, yet so unlikely to succeed, that two independent paths were pursued, in the hopes that at least one of them would produce a war-changing bomb.

One of those methods was based on using enriched uranium to fuel the bomb. The uranium enrichment was done at the Clinton Engineer Works in Oak Ridge, Tennessee. The second method involved producing large quantities of the recently discovered element plutonium. Unlike uranium, plutonium was almost nonexistent in nature, but it could be created in nuclear reactors. And that job would be done at the Hanford Engineer Works in southeastern Washington state.

The manufacturing process at Hanford was developed from what Enrico Fermi and his team proved when they constructed the world's first, albeit small-scale, nuclear reactor in Chicago in 1942. If a reactor could be built sufficiently large, the intense flow of neutrons within it could, almost magically, change uranium into plutonium. This process of transmutation would not be creating gold from straw or lead but would be creating something much more valuable.

To that end, the Army Corps of Engineers commandeered roughly 600 square miles (1553 sq km) of land, including the towns of Hanford, White Bluffs, and Richland, in Washington state. The vast, remote site was bordered by the Columbia River, a critical resource needed for cooling the nuclear reactors.

First, tons of uranium would be formed into 8.7-inch rods (22 cm), about 1.5 inches (3.81 cm) in diameter. Each was then clad in aluminum in a process known as canning. The result was commonly referred to as a fuel slug, tens of thousands of which would be made for the next step of the process.

The next step was to irradiate the fuel slugs in a nuclear reactor. The B Reactor was the first of three plutonium production nuclear reactors built at Hanford during World War II. At the core of each reactor was a huge matrix of graphite blocks, measuring 36 feet (10.97 m) by 36 feet (10.97 m) by 28 feet (8.53 m) front to back, and enclosed in 5 feet (1.52 m) of heavy shielding. From front to back ran 2004, 1.7-inch (51.81 cm) aluminum process tubes, into which were loaded more than 60,000 uranium fuel slugs. Cooling water from the Columbia River would flow in the narrow space between the fuel slugs and the process tubes. Enrico Fermi supervised the first loading of uranium slugs into the B Reactor on September 18, 1944. The B Reactor achieved criticality on September 26, 1944. A reactor achieves criticality (and is said to be critical) when each fission event releases a sufficient number of neutrons to sustain an ongoing series of reactions.

The graphite blocks in the core of a nuclear reactor slow down the fast neutrons released during the fission of uranium 235 (U-235). The fission process generates neutrons that initiate fission in other U-235 atoms in a continual process of splitting U-235 atoms and releasing more neutrons. Soon, there are enough slowed neutrons to create a controlled sustained nuclear chain reaction. Some of the free neutrons are absorbed by uranium 238 (U-238) atoms becoming uranium 239 (U-239). The U-239 atoms then transmute (change into) into neptunium 239 (Np-239). Np-239 transmutes into plutonium 239 (Pu-239), the product of interest.

Every four to six weeks of operation, workers pushed about 10-20 percent of the now highly radioactive fuel slugs out of the back of the reactor and into the water-filled fuel storage basin where they would thermally and radiologically cool off for approximately two to three months. After the cooling off period, the still highly radioactive fuel slugs were loaded into shielded, water-filled casks on train cars. They were then transported to the T Plant where multiple chemical processes would separate the plutonium from the uranium and other radioactive byproducts produced during irradiation. Dissolving the aluminum jacket around the fuel slugs and separating plutonium from the uranium and other radionuclides produced during irradiation required more than a dozen steps in the chemical separations process. Approximately 4000 pounds (1814.36 kg) of uranium were needed to produce 1 pound (0.45 kg) of plutonium. That is like reducing the weight of an elephant at 12,000 pounds (5443.10 km) down to the weight of a kitten at 3 pounds (1.36 kg).

Once the plutonium was extracted, the chemically separated uranium, unwanted radionuclides, and chemicals used in the process became liquid waste and were put into underground waste storage tanks at Hanford. The work during World War II focused on refining the process for chemically separating plutonium from uranium for the war effort. Addressing the chemical waste was put off until after the war. The mix of metals, chemicals, and radioactivity in the nuclear and chemical waste at Hanford lead to a serious and very expensive clean-up process still being dealt with today—more than seven decades later.

The plutonium was carefully and secretly shipped to the Manhattan Project site at Los Alamos, New Mexico in multiple shipments. There, scientists, engineers, and craft workers designed and built a device, known as the Gadget, to test an implosion-design plutonium-fueled atomic bomb. The Gadget used Hanford's plutonium and was successfully detonated during Trinity test in New Mexico on July 16, 1945. The Trinity test was the first human-caused nuclear explosion in history and ushered in the nuclear age. A few weeks later on August 6, the Little Boy atomic bomb, fueled by enriched uranium from Oak Ridge, was detonated over Hiroshima, Japan, the first atomic weapon used in war. And then on August 9, 1945 the US dropped the Hanford plutonium-fueled Fat Man bomb over Nagasaki, Japan. This was the second atomic bomb used on a human population and, so far, the last.

Learn more about the B Reactor and the Science at Hanford.

Pioneers of the Science Leading to the Manhattan Project

Albert Einstein

For decades, the name "Einstein" has been connected with genius and science. Albert Einstein (1879-1955) is best known for his work with relativity and quantum mechanics, but he was not involved in the Manhattan Project, except at the very beginning.

Einstein was born in Germany in 1879, moved to Switzerland in 1897, and to the United States in 1933. Although there is a familiar story that he had difficulty in school, he was a good student. Even as a child, Einstein excelled at math and physics. In his early teens he taught himself algebra, calculus, and Euclidean geometry. He received his PhD from the University of Zurich in 1905. In 1922 he received a Nobel Prize for Physics, for "his services to theoretical physics, and especially for his discovery of the law of the photoelectric effect." That discovery was essential to the development of quantum theory. The year 1905 is known as Einstein's "annus mirabilis," his miracle year, because he published four groundbreaking papers for which he is still known: his theory of photoelectric effect, explanation of Brownian motion, introduction to his special theory of relativity, and his theory of mass and energy equivalency that is expressed as e=mc2, widely considered the most famous formula in the world. In 1933 Einstein moved to the United States to escape Nazi Germany. His house was seized, and his name was on a list of "not yet hanged." Einstein was welcomed into the Institute for Advanced Study in New Jersey.

In 1939 his friend Leo Szilard and two other physicists, Edward Teller and Eugene Wigner, asked him to sign a letter to President Roosevelt alerting Roosevelt to the likelihood of a German atomic weapons program and urging the United States to begin a uranium research program. Einstein agreed to sign the letter even though he supported pacifism but opposed the Nazis getting ahead in the effort to build atomic weapons. Einstein became a naturalized American citizen in 1940, but the US Army Intelligence Office denied him a security clearance. He supported the Allies but not the use of atomic weapons. Einstein was not a part of the Manhattan Project, and he was never in Los Alamos during the project.

Learn more about [Albert Einstein].

Marie Curie

Born Marie Sklodowska in Warsaw in 1867 (then part of the Russian Empire), as a woman she was denied an education under Russian control. To pursue a scientific education, Curie traveled to France, enrolling at the University of Paris in 1891. It was there that she met her husband and research partner Pierre Curie.

Knowing that uranium emitted radiation, Curie researched other elements to see if they produced the same. Soon she learned the element thorium also produced radiation, leading her to deduce that radiation emitted directly from atoms, not from how they are arranged within molecules. In 1898 Curie and her husband discovered two new elements, radium and polonium. In 1903 the couple received the Nobel Prize in Physics for their groundbreaking research on radioactivity. Pierre Curie died after being hit by a horse-drawn cart in Paris in 1906. In 1911 Marie won the Nobel Prize in Chemistry for the discovery of radium and polonium and the isolation of pure radium.

During World War I, Marie Curie directed the Red Cross Radiology Service, providing x-rays for approximately 1 million soldiers. After the war she traveled to the United States to raise funds for more radium research, opening the Radium Insitute in Poland in 1932. With the harmful effects of radiation not being fully understood during her years of research, Marie Curie died of radiation-induced leukemia in 1934. Both she and her husband are buried in a lead-lined tomb because of their radioactive corpses; her laboratory equipment and even her papers and cookbooks remain too radioactive to be handled safely.

Learn more about [Marie Curie].

Notable Manhattan Project Scientists

Lise Meitner

Born in Vienna in 1878, Lise Meitner enrolled at the University of Vienna in 1901 and became only the second woman to earn a PhD in Physics from there in 1905. After receiving her PhD, Meitner moved to Berlin, Germany to work with physicist Max Planck and chemist Otto Hahn. Meitner and Hahn would work together for over 30 years; in 1918 they co-discovered the element protactinium.

In 1922, Meitner became the first female full professor of physics at the University of Berlin. In 1926, Meitner began her research on nuclear fission. In 1938, with Nazi Germany seizing power, Meitner fled Berlin, first to the Netherlands and then Stockholm, Sweden. That same year, Otto Hahn and Fritz Strassmann developed evidence of nuclear fission, but it was Meitner and her nephew, physicist Otto Frisch, who theorized that the process resulted from the uranium nucleus splitting in two. Meitner and Frisch were the first to call the process “fission”, and in 1939 they published a scientific paper explaining the process.

In 1942, Meitner was invited to work on the Manhattan Project but adamantly refused, stating "I will have nothing to do with a bomb!" After the war, Meitner continued to avoid any connection to her research and the atomic bomb.

In 1944, the Nobel Prize in Chemistry was awarded to Otto Hahn for his work on nuclear fission; Meitner and Frisch's contributions were not recognized. After the war, Meitner continued living and working in Sweden, traveling throughout the United States to give lectures. Recognition for her scientific contributions included the Max Planck Medal in 1949 and the Enrico Fermi Award alongside Hahn and Strassmann in 1966. Lise Meitner died in England in 1968.

Learn more about Lise Meitner.

Enrico Fermi

Born in Rome, Italy in 1901, Fermi received his PhD in Physics from the University of Pisa in 1922. In 1927, he became Professor of Theoretical Physics at the University of Rome. It was here in 1934 that Fermi and his colleagues split uranium without fully realizing it, researched nuclear transformation, and discovered slow neutrons, which aided in the discovery of nuclear fission. For these efforts, Fermi won the Nobel Prize in Physics in 1938. That same year, to escape fascist Italy under Benito Mussolini, Fermi and his family left for the United States.

In 1942, Fermi developed the Chicago Pile (CP-1) at the University of Chicago. An experimental nuclear reactor, CP-1 went critical on December 2, 1942. After this breakthrough, Fermi was recruited by J. Robert Oppenheimer to be associate director at Los Alamos. Fermi was the first person to insert a uranium slug into the B Reactor at Hanford. He was present when the X-10 Graphite Reactor went critical at Oak Ridge and witnessed the Trinity test in the New Mexico desert.

After the war, Fermi became a professor at the University of Chicago, dying of stomach cancer in 1954.

Learn more about Enrico Fermi.

Leona Woods Marshall Libby

Born Leona Harriett Woods (later Leona Woods Marshall and Leona Woods Marshall Libby by marriages) on August 9, 1919 in La Grange, IL, she was the youngest person and only female member of the scientists that developed the Chicago Pile (CP-1), the world's first nuclear reactor at the University of Chicago in 1942. Prior to her work in Chicago, Woods graduated with a BS in Chemistry from the University of Chicago in 1938 at just 18 years of age. She continued to work on her PhD dissertation alongside her work on CP-1, receiving her PhD in 1943.

After the CP-1 team relocated to Argonne National Laboratory outside Chicago, Woods traveled to Hanford, WA in 1944 to oversee development of the plutonium reactors which would ultimately provide fuel to Fat Man, the atomic bomb dropped on Nagasaki, Japan on August 9, 1945. Woods was present at Hanford's B Reactor in 1944 when it shut down from xenon poisoning and worked with other personnel to restart and maintain the reactor.

After the war, Woods worked at Princeton University alongside J. Robert Oppenheimer, taught at New York University and the University of Colorado, worked for the RAND corporation, and helped create UCLA's Department of Environmental Science and Engineering. Woods died of a stroke in Santa Monica, CA on November 10, 1986.

Learn more about Leona Woods Marshall Libby.

Edwin Mattison McMillan

Born in California in 1907, Edwin McMillan received his undergraduate degree from Caltech in 1928 and his PhD in chemistry from Princeton University in 1932. In 1940, McMillan and colleague Phillip Abelson produced element 93 which they named neptunium. Produced by bombarding uranium 235 with neutrons, neptunium was the first artificially-created transuranium element. In 1941, chemist Glenn Seaborg, along with McMillan and several others, produced element 94 which Seaborg named plutonium, following McMillan naming element 93 after a planet.

In 1942, McMillan moved to Los Alamos to research implosion methods for the Manhattan Project, living on the famous "Bathtub Row" during his tenure. After the war, McMillan won the Nobel Prize in Chemistry in 1951 for his work on transuranium elements, became a member of the General Advisory Committee to the Atomic Energy Commission, and served as director of the Lawrence Radiation Laboratory from 1958 to 1973. Edwin McMillan died in California in 1991.

Learn more about Edwin Mattison McMillan.

Glenn Theodore Seaborg

Born in Michigan in 1912, Glenn Seaborg received his BA in chemistry from UCLA in 1933 and his PhD in chemistry from the University of California, Berkeley in 1937. In 1941, Seaborg and colleague Edwin McMillan bombarded uranium with deuterons, producing a new element, plutonium 239. Later that same year, Seaborg and colleagues demonstrated that plutonium was fissile, greatly influencing the Manhattan Project's atomic bomb development. Seaborg's contributions ultimately led to the fuel for Fat Man, the atomic bomb dropped on Nagasaki, Japan on August 9, 1945.

In 1942, Seaborg joined the staff at the University of Chicago's Metallurgical Laboratory, refining how to extract plutonium from uranium. His research at the Met Lab influenced the construction of the X-10 Graphite Reactor in Oak Ridge in 1943 and the plutonium production facilities at Hanford in 1944.

After the war, Seaborg received the Nobel Prize in Chemistry in 1951, became associate director of the Lawrence Radiation Laboratory, Chancellor of the University of California, Berkeley, and Chair of the US Atomic Energy Commission. During his career, Seaborg was responsible or partly responsible for the discovery of ten elements. Glenn Seaborg died in California in 1999.

Learn more about Glenn Theodore Seaborg.

Ernest Orlando Lawrence

Born in Canton, SD in 1901, Ernest Lawrence received his PhD in physics from Yale University in 1925. In 1929 at the University of California- Berkeley, Lawrence invented what would become one of the most important contributions to the success of the Manhattan Project, the cyclotron. The cyclotron accelerated nuclear particles to a high velocity without using high voltage; these particles bombarded atoms of several different elements, often forming new elements. In 1939, Lawrence was awarded the Nobel Prize in Physics for his invention.

From 1943 to 1946, Lawrence developed and supervised the electromagnetic separation process at Berkeley and at Oak Ridge's Y-12 Electromagnetic Separation Plant. Cyclotrons (now called calutrons as a combination of California University and cyclotron) were used at Y-12 to separate lighter uranium 235 from heavier uranium 238. This separated uranium was used as fuel for Little Boy, the atomic bomb dropped on Hiroshima in August 1945.

Lawrence was influential in the selection of J. Robert Oppenheimer to lead the Los Alamos laboratory and witnessed the Trinity test firsthand on July 16, 1945. After the war, Lawrence resumed his research and instruction at Berkeley and joined the Atomic Energy Commission, the civilian-controlled agency that superseded the Manhattan Project in 1947. Lawrence spent the majority of his post-war career advocating for "Big Science." Ernest Lawrence died in Palo Alto, CA in 1958.

Learn more about Ernest Orlando Lawrence.

Robert Oppenheimer

Robert Oppenheimer began collaborating with Ernest Lawrence in early 1941 on questions of atomic bomb development. Lawrence used his Cyclotron particle accelerator to develop a method of uranium isotope separation for bomb making, and brought Oppenheimer into a secret meeting about the atomic bomb in October 1941.

In the spring of 1941, the Roosevelt Administration received a British report on atomic bombs, prompting them to create the S-1 Committee of military and academic personnel to focus on an atomic bomb building project. Robert Oppenheimer was made S-1's "Coordinator of Rapid Rupture" to direct fast-neutron research. Oppenheimer organized a secret seminar of theoretical physicists to make the basic outline for atomic bomb design. Participant Hans Bethe said, "I could see the tremendous intellectual power of Oppenheimer who was the unquestioned leader of the group."

By the fall of 1942, S-1 Committee members Vanevar Bush and James Conant wanted Oppenheimer to direct an atomic bomb laboratory. Bush and Conant pressured the War Department to approve security clearances for Oppenheimer and other scientists with left wing political views. On September 18, 1942, General Leslie Groves took charge of S-1's work and the Manhattan Engineer District, later known as the Manhattan Project, was established. With Groves' support, Oppenheimer was appointed as the Director of the Los Alamos Laboratory at a secret atomic bomb-making laboratory.

Learn more about Robert Oppenheimer.