LECTURE NOTES
1999-2001 Sigma Xi Distinguished Lecture

THE RACE TO BUILD THE ATOMIC BOMB

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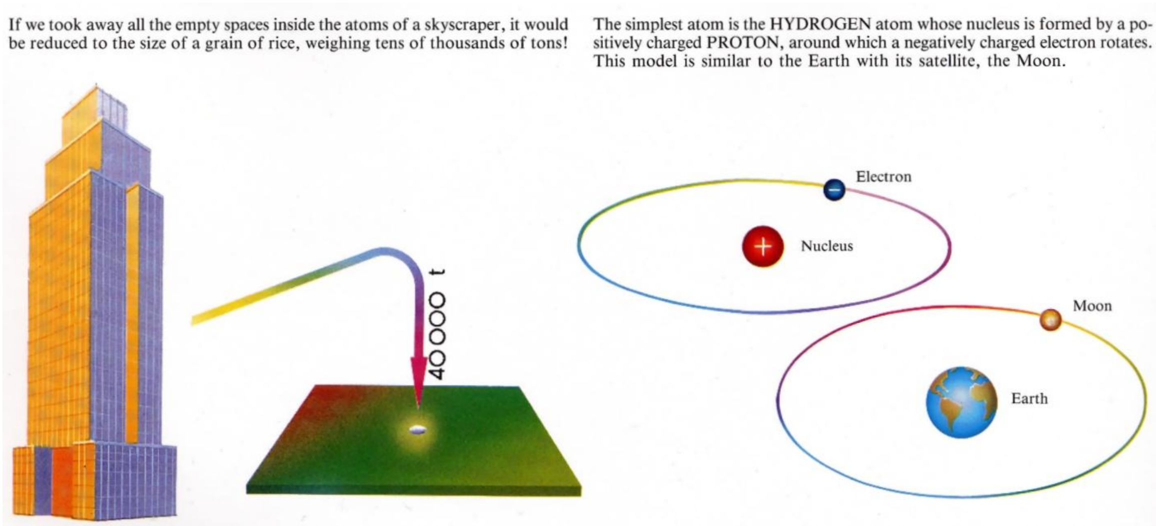
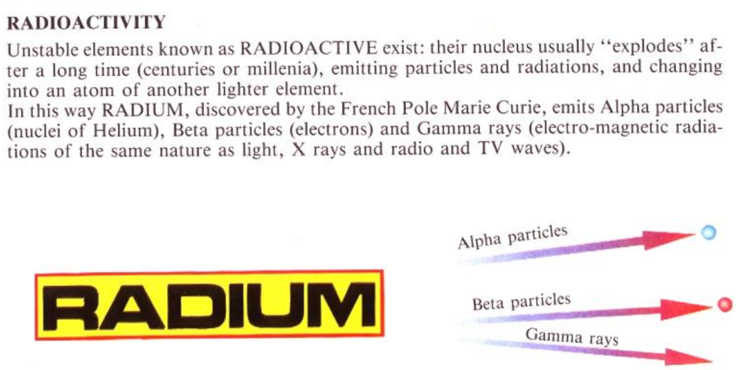
Unraveling the Mysteries of Atomic Structure and Radioactivity



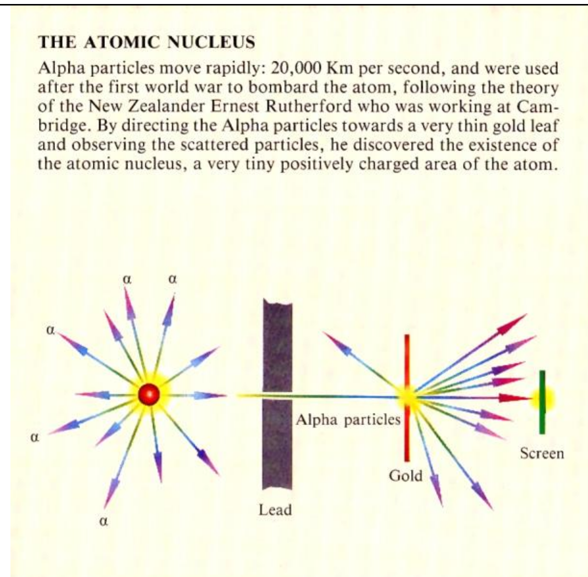
The scale of atomic structure made it one of the last mysteries of science to be unraveled, during the first half of the 20th Century.

1905 - **Marie Sklodowska Curie** (1867-1934), her husband **Pierre Curie** (1859-1906), and **Henri Becquerel** received the Nobel Prize for physics for their work on radioactivity, and Marie was granted her doctorate the same year. After Pierre was killed while crossing a street in 1906, Marie continued with her work, and the couple received a second Nobel Prize in 1911 for discovering two radioactive elements, radium and polonium.



1906 – While working at the Cavindish laboratory at Cambridge University, New Zealander **Ernest Rutherford** discovers that alpha particles were deflected on passing through atoms, by measuring the deflection in a magnetic field and allowing the particles to impact photographic film. He receives the 1908 Nobel Prize in Chemistry for this discovery.

Ernest Rutherford (1871-1937)



<u>The Fission Dream</u>

1907 - While working at the Swiss Patent Office in Bern, **Albert Einstein** publishes three articles in the German publication *Annals of Physics.* These include 1) The quantum theory to explain the photoelectric effect; 2) The relation of mass to energy; and 3) A special theory of relativity. A fourth article on *Brownian Motion* confirmed the atomic theory of matter. He demonstrates theoretically that mass and energy are different aspects of the same thing. **Einstein's** radical new theory suggests that if a nucleus were to be broken, the mass of the two parts would be less than the original sum, the difference being accounted for in the release of energy. If the atomic nucleus could be broken apart, an enormous amount of theoretical energy would be released.

Albert Einstein (1879-1955)

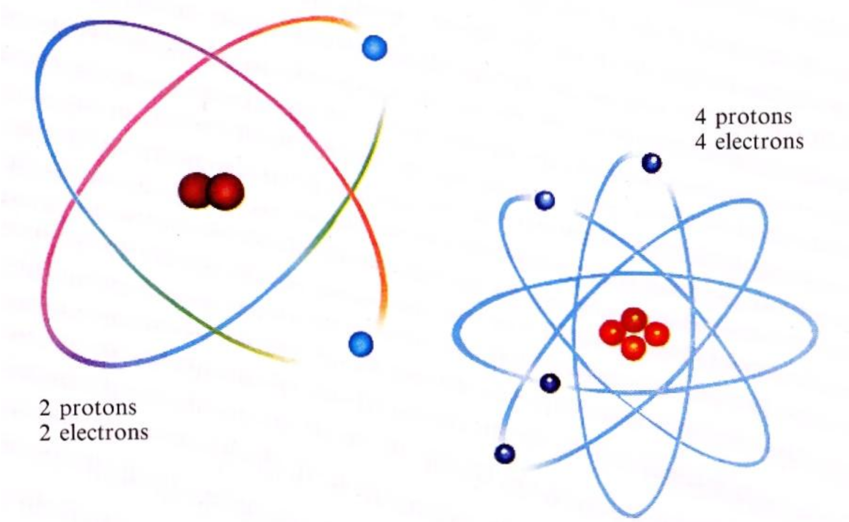
Nils Bohr (1885-1962)

J. Robert Oppenheimer(1904-67)

1920s – **Einstein** is awarded the Nobel prize in Physics in 1921, **Nils Bohr** of Denmark receives it in 1922. Experimental and theoretical physics is explored by many scientists working a major centers of learning in Europe and America. One of the most famous schools is the *University of Gottingen* in Germany, who graduates a young American Ph.D. named **J. Robert Oppenheimer** in **1927**.

FROM 1 TO 92 ELECTRONS

The other atoms, with a greater mass, have a nucleus which is also positively charged and made up of 2, 3, 4, ... protons, surrounded by 2, 3, 4 ... negative electrons, so that each atom is electrically neutral.



Atomic numbers refer to the mass of atoms, which increase with the number of positively charged protons and neutrally charged neutrons in their respective nuclei, as sketched here.

THE MASS-ENERGY EQUIVALENCE: EINSTEIN'S EQUATION

According to the Theory of Relativity of the German Albert Einstein, drawn up in 1905, if the mass m in a system disappears, then energy E is created, and vice versa, energy E may ''create'' the mass m according to the equation:

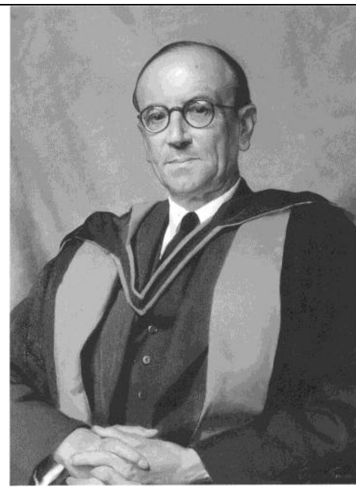
$$\boxed{E = m c^2}$$

where c is the speed of light (and c^2 is the speed of light squared). Since c is very large (300 million metres per second) it follows that a small quantity of material may produce a large quantity of energy. For example, from the complete destruction (annihilation) of a gramme of material of any substance, the energy obtained is:

$$E = 10^{-3}\,(3 \cdot 10^{8})^{2} \text{ joule} = 9 \cdot 10^{13} \text{ joule}$$

enough to light about thousand billion 100 Watt electric light bulbs for a second!

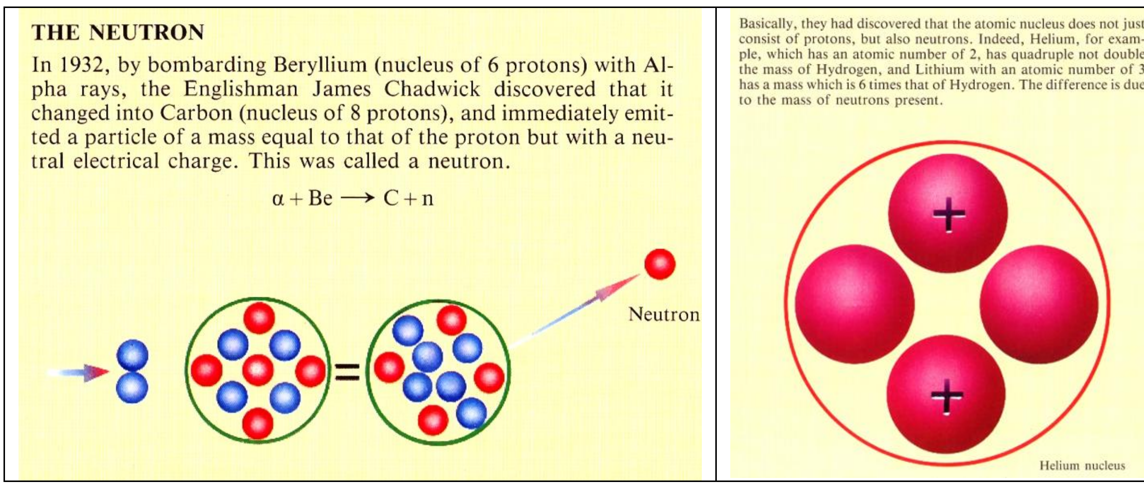
Einstein's famous mass-energy equivalence equation was originally conceived in 1905, 40 years before the first atomic device was detonated near White Sands, New Mexico.



Harold Urey (1893-1981) ***James Chadwick (1891-1974)*** ***Irene and Frederick Joliot-Curie***

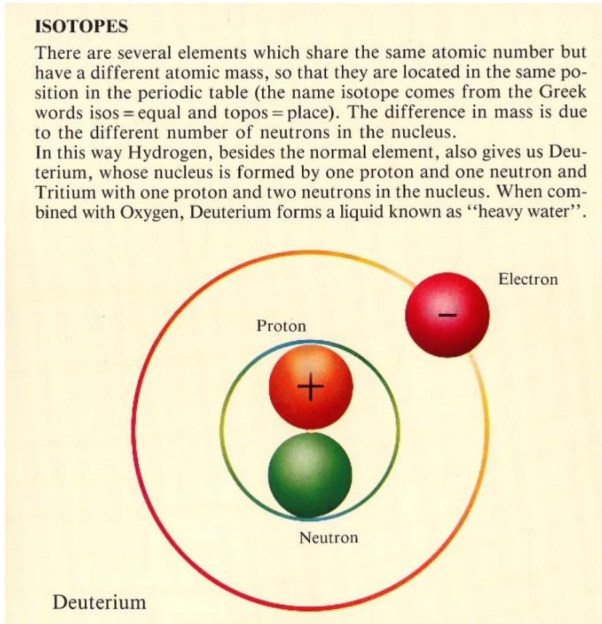
1932 – Harold Urey of *Columbia University* discovers the hydrogen isotope Tritium, leading to the recognition of "heavy water". He is awarded the **Nobel Prize** for this discovery in **1934**. Deuterium has twice as many hydrogen atoms as ordinary water, and weighs about 10% more than normal water. **Gilbert Newton Lewis** (1875-1946) at *U.C. Berkeley* isolated the first sample of pure heavy water in 1933.

1932 – The neutron is discovered by English scientist **James Chadwick**, working in the *Cavendish Laboratory* at *Cambridge* (and awarded a **Nobel Prize** in **1935**). Neutrons were electrically uncharged particles which could be used a "missiles" to split an atom without being deflected.



Chadwick's discovery of the neutron in 1932 was of monumental significance in helping to unravel atomic structure.

1934 – The Norwegian government (Norsk Hydro) builds a giant hydroelectric facility at Vemork, about 60 miles west of *Oslo*, along the coast. This plant uses electrolysis to produce ammonium nitrate fertilizer, producing deuterium oxide as an unintended byproduct of the electrolysis (deuterium cannot be split up into hydrogen and oxygen components like normal H_2O via electrolysis). Ordinary water contains 1 out of 6,760 hydrogen atoms that is deuterium, so vast quantities of water must be passed through an electrolysis process to collect minute quantities of deuterium (Deuterium has an atomic number of 20 versus 16 for ordinary water). Vemork becomes the only facility in the world routinely producing deuterium oxide, or heavy water.



Harold Urey's discovery of the hydrogen isotope deuterium oxide D_2O was given the name "heavy water" when separated from regular H_2O. Only one in 6760 H_2O atoms is D_2O, so enormous quantities of water were necessary to extract minute volumes of heavy water.

May 1935 – French physicist **Frederic Joliot-Curie** and his wife **Irene** (daughter of **Pierre** and **Marie Curie**) are awarded the **1935 Nobel Prize** in Chemistry for their discovery of artificial radioactivity.

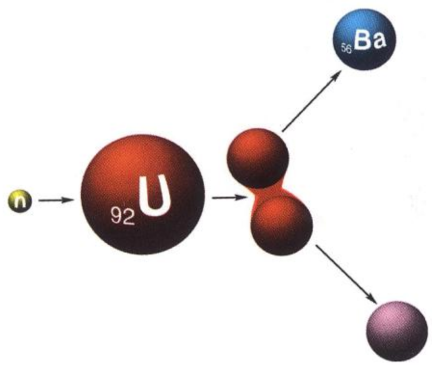
1936 – Enrico Fermi awarded the **Nobel Prize** for splitting a uranium atom in 1934 by bombarding it with neutrons

Left: Enrico Fermi (1901-54); Middle: Leo Szilard (1898-1964); Right: Lise Meitner (1878-1968) and Otto Hahn (1879-1968)

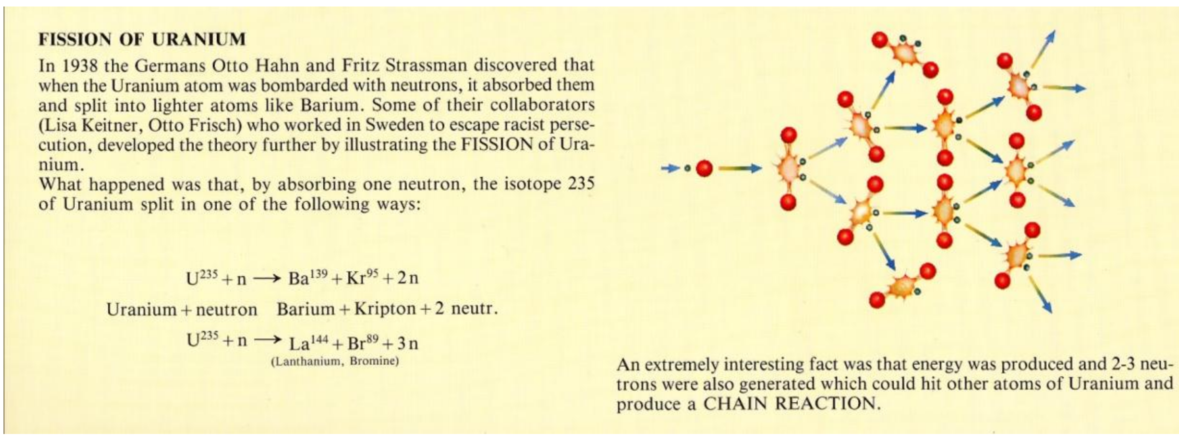
1938 – Hungarian physicist **Leo Szilard** arrives in the United States, joining **Enrico Fermi and Herbert Anderson** at *Columbia University* on a reactor project using heavy water as a neutron moderator.

Late 1938 – German physicists **Otto Hahn**, **Lise Meitner** and **Frederich Strassman** discover fission during experiments. Sometime later, **Hahn's** former assistant **Lisa Meitner** and her nephew **Otto Frisch**

proved that the nucleus of a uranium atom that absorbs a neutron will split into two nearly equal parts. A chain reaction was, therefore, possible.



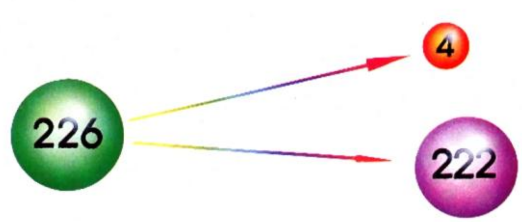
In 1938 German scientists Otto Hahn and Fritz Strassman excited the scientific world by reporting the formation of Barium, Kripton and two neutrons by bombarding the heavier U235 with neutrons.



The discovery by Hahn and Strassman conformed Einstein's theory that energy would be released when the atomic nucleus gave up neutrons, which could ht other atoms of uranium and give rise to a chain reaction. The chain reaction made production of an enormous energy-releasing bomb theoretically possible, as sketched here. .

March 1939 – **Frederic Joliot-Curie** and his assistants publish an article in the scientific journal *Nature* titled "*Liberation of Neutrons in the Nuclear Explosion of Uranium*". They state that when neutrons split a uranium atom, the reaction causes new neutrons to spew out of the atom at high speed. The authors assert that they intend to achieve such a sustained reaction in the near future by producing one neutron for each fission. **Szilard** and **Fermi** made the same discovery at about the same time at *Columbia*, but do not publish it, out of fear that their German colleagues will pursue similar avenues of research.

On **April 22, 1939 Joliot** publishes a second article in *Nature* stating that "on average, about 3.5 neutrons were emitted by a uranium nucleus during fission.



When its Alpha particle is emitted, the Radium atom falls from the atomic mass of 226 to a mass of 222 and becomes the gas Radon.

Niels Bohr of Denmark, **Yakov Frenkel** of the Soviet Union and **John Wheeler** of the USA had all published papers describing the process of fission before World War II commences, on **September 1, 1939**, when Germany and the Soviet Union jointly invade Poland.

Hastened by recent German aggression, **Leo Szilard** drafts a letter for **Albert Einstein** to send to **President Roosevelt** on **October 11, 1939**, outlining the possibility of setting up nuclear chain reactions from uranium, through which enormous volumes of energy could be released, possibly as a gigantic bomb. Although **Roosevelt** agrees to support investigative work at *Columbia University***,** a coherent plan of nationally-funded research does not arise for another two years. At the end of **1939** there was only one ounce of ordinary metallic uranium in the entire United States.

Albert Einstein and Leo Szilard reenact their historic October 1939 meeting at Princeton in late 1945, after the secret Manhattan Project became public.

In **January 1940** the Germans convened a governmental conference on heavy water in Berlin. **Paul Harteck** and **Han Suess** of the *University of Hamburg* felt that deuterium could be an effective moderator for a nuclear reactor, thereby facilitating a chain reaction. **Harteck** warned that the uranium fuel and the deuterium moderator should not be mixed in the reactor but should be separated in alternate layers to prevent an explosion. German officials were dubious about the production of deuterium because one hundred thousand tons of coal would have to be burned to supply the electrical power to produce one ton of heavy water.

May 1940 – Edwin McMillan and **Philip Abelson** produce the first man-made element (#93), Neptunium, by bombarding uranium at the *University of California, Berkeley*.

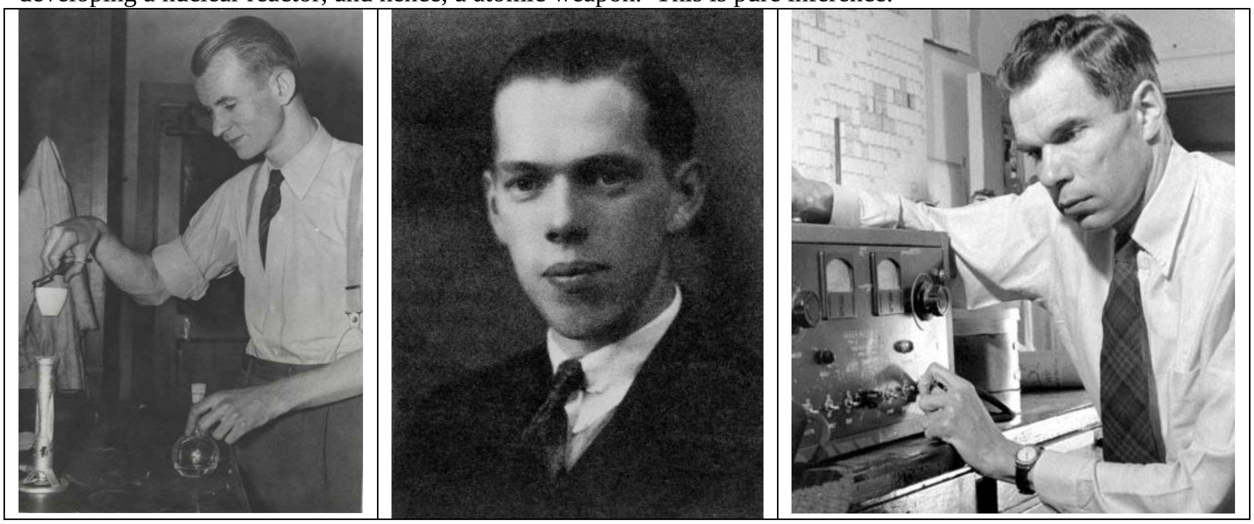
June 1940 – **President Roosevelt** forms a committee of executives, engineers, scientists and economists to provide advice on technical defense related projects. This became the **Office of Scientific Research and Development (OSRD)**, headed by **Vannevar Bush** and his deputy, *Harvard University* President **James B. Conant**.

Summer 1940 – Word reaches the west that the Germans have recovered 3,500 tons of uranium ore from Union Miniere in Belgium, which had been mined at Katanga, in the Belgian Congo. After April 1940 the Germans now had control of the greatest stockpiles of raw uranium and heavy water (at Vemork, Norway). In addition, the Germans also controlled uranium deposits in Czechoslovakia.

Late 1939 through **August 1940** - **Edgar Sengier**, director of the Belgian uranium mine at Katanga, heard about uranium's military potential in 1939. He has the foresight to quietly ship 1,200 tons of high grade uranium ore to New York in 2,000 steel drums, before it could be sent to Belgium and confiscated by the Germans.

In **October 1940 Edwin McMillan** and **Glenn Seaborg** at *Berkeley* produce the new element by bombarding Uranium-238 with neutrons, becoming U-239. After U-239 losses two beta particles it becomes Pu239, which they christen Plutonium. This material showed promise of being fissionable, like the U-235 isotope of uranium.

Summer 1941 – English physicists **Rudolf Peierls** and **Otto Frisch** found that it was possible to separate a sufficient quantity of U-235 to fashion a fission process atomic bomb. The Germans came to the same conclusion around the same time. By **September 1941**, German scientists formally recognize the theoretical possibility of a fission bomb, but doubt that it is technically feasible. Their vigorous pursuit of heavy water production at Vemork convinces British and American intelligence that they are working on developing a nuclear reactor, and hence, a atomic weapon. This is pure inference.



Three young scientists at Berkeley who had an enormous impact on the Manhattan Project: From left, Edwin McMillan (1907-91), Philip Abelson (1913-2004,) and Glenn Seaborg (1912-99).

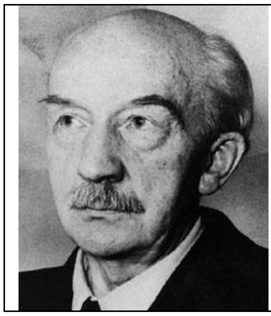
October 1, 1941 – **Dr. Vannevar Bush** briefs **President Roosevelt** and **Vice President Wallace** about ongoing research by British atomic physicists, who had determined how much uranium might be required to assemble an atomic bomb. The President agreed to finance American efforts with secret funds for the time being.

Saturday **December 6, 1941 –** First meeting of the newly formed Atomic Sub-committee (called S-1) of **OSRD** was held in Washington, DC. The committee was charged with determining whether or not an atomic bomb device could be built, and if so, at what cost. They were to report back to **President Roosevelt** in 6 months. Pearl Harbor was attacked the next day. In the **late spring of 1942** the S-1 Sub-committee reports that a bomb might be buildable, would cost upwards of $100 million, and could not be completed prior to **July 1944**.

<u>Moderators</u>

The extra weight of deuterium oxide (heavy water) served as a slow motion mechanism, moderating the speed of neutrons set free in a nuclear reactor (atomic pile), and thereby allow the neutrons to split uranium atoms in a chain reaction to produce P-239 plutonium – the fissionable element that could be used to make an atomic bomb. Plutonium contains an additional neutron as compared to the more stable U-238.

In **June 1939** German physicist **Walther Bothe** sails for the United States to attend a scientific meeting in Chicago. Along the way he meets a young lady named **Ingeborg Moerschner**, with whom he becomes romantically involved. Upon debarkation in New York, they visit the New York World's Fair and San Francisco Pan Pacific Exposition at Treasure Island. After his return to the *University of Heidelberg*, he resumes work on the nuclear qualities of graphite as a neutron moderator, between letters to **Ingeborg**.



Walther Bothe's (1891-1957) affair with Ingeborg Moerschner may have changed the course of the Second World War. Upon his return to Germany he made uncharacteristic mathematical errors in calculating the potential of graphite as an effective neutron moderator. These errors were not discovered for a year and a half. This led the Germans to pursue heavy water as their reactor moderator, demanding increased production at Vermork. These events were passed on to Allied intelligence almost as soon as they occurred at the Vemork hydroelectric facility in Norway, causing the Allies to believe that German physicists were ahead in the race to develop nuclear weapons.

In **January1940** the French government contacts the Norwegians about procuring their available stores of heavy water, to prevent the Germans from taking them. German firm I.G. Farben owned 25% of the shares of Norsk Hydro. At that time Norsk Hydro was producing about 10 kg of heavy water each month and had amassed a stockpile of almost 200 kg. Between **March 4-10, 1940** French agents clandestinely visit Oslo and Vemork, and take 185 kg of heavy water in canisters to Scotland, then on to France.

Vemork, Norway was the largest hydroelectric power plant in the world during World War II (left). The plant as it appears today (right).

The Germans invade Norway in **April 1940** and commandeer the Vemork facility, initially asking them to triple their production of heavy water, from 10 kg/month to 30 kg/month. On **May 10, 1940** the Germans invade France, Belgium and Netherlands. By **May 16th** the French lines were penetrated near Sedan, and the heavy water canisters are spirited off to England (Paris was subsequently occupied by the Germans on **June 15th**).

In **1940** no heavy water existed in the United States. Because of this **Szilard** and **Fermi** sought alternative materials. **Szilard** considered graphite, and gained an audience with Union Carbon and Carbide Company, who had hoped to meet with **Fermi**. **Szilard** asked them to donate $2000 worth of pure graphite. Unable to reveal the precise reason for the requisition, he was politely turned down.

On **November 1, 1940** the US Government awarded a $40K grant to *Columbia University* to fund fundamental research on nuclear chain reactions. This grant provides the first formal support for **Leo Szilard** since he emigrated from Hungary in **1938**.

By **January 1941** a love-struck **Walther Bothe** concludes that graphite, no matter how pure, will not work as an effective moderator of freed neutrons. The errors in his calculations were subsequently discovered by German scientist **Karl Wirtz**, but too late in the War to have any effect on the outcome of the German atomic program.

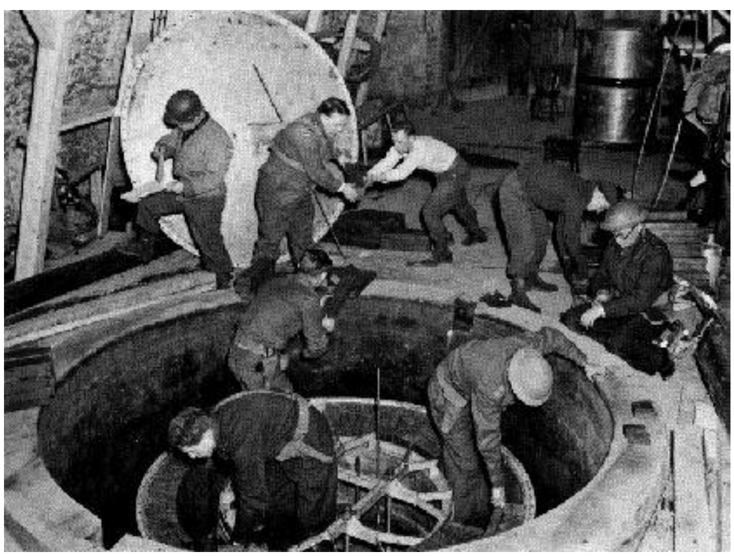
After **President Roosevelt** appointed a Uranium Committee in 1942, and its members met on **October 21, 1942. Leo Szilard** again asked for $2000 to cover the cost of pure graphite. This time the request was quickly granted.

<u>The German Reactor Explodes</u>

In **1939** the German government agreed to financially support the efforts of German physicists to build a nuclear reactor at Leipzig, purely for research. By **May 1942 Werner Heisenberg** and **Robert Doepel** had managed to construct their fourth attempt at an atomic reactor pile in their Leipzig laboratory, using jacketed U-238 surrounded by 140 kg of heavy water. They were trying to construct the world's first chain reacting nuclear pile.

On **June 4, 1942** Germany's top military and scientific leaders convened a meeting at the *Kaiser Wilhelm Institute* in Berlin-Dahlem to determine priorities for war production. **Werner Heisenberg,** the country's leading nuclear physicist, describes the vast power stored up in an atom. Several weeks after this meeting **Albert Speer** briefs **Adolf Hitler** on atomic fission and the assistance his government will render for scientific research. At this point, things were looking up for the Germans, after all, they had the largest cache of raw uranium in the world, and the only reliable supply of heavy water, thought to be the only effective neutron moderator at the time.

The same day that **Speer** briefed **Hitler** (**June 23, 1942**), the German program suddenly and irrevocably goes awry. **Heisenberg** and **Doepel** had amassed atomic pile L-IV in their laboratory in Liepzig in **May**. On **June 23rd** it had almost reached critical stage when the mass unexpectedly began to emit bubbles. Upon testing **Doepel** found them to be hydrogen, and immediately suspected a leak had developed between the jacketed uranium and the surrounding heavy water. When **Doepel** ordered a technician to unscrew the inlet so he could determine the extent of the leakage, the sudden drop in pressure allowed a stream of hot gasses to vent, glowing with bits of burning uranium. A flame then shot out of the opening and more uranium was set on fire.



American soldiers dismantling the German's unfinished nuclear reactor at Heigerloch in April 1945. The Allies also recovered 1200 tons of uranium ore the Germans had confiscated in 1940.

Doepel panicked, dumping a bucket of water on the fire, which quenched the flames, but was followed by a plume of black smoke pouring out of the opening. He then rushed to the phone and called **Heisenberg**, describing the increasing heat of the pile. The two men decided to open up the pile with a chisel to reduce the buildup of pressure at several points around the jacketed uranium. As they did so, the uranium began to swell and shudder. The two exchanged glances and decided to run for it. Just as they reached the street, the laboratory exploded, showering the area with bits of burning uranium. The Leipzig fire department arrived on the scene shortly thereafter, but was unable to extinguish the fire for another two days!

This was the turning point in the "race" to develop the atomic bomb (June 23, 1942). The Germans spent the next few years trying to get back to where they had been, needing to replace the lost heavy water and enriched uranium. They never came close to actually designing an atomic bomb, in part, because Heisenberg never calculated the critical mass of U-235, believing it would exceed their ability to manufacture.

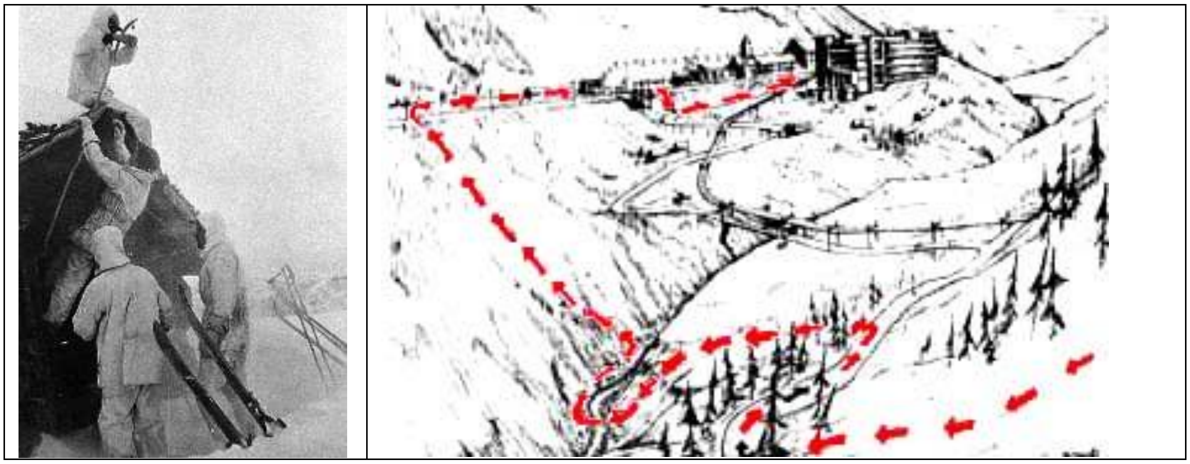
Allied Attempts to Disrupt Heavy Water Production at Vemork

In **early 1942**, the Germans charge the Vemork facility with producing 5 tons annually (a 3800% increase over pre-war production). The Vemork hydro plant had 18 high concentration cells of deuterium, each 4'-2" high, placed in the basement of the powerhouse. The SIS-Norwegian Section of British military intelligence enjoys an unceasing train of reliable intelligence from Vemork, via a system of British trained Norwegian underground agents who live and work around the Vemork facility. Based on this intelligence, British scientists conclude that the Germans must be well on the way to building an atomic pile using deuterium as the neutron moderator.

Oct 16, 1942 – Following a successful British commando raid on the Glomfjord hydroelectric plant in northern Norway, **Hitler** orders all allied commandos (whenever captured) to be turned over to the Gestapo for immediate execution, within 24 hours of capture.

November 19-20, 1942 – The British launch *Operation Freshman*, sending 46 commandos of the Royal Engineers, First Airborne Division, into southern Norway in two Horsa Gliders, towed by two RAF Halifax bombers. Both gliders and one Halifax crashed in the mountains west of Vemork. 10 of the 34 commandos were killed in the crashes, while another 7 died aboard the Halifax bomber. The 24 commandos who survived were taken prisoner by the Germans and promptly executed.

On the night of **February 27-28, 1943,** nine British-trained Norwegian commandos sneaked into the basement of the *Vemork* electrolysis plant and planted plastic explosives around all 18 deuterium cells, setting these off in a muffled explosion that destroyed 1000 pounds of heavy water. All 9 commandos evaded capture. By **June 1943** Norwegian intelligence reports that damage to deuterium cells has basically been repaired by the Germans, and heavy water production resumes.



Nine British-trained Norwegian commandoes accomplished the impossible by disrupting heavy water production at Vemork in February 1943. This diagram shows the ski hut they used as a base of operations in the mountains and the precipitous route used to approach the hydroelectric powerhouse, where they planted plastic explosives. All nine survived the raid and the ensuing German reaction.

August 1943 – British intelligence informs the Americans that deuterium production at Vemork is back up to 4-1/2 kilos per day. **BGEN Leslie Groves** and **Vannevar Bush** request that Vemork be targeted by the US 8th Air Force stationed in England. On **Nov. 16, 1943** the US 8th Air Force hits Vemork with 388 B-17s and B-24s launched against various Norwegian targets, to split German aerial defenses. 160 B-17s of the 3rd Air Division (including the veteran 95th and 100th Bomb Groups) are tasked to bomb Vemork. Each plane carries six 1,000-lb or 12 500-lb bombs, with an additional 15,000 lbs of fuel. The hydroelectric power plant was hit by 174 aircraft, which dropped 828 500 and 1000 lb bombs, between 11:30 AM and 12:15 PM. Because of its position beneath the hydroelectric facility, only two of the bombs actually hit the electrolysis plant, and the heavy water tanks were untouched. One bomb hit the civilian bomb shelter in Vemork, killing 8 men and 14 women and children. The Nitrate plant in nearby Rjukan was accidentally destroyed by B-24s of the 392nd BG The Norwegian government-in-exile in England strongly protested the raid because it was carried out without their approval or prior notification.

The American bombing raid on the Vemork plant at Rjukan did considerable damage and killed a group of school children huddled in the town's only bomb shelter, which took a direct hit. Although the bombs could not penetrate to the lowest galleries of the power plant where the heavy water was extracted and stored, it did manage to destroy the exposed penstocks feeding water into the plant and convinced the Germans that they should relocate their heavy water extraction program to the Alps.

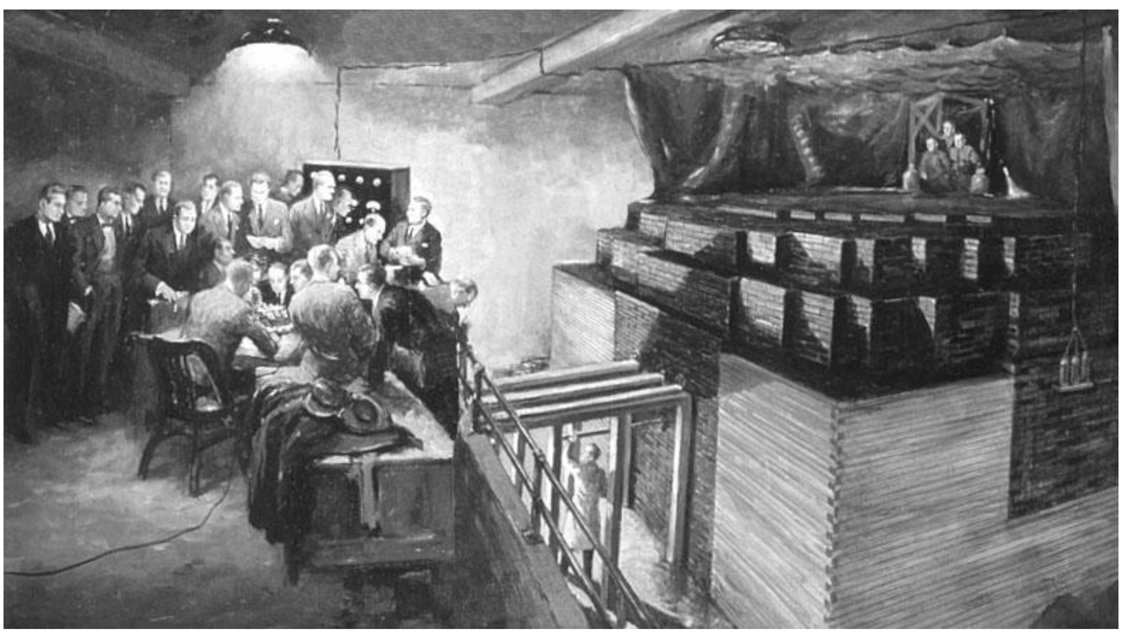
Even though the electrolysis plant was only hit by two bombs, the exposed steel penstocks leading into the hydroelectric plant were heavily damaged, severely limiting how much water could be fed into the electrolysis plant. The Germans dispatched physicist **Frederich Berkei** to survey the damage and he concludes that the damage is too extensive to justify complete repair (as the penstocks could simply be bombed again). Three days after the raid, the Germans announce that new heavy water separation plants will be constructed in Bavaria and at the Montecatini hydroelectric plant in northern Italy, which were more protected (having underground penstocks) and further from American heavy bombers. All existing stores (canisters) of heavy water at Vemork were to be shipped to Germany. Members of the British-trained Norwegian underground prepare to intercept this shipment.

The Norwegian ferry Hydro (at left) was sunk in the deep waters of Lake Tinn (right) in February 1944, carrying all the remaining heavy water supplies from the Vemork hydroelectric facility.

On **Feb 19-20, 1944** – Norwegian resistance saboteurs (including one of those who led the February 1943 commando raid) planted plastic explosives charges in the bilge of the Norwegian ferry *Hydro,* which was transporting railcars and passengers across Lake Tinn. The commando stole aboard at Mael on a Saturday night. The ferry exploded around 11 AM Sunday morning, when ¼ mile from its destination at Tinnoset, on the opposite shore, where the lake was 1,300 feet deep. The railroad cars carrying the canisters of deuterium slid off the listing ferry, into Lake Tinn and were lost. 26 passengers perished while 27 survived, including 4 German soldiers.

In **April 1945 –** The dismantled electrolysis plant from Vemork was captured by American forces in Bavaria, together with stores of heavy water and uranium. The Germans lacked about 700 liters of heavy water to get their reactor started.

Pencil Lead – The Graphite Pile

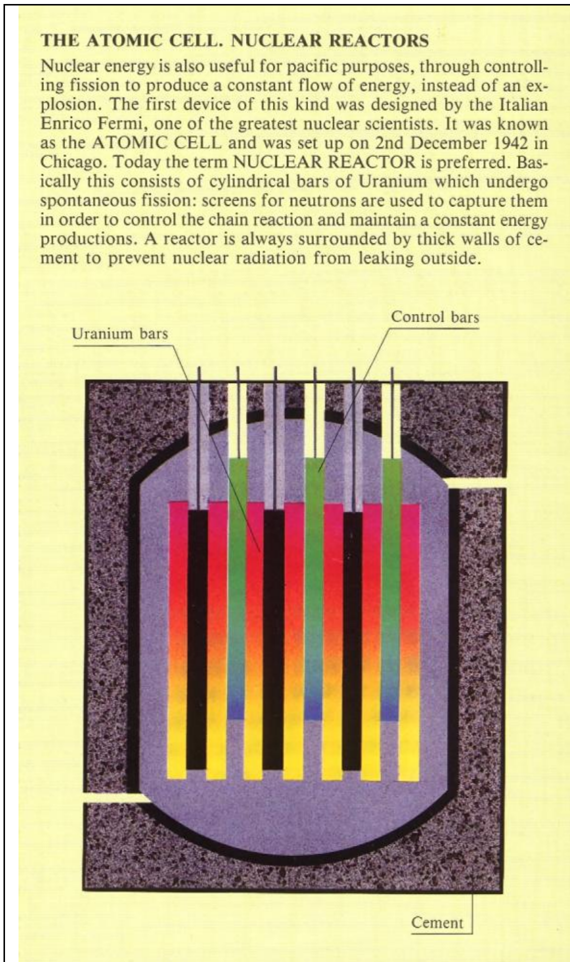


The world's first successful nuclear reactor was constructed on a squash court beneath the bleachers of Stagg Field at the University of Chicago. It incorporated 40,000 blocks of pure graphite, weighing 500 tons, provided by Union Carbide. The first successful chain reaction was recorded on December 2, 1942, six months after the German reactor in Leipzig caught fire and was destroyed.

In **May 1942 Enrico Fermi** assembled a reactor pile at *Columbia University* that came within 5% of emitting more neutrons than it absorbed (a chain reaction is defined as the process wherein more neutrons would be emitted than were absorbed by the uranium). This near successful test in the heart of New York City had enormous impact on funding the Manhattan Engineering Project.

The pile tests were shifted from *Columbia* to the *University of Chicago* in the fall of 1942, under **Enrico Fermi's** direction, during construction of permanent test facilities at *the Argonne National Laboratory (*20 miles outside Chicago). Fermi's group assembled a graphite reactor pile in the squash courts beneath the University's Stagg Field. The pile was comprised of 40,000 blocks of pure graphite, weighing 500 tons. These were stacked in 57 layers, into which tiny cubes of uranium or uranium oxide were inserted. It took workers two shifts a day for 16 days to construct the 16 feet high pile.

The first pile tests began on November 7, 1942, and by December 2nd, the world's first sustained chain reaction was recorded. Control bars coated with cadmium were used to stabilize the pile, until the chain reaction was initiated. As the cadmium rods were withdrawn, fewer and fewer of the uranium's freed neutrons were absorbed, inducing increased fission. Once all the cadmium coated bars were withdrawn at



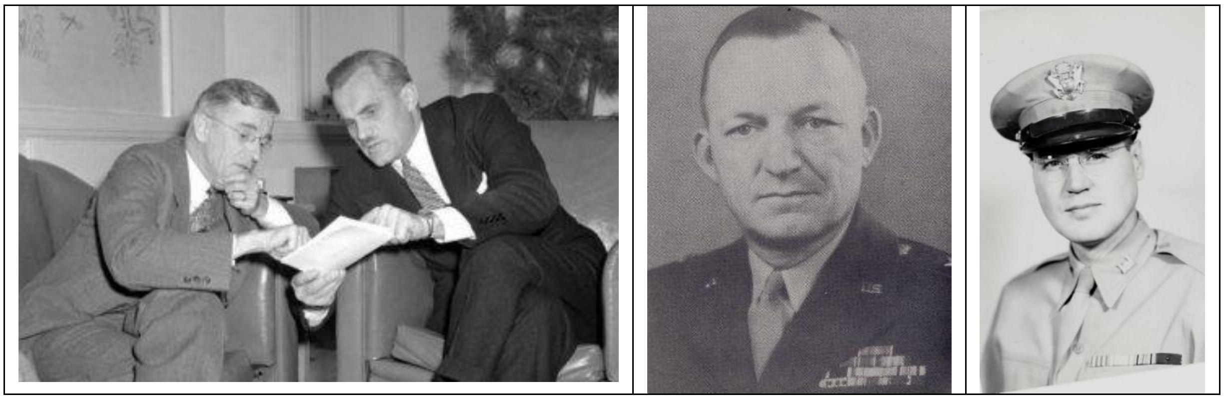
10:37 AM, more and more neutrons were freed faster than they could be absorbed, and a chain reaction resulted at 3:25 PM. The success of the crude reactor suggested that plutonium could be produced as a byproduct of the process. Plutonium and U-235 were the only radioactive elements thought capable of producing very rapid chain reactions, necessary for building bombs.

As a back-up for graphite, the Americans initiated production of heavy water using electrolysis, beginning in **January 1943**. Heavy water was produced at hydroelectric facilities located at Trail, British Columbia, the Wabash River ordnance plant and an electrolytic finishing plant in Morgantown, Alabama.

Maximum Effort - The Manhattan Project

June 1942 Arthur H. Compton (who directed nuclear research at the *University of Chicago*) wrote to ORSD head **Vannevar Bush** stating that "We have just recognized how a chain reaction started with a small heavy-water plant can quickly supply material for a high power plant for producing [fissionable material]". He also assumed the Germans were preceding along the same track (intelligence reports filtering in from Norway confirmed that the Germans had stepped up heavy water production at Vemork by ten-fold). Compton concluded that the Americans would not be able to overtake the Germans unless they overlooked some possibilities that the Americans recognized, or through delays caused by military intervention.

The Corps of Engineers organization responsible for developing the atomic bombs was officially created on **June 19, 1942** in New York City, under the command of **Col. James C. Marshall**, a 1918 graduate of West Point, then serving as District Engineer at Syracuse, New York. The new organization was called the Laboratory for the Development of Substitute Metals and was based in New York City, not far from Columbia University. Marshall chose 34-yr old **LCOL Kenneth D. Nichols** as his deputy, who was then working at the Pennsylvania Ordnance Works. Nichols was a **1929** West Point graduate with an MSCE from Cornell (**1933**) graduate study at the Technische Hochschule, Charlottenburg, Berlin, Germany (**1934-35**), and a Ph.D. from Iowa State University (**1937**) in hydraulics (only the second regular Army officer to receive a PhD in engineering). On **August 13, 1942** the project was formally established as the Manhattan Engineer District, which provided an effective cover because Corps districts were named after the cities in which they were based. Unlike other districts, the Manhattan District had no geographic boundaries. The United States would eventually commit $2 billion to funding what became know as the *Manhattan Project*.



From left: Former professors Vannevar Bush (1890-1974) and Arthur Compton (1892-1962) conferring during the war. Bush was Director of the Office of Scientific Research and Development while Compton served as Chairman of the National Academy of Sciences Committee to Evaluate Use of Atomic Energy in War. They essentially represented the nation's scientific talent to Presidents Roosevelt and Truman. Middle: Colonel James C. Marshall, first commander of the newly formed Manhattan Engineering District in June 1942. Right: Lt-Colonel Kenneth D. Nichols (1907-2000).

<u>The Chaplain's Son</u>

Major General Leslie R. "Dick" Groves (1896-1970) and Professor J. Robert Oppenheimer (1904-1967) were the consummate odd couple, who, together, accomplished the impossible. Groves initially thought that the appointment would be a disastrous dead end, but his promotion to brigadier general was obligatory for a career Army officer. He referred to the atomic bomb as "the gadget" while it was under development.

Leslie R. Groves, Jr. – Dick Groves was the descendent of French Huguenots that settled in America in mid-seventeenth century. He was born in **August 1896** in Albany, New York, son of a career Army Chaplain recognized for valor during the Boxer Rebellion in Peking, China in **1900**. Groves was unusual for a career Army officer in that he possessed 10 years of formal education. He had attended the University of Washington for a year, and MIT for two years, before spending 2-1/2 years at West Point, he graduated 4^{th} in his (accelerated) Class of **June 1918**. After graduation, he spent the next three years attending various Army Engineer schools at Fort Belvoir. He missed overseas duty during the First World War and was not promoted to Captain until **1934**, achieving the rank of Major in **1940**.

Groves was consistently recognized in the Corps of Engineers as a capable officer and organizer, and he was jumped over a number of people to become the Chief of the Operations Branch of the Corps of Engineers Construction Division in **1940**, directing $800 million of construction each month! He was tapped to head the Manhattan Engineering District along with a promotion to Brigadier General on **Sept 23, 1942**. He knew he had accepted a "make-or-break proposition, upon which his career and the very outcome of the war might depend. **Groves** was subsequently promoted to Major General in **1944**. After **COL Marshall's** transfer (and promotion to brigadier general) in **mid-1943 Kenneth Nichols** became his senior assistant and was promoted to full Colonel. In January 1945 **BGEN Thomas F. Farrell** was appointed as **Groves'** formal deputy.

<u>The Communist Sympathizer</u>

J. Robert Oppenheimer was born in New York City of German-Jewish immigrants in **April 1904**. **Oppenheimer** was something of a prodigy, completing a 4-year course in chemistry at *Harvard* in three years, then heading for the famous *Cavendish Physics Laboratory* at *Cambridge* in the summer of **1925**, where he went to work for English physicist (and later, Nobel Laureate) **J.J. Thompson**. But, after only 3 months, he accepted an offer from **Max Born** to study physics at the *University of Gottingen* in Germany, where he began working on the elemental theories of quantum mechanics with Gottingen **Professor Erwin Schrodinger**. That same year **Oppenheimer** published his first articles (on quantum mechanics), in *the Journal of the Cambridge Philosophical Society*. **Oppenheimer** completed his doctorate in physics with distinction in the spring of **1927**. He returned to *Harvard* for short while as a research fellow, then accepted a National Research Council fellowship at the *California Institute of Technology* in Pasadena. While in residence at *Caltech*, he received 12 offers for university professorship, 10 in the USA and two from abroad. He decided on accepting a position at the *University of California,* at Berkeley, though he continued to lecture at *Caltech* each spring, and was retained the privileges in title and pay as a member of Caltech's faculty from 1928-45, advancing to full professor at Berkeley in 1937 and at Caltech in 1938. When he joined the Berkeley faculty in 1930 he began collaborating with experimentalist **Ernest O. Lawrence** (see below) and gained a reputation as an adored intellectual and fascinating lecturer, who "*could charm the pants off most anyone*."

Ernest O. Lawrence (1901-58) was a professor at the University of California, Berkeley between 1928-58. He played a major role in the Manhattan Project, developing the U235 separation schemes employed at Oak Ridge. In 1929 he invented the cyclotron, a device for accelerating nuclear particles to very high velocities without the use of high

voltages. The swiftly moving particles were used to bombard atoms of various elements, disintegrating the atoms to form, in some cases, completely new elements. The image at right shows the 27-inch cyclotron, completed in December 1932. Larger and more powerful versions of the cyclotron were built by Lawrence during his distinguished career. He received the Nobel Prize in Physics in 1939.

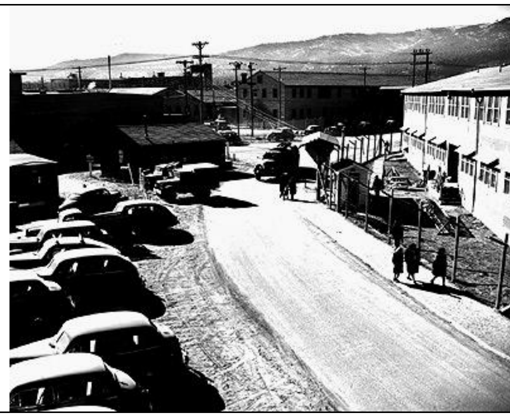
Frustrated by his student's inability to gain employment in teaching physics because of the Great Depression, **Oppenheimer** flirted with left wing politics, becoming involved with several organizations that harbored lose ties with American communists. His younger brother and fellow physicist Frank joined the Communist Party in **1936**. Although he never joined the communist party, he married the ex-wife of a former party functionary in **1940**.

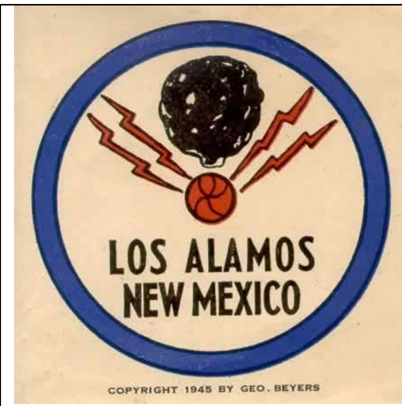
Oppenheimer became involved in the newly-kindled American research efforts into nuclear fission research in the **fall of 1941** through **E. O. Lawrence**. In **January 1942 Arthur Compton**, then Head of the *Metallurgical Laboratory* at the *University of Chicago*, asked **Oppenheimer** to work full time on the new research project, asking him to become "*Coordinator of Rapid Rupture*", basically the scientist charged with designing an atomic bomb – if it could be done. The initial goal was determine the critical masses of potentially fissionable materials. In the **summer of 1942, Oppenheimer** convened a team of experts at Berkeley, meeting in the top of LeConte Hall, near his office. That group was making impressive progress when newly-promoted **BGEN Leslie Groves** arrived at Berkeley on **October 8th**, as part of his inaugural tour of the nation's atomic research centers. **Oppenheimer** singularly impressed **Groves** as the man who had the organizational skills to deal with fellow scientists, while maintaining their collective respect.

A week later, **Oppenheimer** was riding a train with Groves and his senior aides **Kenneth Nichols** and **James Marshall** between Chicago and New York, where he outlined an ambitious plan to bring all the scientists together in one giant cohesive think tank, a larger version of what *Gottingen* had been to the physics world in the 1920s. **Oppenheimer** pushed for a remote site, and convinced **Groves** that Los Alamos, New Mexico would suffice. **Groves** chose **Oppenheimer**, even though the FBI recommended against granting him a security clearance. Groves knew the task before him was unprecedented, and he reasoned that anyone who would freely admit all his left wing sympathies on his initial security questionnaire (filled out in **January 1942**) was unlikely to be a spy. His hunch proved correct.

<u>The Dude Ranch - Los Alamos</u>

Oppenheimer and **Groves** agreed that a central research facility should be established where scientists could gather to work out the methods of constructing an atomic bomb. The big problem was how to make a sub-critical mass within a bomb container and suddenly cause it to go critical. On **November 25, 1942** approval was given to acquire the Ranch School at Los Alamos, New Mexico, along with about 50 miscellaneous structures. The school as located about 20 miles northwest of Santa Fe, surrounded by national forest. The project are encompassed about 50,000 acres (75% of this being in the former national forest). Administration of the facility was to be under the *University of California*. Everyone's address at Los Alamos was "P.O. Box 1663, Santa Fe, NM". In **March 1943** construction of Los Alamos Laboratory began.





Los Alamos Laboratory was a top secret installation during the Second World War that would nurture several thousand of the nation's most promising scientists, who would go on to dominate post war teaching and research in physics, chemistry, and weapons research. Its improbability as a likely site for such a significant project was tied solely to Robert Oppenheimer.

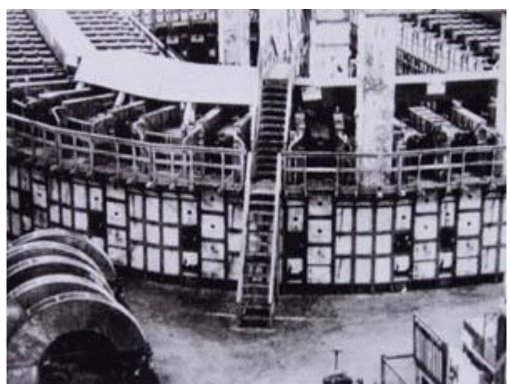
Rube Goldberg Machines

The Manhattan project set about design and construction of specialized manufacturing facilities, intended to separate the U-235 uranium isotope and produce the new element plutonium (Pu-239). Natural uranium only comprises about 1 percent of U-235, with the rest being U-238 and U-234. These were the only radioactive elements thought capable of fomenting a rapid sustained chain reaction, necessary for constructing an explosive device.

In late **September** and early **October 1942 BGEN Groves** and his assistants toured the various research facilities involved in government-funded atomic research. These included: 1) the reactor pile group under **Fermi** recently transplanted to the *University of Chicago*; 2) the *U.C. Berkeley* group investigating electromagnetic separation of U-235 and the theoretical requirements to produce a bomb; 3) a centrifuge separation method by Westinghouse Research labs in Pittsburgh; and, 4) gaseous diffusion of uranium hexaflouride at *Columbia University*. The centrifuge process was discarded, but work proceeded on constructing enormous enrichment facilities at a 92-sq mile site near Oak Ridge, Tennessee, about 20 miles west of Knoxville. The location was relatively remote, had abundant supplies of water and hydroelectric power. In **September 1942** construction began.

The **Y-12 Plant** was the first uranium manufacturing facility to house the electromagnetic process for separation of U-235 from U-238. These plants were operated by Tennessee Eastman, a subsidiary of Kodak. The Berkeley magnets were scaled up to be 250 feet long, creating a magnetic field so powerful it could pull tools out of the pockets of passing workmen. The magnets each weighed between 3,000 and 10,000 tons. These were wrapped with 6,000 tons of silver wire, supplied by Fort Knox. Altogether five such "Alpha Plants" were built, each with 96 separation units in two oval racetracks, with semi-circular mass spectrometer tanks. All of these could be operated independently. These were dubbed the "Caluatrons". The resulting product was only 13 to 15% pure, and had to be concentrated in Beta machines, where 90% of the U-235 was again lost. It was a slow process of enrichment, subsequently discarded in favor of plutonium manufactured at Hanford.

The massive Y-12 plant at Oak Ridge, Tennessee was designed and built in record time by the legendary Boston engineering firm Stone & Webster.

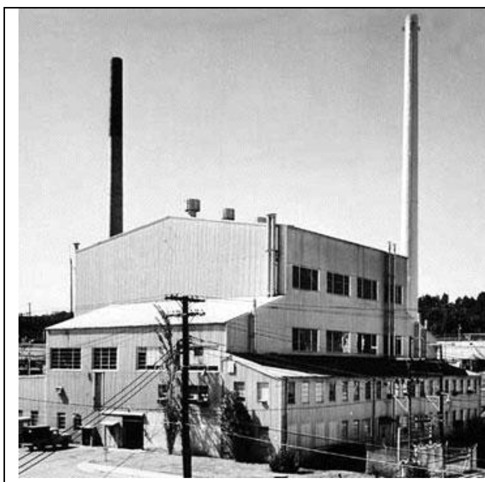


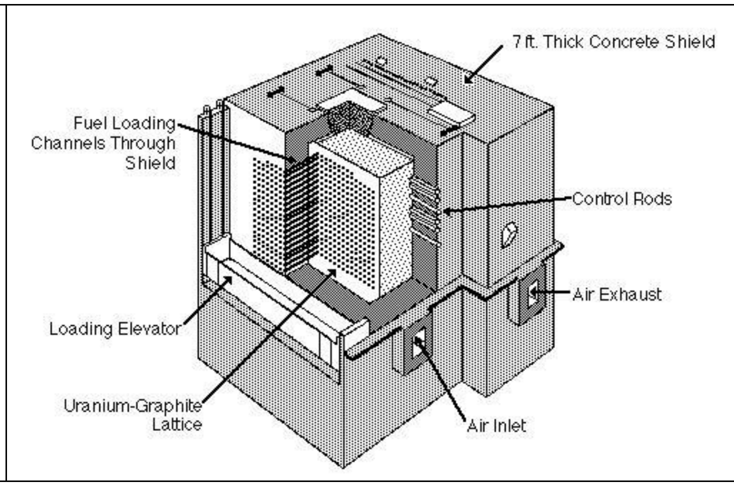
Alpha tracks, or Caluatrons, at the Y-12 Plant were constructed as oval racetracks, for separation and enrichment of U-235. These were conceived by Ernest Lawrence at Berkeley. Only one U-235 atomic bomb was ever manufactured, this enrichment process being discarded in favor of the plutonium plant in Hanford, Washington.

The Carbide and Carbon Chemicals Co. was given charge of operating the gaseous diffusion process of U-235, using a uranium hexaflouride HF_6 feed stream. A huge U-shaped facility was built, 2,500 feet long on each side, 450 feet wide and 60 feet high. It occupied 44 acres and was dubbed the **K-25 Plant**. The HF_6 had to pass through 3,000 stages in a continuous cascade, to slowly filter out the lighter U-235 atoms. The diffusion holes were two millionths of an inch in diameter. The plant did not enter operation until **February 20, 1945** and the resulting U-235 only had a purity of 1.1%. This material was then fed into the Y-12 plant for final enrichment.

K-25 Plant at Oak Ridge. This U-shaped facility was 2,500 feet long on each side, 450 feet wide, and 60 feet high, occupying 44 acres. Here uranium hexafluoride (HF_6) was forced through 3,000 stages in a continuous cascade, to slowly filter out the lighter U-235 atoms.

Another enrichment process attempted at Oak Ridge was thermal diffusion, pioneered by the Navy and undertaken at the **S-50 Plant**, which began operation on **September 16, 1944**. The resulting product was only 1.4% pure, and was also added to the feed stream in the **Y-12 Plant**.



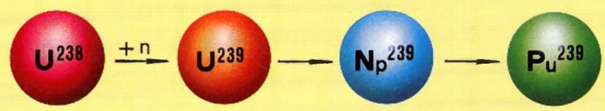


The X-10 graphite reactor at Oak Ridge opened Nov 4, 1943 as the prototype reactor for plutonium production at Hanford. Thousands of reactor operators were trained here over the ensuing 20 years, until the reactor was shut down in 1963. The oldest nuclear reactor in the world, it is a National Historic Landmark and open to the public at the Oak Ridge National Laboratory.

The **X-10** graphite reactor at Oak Ridge was supervised by the scientific team from the *University of Chicago*. It was to serve as a pilot plant for the design of larger production reactors to be built out at Hanford, Washington. The purpose of the **X-10** reactor was to produce sufficient plutonium to allow for further research on enrichment of the material. The **X-10** reactor came on line in **November 1943** and remained in operation until **November 4, 1963**.

FROM URANIUM TO PLUTONIUM

Of the two most important isotopes making up Uranium, the one with the atomic mass of 235 undergoes fission more easily, but it only makes up 0.7% of natural Uranium, while fission of the remaining part, Uranium 238, is much more difficult.
However it so happens that if Uranium 238 is bombarded with neutrons, it turns into Uranium 239 and this spontaneously and rapidly turns into Neptunium 239, which in turn is very rapidly changed into Plutonium 239. Unlike the two previous elements, Plutonium is a stable transuranic element, its life span may be calculated as more than 24,000 years, and like Uranium 235, it also undergoes fission easily.
By taking advantage of these facts it is possible to make use of all the Uranium available using the nuclear reactor.

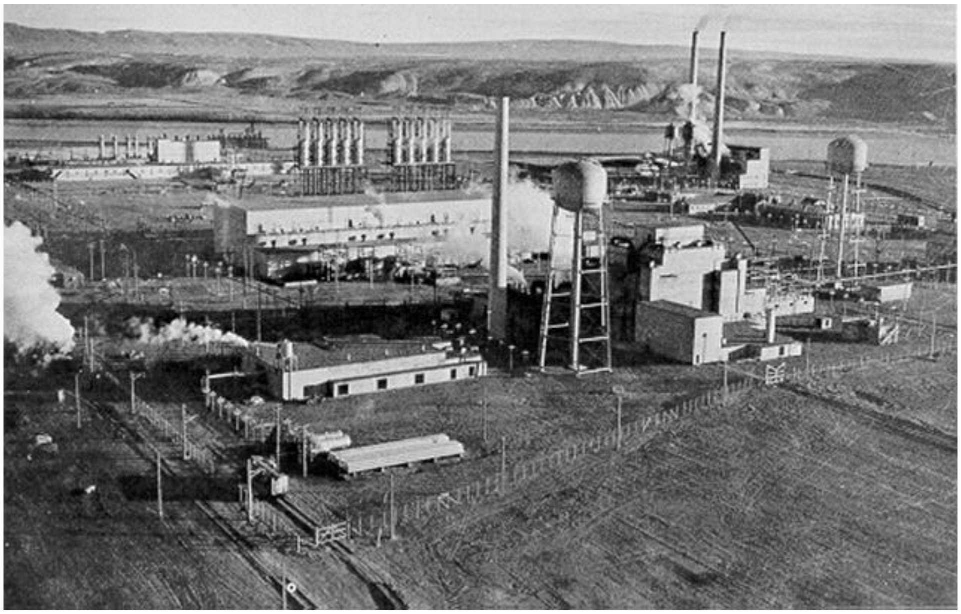


The process of transforming U238 to Pu239 was explored at the X-10 reactor throughout 1944-45. This shows how U238 is bombarded with neutrons, gradually transforming it to the more stable Plutonium 239. These developments were unforeseen at the outset of the Manhattan Project.

Hanford -The Plutonium Capitol

Like Oak Ridge, Hanford was initially selected because of its remote location and proximity to water and hydroelectric power. The primary purpose of the Hanford facility near Richland, Washington was to produce plutonium. The critical mass of plutonium need for a bomb was only 11 pounds, less than a third of that required for U-235. Plutonium was produced when the uranium in an atomic pile (reactor) was subjected to a slow chain reaction. Some of the bombarded uranium is converted to P-239, but remains within the U-238 ingots, slugs or rods. Separation of the P-239 from the uranium and subsequent enrichment were necessary to produce pure quantities of plutonium. Construction of the necessary facilities began in **June 1943**.

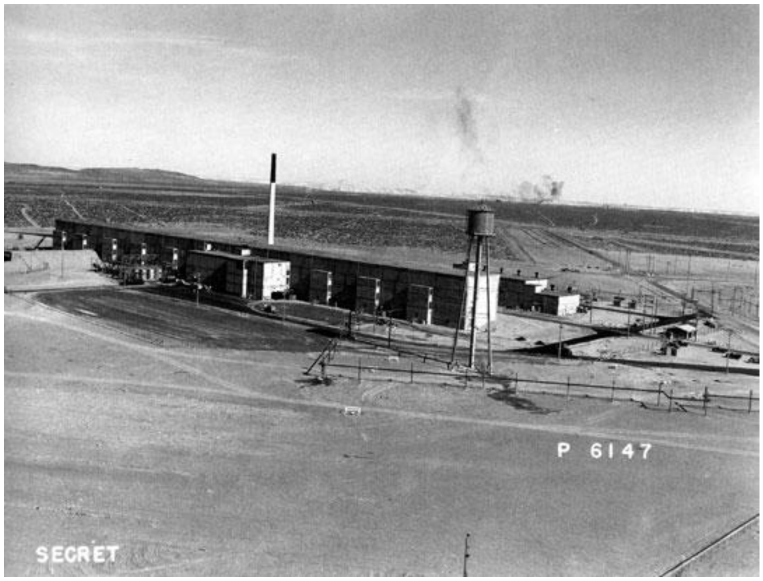
The first plutonium reactor built at Hanford was dubbed the **B Reactor**. It used 2,000 tons of pure graphite as a moderator and was brought on line during **September 1944**. The reactor had to be shut down because of the unanticipated build-up of Xenon-135 gas, a byproduct of the fission process. The mass of uranium was subsequently increased by 25% to boost capacity and overcome the neutrons lost to the Xe-135. On **December 25, 1944** the plant produced its first irradiated slugs containing plutonium. The reactor was shut down after the war, but reactivated in **1948** and operated almost continually until **February 1968**.



The B Reactor complex was the first constructed at Hanford, Washington, coming on-line in September 1944. Plutonium production fell to near zero on several occasions, and Enrico Fermi and his team had to troubleshoot the problems and develop workable protocols to maintain output during the war.

Hanford B Plant separation and enrichment facility, as seen in 1945.

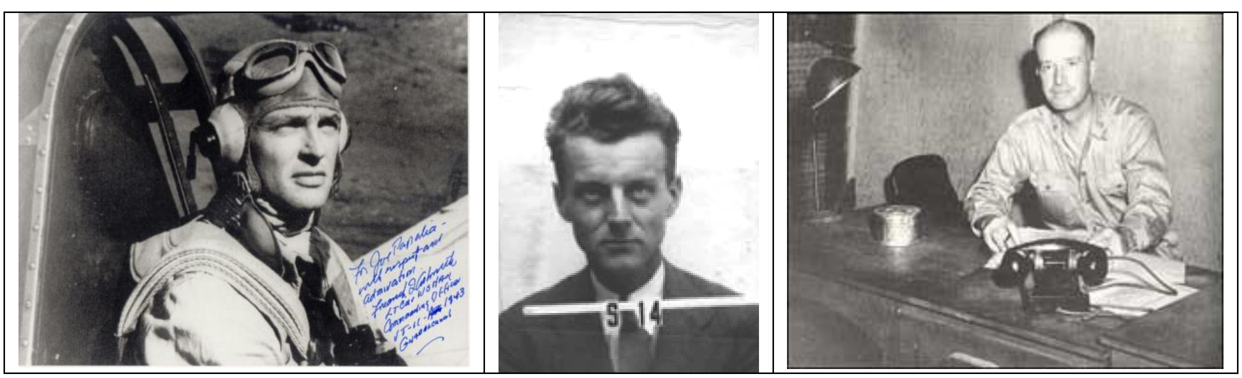
Separation and enrichment of the resulting plutonium was handled at two huge installations, called the **B and T Plants**, located 3 miles apart, and about 5 miles from the **B Reactor**. Separation from the enriched slugs was achieved using bismuth phosphate, an excellent carrier of plutonium. The first quantities of enriched plutonium were shipped from Hanford at the end of **January 1945**. **T Plant** produced the plutonium used in the Nagasaki bomb and the subsequent atomic tests carried out at Bikini Atoll in **July 1946**.



The T Plant at Hanford was completed in December 1944 as the world's first large-scale plutonium separation facility. Only about one atom in 4,000 was converted to plutonium in the three Hanford production reactors, so these atoms had to be separated from the remaining U238 and other fission products that had been created.

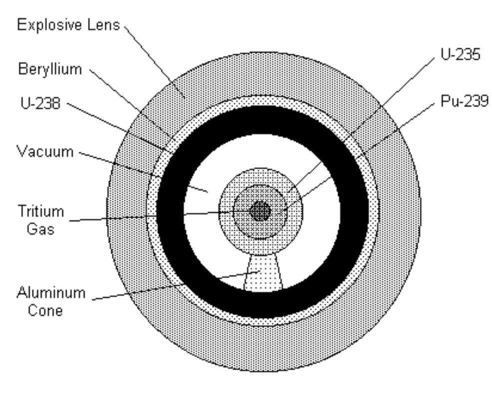
Perfecting the Implosion Device

Work originally centered around the idea of firing one piece of fissionable material into another, using a sort of gun barrel. This technique was deemed workable for U-235, and the details were worked out under the guidance of three Navy ballistics experts, **CDR William S. "Deak" Parsons, CDR Fred Ashworth** and **LCDR Francis Birch**. Some portion of the plutonium absorbs extra neutrons, becoming P-240. P-240 undergoes spontaneous fission, which might initiate a chain reaction prior to reaching critical mass, leading to a premature explosion of slight magnitude. By **July 1944** it was evident that the P-239 core could not be compressed fast enough to initiate a rapid chain reaction by the gun method. This was particularly frustrating, because it was becoming more and more apparent that plutonium would be the fissionable material most readily obtainable from the various plants at Oak Ridge and Hanford.

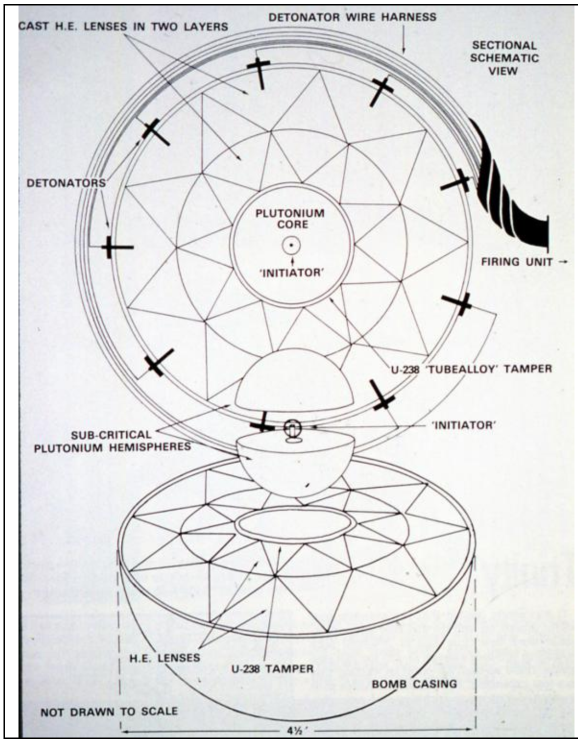


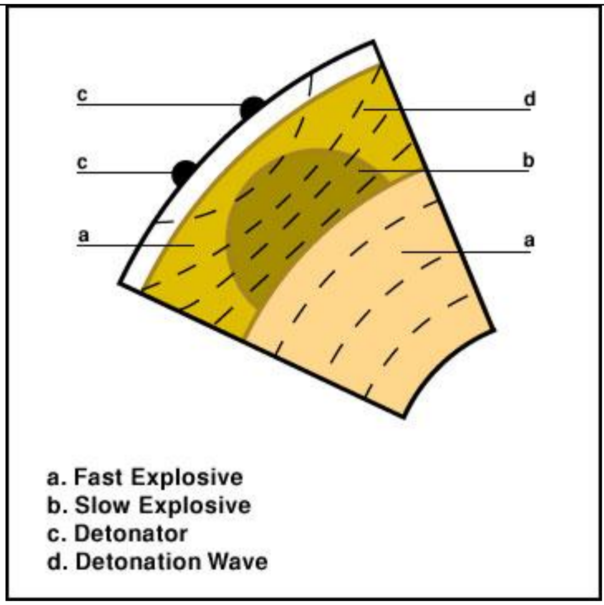
Left to right: Commander Fred Ashworth (1911-), Seth Neddermeyer (1907-88), and Captain Deak Parsons (1901-53). A weapons expert, Ashworth had commanded a carrier Air Group in the Pacific prior to his assignment at Los Alamos. Parsons flew as weaponer aboard the Hiroshima mission, while Ashworth served as weaponer and senior officer on the Nagasaki mission.

In **July 1943** one of Project Y's scientists, **Seth Neddermeyer** (PhD physics Caltech '35) proposed assembling a critical mass of P-239 through implosion, using concentrically-placed explosives, surrounding a subcritical mass of plutonium. The idea was enthusiastically taken up by the other scientists at Los Alamos, and **Oppenheimer** ordered the creation of an implosion work group that fall. An implosion bomb required enormous engineering and split second timing. But, by early **August 1944 Neddermeyer's** experiments reached an impasse.



A Soviet Jewish émigré, shaped charge pioneer George Kistiakowsky (1900-82) was brought in to supervise the design of the plutonium implosion device. Kistiakowsky was a professor of chemistry at Harvard, and returned to his position after the war, later serving as Special Assistant for Science and Technology to Presidents Eisenhower and Kennedy, after which he came to oppose the nuclear arms race.





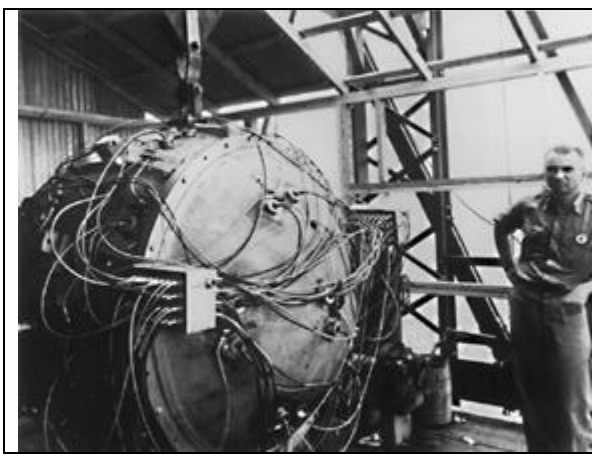
Kistiakowsky's rapid reaction team employed shaped layers of slow and fast explosive lenses to concentrate the energy on the hollow plutonium core simultaneously, a tremendous challenge. This became the model for post-war fission atomic bombs.

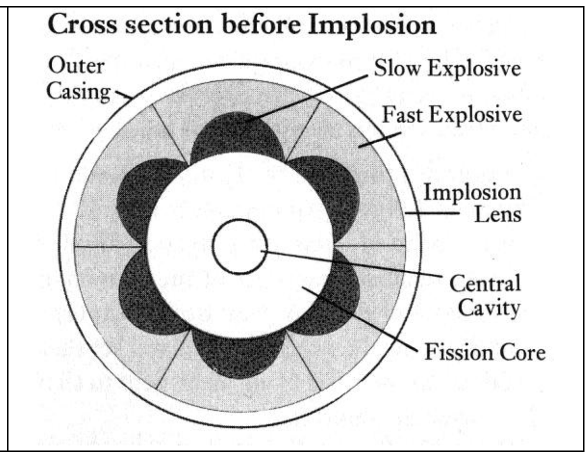
In **September 1944, Oppenheimer** placed Russian-born scientist **George B. Kistiakowsky** in charge of developing the implosion device. Kistiakowsky had been in charge of the National Defense Research Council's explosives group, working around the country. **Kistiakowsky** had been visiting Los Alamos as a consultant since January 1944, but immediately found himself at odds with **Deak Parsons**. A desperate **Oppenheimer** intervened, placing development of the implosion device outside of **Deak Parsons'** control.

Like **Groves** and **Oppenheimer**, **Kistiakowsky** found himself in a do-or-die proposition. **Kistiakowsky** was assigned 600 men to help him out, 400 of which were draftees with engineering and science backgrounds, called "SED's" (a military acronym for Special Engineering Detachment). Another British scientist recently attached to the implosion group was **James Tuck**, who had worked previously on developing "shaped charges", using fast and slow explosives. The infusion of **Kistiakowsky** and **Tuck** into the group provided the necessary synergism for eventual success, though this group felt the greatest stress of any involved in the Manhattan Project. They ended up using 5,300 pounds of Composition B and Baritol, high grade explosives laid out as shaped charges, capable of compressing the 11 pound plutonium core of a bomb with split second timing. The device was never successfully tested before the Trinity Test ordered by **President Truman** in **July 1945**, because he was meeting with Soviet dictator **Josef Stalin** in Potsdam, Germany. The implosion device was successful fired at the Trinity site on **July 17, 1945**, 2-1/2 months after the German surrender. It became the model for the post-war atomic bombs. **Kistiakowsky** would move on to Harvard after the war, teaching chemistry, then serving in a variety of roles in the Eisenhower, Kennedy, Johnson, and Nixon administrations.

<u>The McDonald Ranch and Trinity</u>

The Los Alamos scientists began looking for a remote location to test an atomic bomb. They settled on the White Sands area south and east of Albuquerque, and west of Alamagordo. The government purchased the taciturn McDonald Ranch and ordered boilermaker Babcock & Wilcox to fabricate a 214-ton steel containment vessel, dubbed "jumbo". It was 25 feet long, 12 feet in diameter, 6 inches thick, with walls 14 inches thick at both ends. The idea was to contain any unspent plutonium in attempt to detonate the first atomic bomb. The initial batch of enriched plutonium was shipped to Los Alamos in late **January 1945**, with increasing quantities coming on stream each month thereafter. By **July 1945** it was decided that a sufficient supply of plutonium was available to enable an outside test. Jumbo was suspended on a steel frame about 800 feet from Trinity ground zero. Trial tests of the blast monitoring equipment were carried out on **May 7, 1945**, using 100 tons of TNT. This test explosion was performed about 10,000 feet south of Trinity ground zero.





Left: The original Fat Man Pu239 plutonium bomb that was detonated at the Trinity site on July 17, 1945. Right: Schematic representation of how the implosion process was achieved using shaped lenses of slow and fast burning explosives to bring the plutonium core to critical mass at the same instant.

The Trinity Test was carried out at 5:30 AM on Monday **July 17, 1945** using a plutonium implosion bomb mounted atop a steel tower, 100 feet high. Most of the close-in film was damaged by radiation before it could be developed. A saucer like depression 1,200 feet in diameter and 25 feet deep identified ground zero. There was nothing left of the supporting steel tower. A greenish colored glass was strewn about the crater floor, dubbed "trinitite". Windows were blown out as much as 200 miles away (to the northwest). People up to 150 miles away reported seeing the sun come up, then going down again. A radiation band 30 miles wide drifted northeast at 10 mph for over 120 miles. Fermi went into the crater area almost immediately in a Sherman tank configured with lead shielding.

Rationale for Japanese Cities to be Viewed as Legitimate Military Targets

The strategic decision to lay waste to Japanese cities filled with civilians in deference to limiting our bombing to strategic military targets had its origins in the disastrous outcome of the first American raid on Japan, just four months after the Pearl Harbor attack. Four Army Air Corps officers who participated in the Doolittle Raid were tried as war criminals and publicly executed, in uniform. In addition, some 250,000 Chinese civilians were murdered by the Japanese in reprisal for allowing downed Doolittle Raid fliers to pass through their villages, as they sought to escape capture by the Japanese.

Left – Propaganda images of Allied servicemen being executed in uniform appeared in Japanese newspapers during the war. These were intended to shame Japan's enemies and bolster resolve, but many were leaked back to America through the Swiss consulate. These had a disastrous backlash because American military planners came to regard the Japanese as inhuman and barbaric.

Added to this were the revelations in mid-1944 onward that the Japanese were systematically murdering American prisoners-of-war in the Philippines and elsewhere, to prevent their repatriation by advancing American forces. During the Pacific War, 40% of Allied POWs would die in Japanese POW camps, as compared to 1% of the Allied POWs incarcerated by the Germans. For these reasons, and others discussed below, the Japanese were not regarded with the same measure of respect as the Germans, who were signatories to the Geneva Convention, whereas the Japanese were not.

Lt. Colonel James H. Doolittle (1896-1993) led the first American air strike on Japan on April 18, 1942, just four months after the surprise attack on Pearl Harbor. The attack was comprised of 16 Army Air Corps B-25 Mitchell bombers launched from the American carrier Hornet, 700 miles east of Japan (shown at right). Doolittle was promoted to brigadier general and received the Medal of Honor, the first American general officer to have an earned PhD (aeronautical engineering from MIT, 1925). He was also the first reserve officer to achieve 3 or 4 star rank, and received Berkeley's first Alumnus of the Year Award, in 1943 (BS mining engineering, U.C. Berkeley, 1922).

The **Doolittle Raid** was carried out on **April 18, 1942**, when 16 Army Air Corps B-25B Mitchell bombers led by Reserve **LCOL Jimmy Doolittle** hit five Japanese cities during the lunch hour. The attack occurred just 4 months and a week after the Japanese had attacked Pearl Harbor. In military terms, the raid was modest, but its ramifications were enormous, as it shocked and embarrassed the Japanese militarists, forcing the disastrous showdown at Midway in early June. The carriers *Enterprise* and *Hornet* (commanded by **RADM W.F. Halsey**) were sighted about 18 hours before the scheduled take-off point, 500 miles from Japan. The bombers were hastily launched after learning that a Japanese picket ship had radioed the task force's position to Tokyo. Although the bombers achieved complete surprise, none of them actually landed in China, as planned (one crew was interned by the Soviets). Several of the planes ditched in the ocean off Japanese-occupied China. Two of the 16 aircrews availed themselves to "friendly" Nationalist Chinese forces, but were turned over to Japanese occupation forces. Approximately 250,000 Chinese civilians were executed by the Japanese for assumed complacency on the part of those American airmen successful in evading capture.

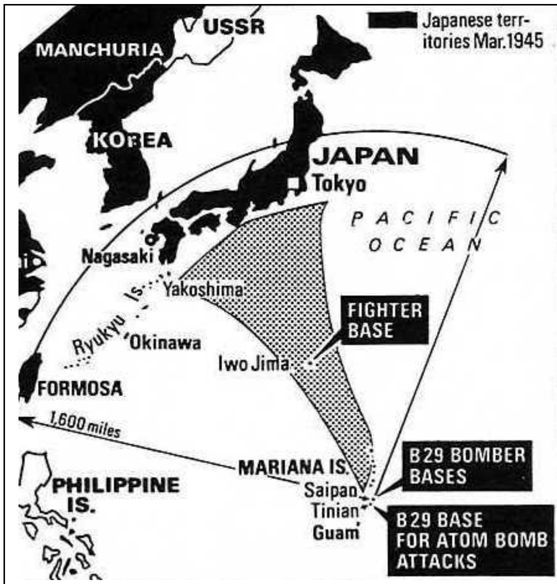
These prisoners of war included the men of Crews #6 and #16.

Crew # 6		**Crew #16**	
Dean Hallmark (pilot)	executed	**William G. Farrow** (pilot)	executed
Robert J. Meder (co-pilot)	died in prison	**Robert L. Hite** (co-pilot)	survived
Chase Nielsen (navigator)	survived	**George Barr** (navigator)	survived
William J. Dieter (bombardier)	died on landing	**Jacob DeShazer** (bombardier)	survived
Donald Fitzmaurice (engr-gunner)	died landing	**Harold Spatz** (engr-gunner)	executed

After a highly publicized trial in Japan, three of the raiders were executed by firing squad in Peking, China on **Oct. 15, 1942**, and reported in the American news media on **April 22, 1943**. The remaining five were held in solitary confinement in Peking. **Lt. Meder** died in captivity in 1944, while **Lt. Barr** barely survived. The four surviving prisoners were rescued in an audacious mission commanded by OSS **Major Ray A. Nichol** on **August 16, 1945**, two days after the Japanese announced their surrender. The OSS believed that the Japanese might execute the remaining Doolittle Raid prisoners, whose POW status had never been officially acknowledged.

<u>Laying Waste to Japan</u>

The high profile trial of the captured Doolittle airman in late **1942,** their subsequent executions, and that of thousands of American POWs in the Philippines inculcated a sense of rage from Air Corps planners. The conduct of the strategic bombing campaign against Japan differed from that executed against Germany, which concentrated on industrial targets. The campaign against Japan targeted key industries, but did not differentiate between bombing a specific factory, as opposed to the city surrounding it. In part, this problem was due to the inability of the faster B-29s to effectively use the Norden bombsight at such high speed (300+ kts) and altitude (30,000 feet). Another factor was the rationalization that all Japanese engaged in war-related work at home, such as sewing uniforms, and were, therefore, legitimate military targets. The fact that Japanese tortured and executed military prisoners of war influenced this thinking. Area bombing using radar became the preferred method of delivering destruction upon Japan, and it was anything but accurate. B-29s began combat operations against Japan from bases in northern China in the **late spring of 1944**. These bases were so far from fuel sources, that very few planes could be mounted on any given mission.



The Mariannas Islands were invaded in the **summer of 1944** to provide air bases on Saipan and Tinian within combat range of B-29s, 1,700 to 2,200 miles from most Japanese cities. North Field and West Field at Tinian each had four great runways, 8,500 feet long, and could launch 300 B-29s on a single mission. Mission profiles averaged 18 hours in the air, round trip, necessitating an extra day of crew rest. Most aircrews could not fly combat missions less than 2 or 3 days apart. B-29 raids against Japan staged from the Mariannas commenced in **late October 1944.** The first B-29 raid against Tokyo was launched on **Nov. 17, 1944**.

Bases in the Marianna Islands allowed long ranging B-29 bombers to strike 70% of the Japanese home Islands, where most of their industrial base was located. Many critical war industries were moved to the Korean Peninsula, including the Japanese heavy water production plants near the Manchurian border.

Virtually every city in Japan with more than 35,000 people was destroyed in area-wide bombing by B-29s between **November 1944** and **July 1945**. The tactics were changed in **early March 1945**, when incendiary bombs were dropped on Tokyo. The aircraft were strung out at altitudes between 6,000 and 8,000 feet. On the night of **March 9-10, 1945**, 325 B-29s hit Tokyo, each carrying 7 tons of incendiaries. The raid destroyed 16 square miles of Tokyo and killed upwards of 115,000 Japanese in a single “fire raid”. By war’s end 3,895 B-29s had been built, accounting for 29,150 combat missions. The Japanese ceased resisting American bombers with defensive fighters on **July 1, 1945**, hoarding these for the use as Kamikazes in the anticipated invasion of the Japanese home islands in the **fall of 1945**.

The North Field complex on Tinian Island in the Mariannas. Eventually equipped with four 8,500 foot runways and 265 hardstands, North Field was the largest airdrome constructed during World War II. The atomic missions were flown from this base, with the 509th Group occupying the area at extreme left in this image.

<u>The Superfortress</u>

The Boeing B-29 Superfortress was a quantum leap in technology as compared to other bombers used in World War II. The first prototype flew in **August 1942**. Bigger, faster, 4X bomb load, 2X the effective combat range of any other bomber in production during World War II. It was also the first aircraft to have pressurized cabins.

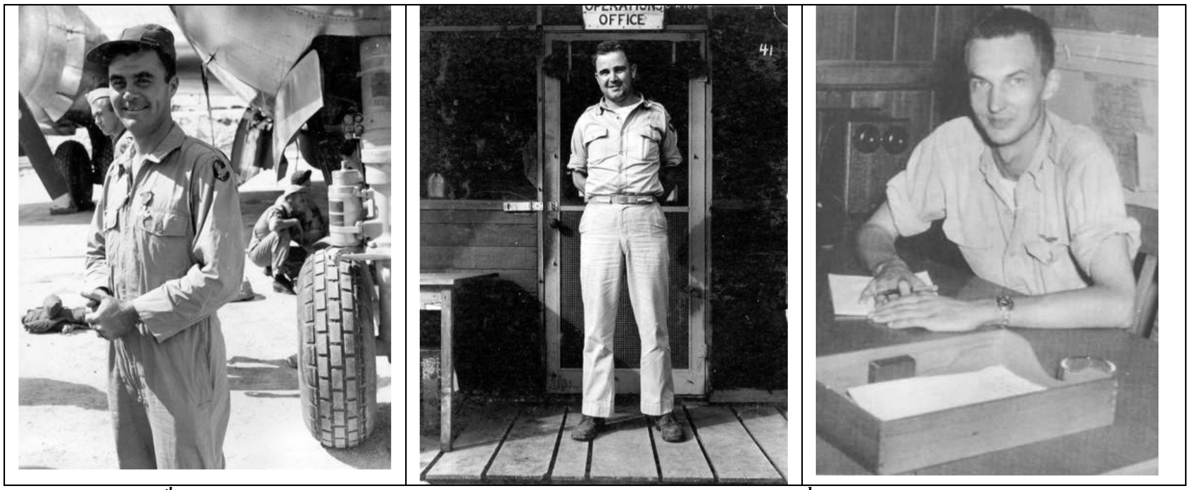
Enormous armadas of B-29 Superfortress bombers equipped with incendiary bombs wrecked havoc on the Japanese home islands during 1944-45. These aircraft were the first to employ pressurized cabins and turbo superchargers for their engines, allowing them to fly missions up to 34,000 feet altitude, well above Japanese interceptors. They carried four times the bomb load of the B-17 or B-24 heavy bombers used against Germany.

The biggest problem with the B-29 was its Wright Cyclone R-3350 air cooled duplex piston engines. These were termed "3350's" because the piston displacement was 3,350 cubic inches, spread over 18 cylinders (186 in^3 per cylinder), collected in twin banks. The banks were so tightly formed that the engine was only 55 inches in diameter (about 4-1/2 feet). The R-3350 was intended to develop up to 2,600 HP on takeoff, with 2,000 HP during cruise. This was more than double the horsepower of the R-1820 engines that powered the B-17.

The engine was rushed into production before all the teething problems had been worked out. There were chronic problems with the exhaust valves and cooling systems. Although the engines cost just over $25,000 apiece to produce, 31% failed during **1944**, necessitating over 2000 design modifications by **early 1945**. In **1944** B-29 maintenance personnel referred to the R-3350 as the world's first "disposable engine", because thousands were cast aside in the Mariannas. By **mid-1945** engine production increased to 11,000 units per year, with a 2% failure rate (down from 31% the year previous). Many B-29s were converted to KB-29P aerial refueling aircraft during the 1950s, and many of these aircraft were not retired till **1959-60**.

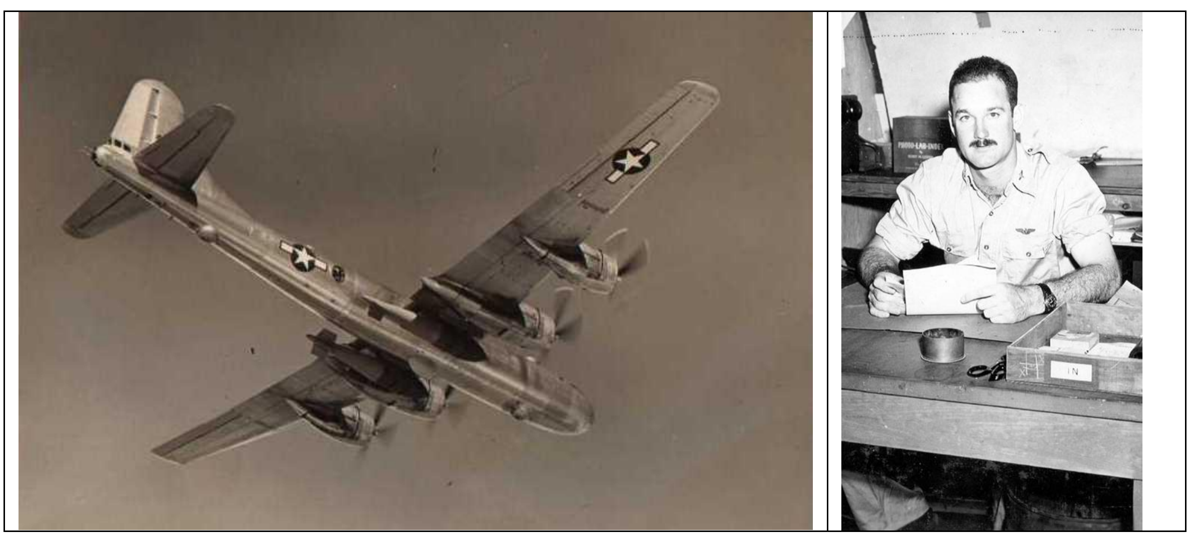
Silverplate - The 509th Composite Group

In September 1944 LCOL Paul W. Tibbets, Jr. was selected to command a special Army Air Corps unit that would be capable of dropping atomic bombs from specially configured B-29s. The 509th Composite Group was officially activated at Wendover, Utah on **December 17, 1944**. It consisted of 1,800 men, split into the 393rd Bomb Squadron (taken from the 504th BG), 320th Troop Carrier Sqn., 390th Air Service Group, 603rd Air Engineering Sqn., 1027th Air Material Sqn. and the 1st Ordnance Sqn. At the Core of the original unit were 15 B-29 Superfortress bombers, under command of **LCOL Tom Classen** (who subsequently became Deputy Group C.O.) which arrived in November 1944. The group underwent extensive training at Wendover, Utah, where they practiced dropping concrete-filled 8,000 pound "pumpkin" bombs within an area 400 feet in diameter from an altitude of 30,000 feet (a miss of no more than 200 feet was allowed). They received about 200 of these dummy bombs to practice with.



From left: 509th Group Commander Colonel Paul W. Tibbets, Jr. (1915-), 393rd Bomb Squadron commander Major Charles W. Sweeney (1919-2004); and Deputy 509th Group Commander Lt. Colonel Tom Classen.

After experimenting with removing the gun turrets at a rework facility, **Tibbets** ordered specially-built B-29s from the Glen L. Martin factory in Omaha, who was building the bomber under license. The new craft were built without defensive turrets to save 7000 lbs.; pneumatically operated bomb bay doors; Curtis Electric hydromatic propellers (capable of reversing on landing); and fuel injection for the engines. They were the only B-29s with Curtis Electric props to see combat. They were delivered via Offutt AFB in **March** and **April 1945**. Upon completion of their training, **Tibbets** was promoted to Colonel and **MAJ Charles W. Sweeney** given command of the 393rd BS just before the 509th was deployed to North Field at Tinian Island during **May** and **June 1945**. North Field was the largest combat airfield in the world, home of the 313th Bomb Wing (Circle R tail code), under the 21st Bomber Command (consisting of five B-29 wings under the command of **MGEN Curtis LeMay**, spread out over Guam, Saipan and Tinian Islands).



Left: B-29A carrying two 12,000 lb British Tallboy bombs on a training mission working out the ballistics problems with delivering such heavy ordnance. Right: Group bombardier Major Thomas W. Ferebee (1918-2000), who solved the complex ballistics and delivery problems delivering 10,000 lb payloads. He had been Tibbet's bombardier flying the first B-17 combat missions of World War II out of England in the summer of 1942.

Upon their arrival, the 509th B-29s carried a distinctive tail code of a forward arrow in a circle (see picture). On **July 6th**, they began flying practice missions with conventional "fat man" bombs in 3 to 5 plane elements to Marcus Island, Truk, Rota, and Guguan Islands. After these practice flights, they were assigned 14 pinpoint targets in Japan (Otso, Taira, Fukashima, Nagaoka, Toyama and Tokyo). They dropped their familiar orange-colored "pumpkins", using the steel shell of a "fat man" plutonium bomb, but filled with explosive torpex. They began these missions on **July 21st**, in groups of 8 to 10 aircraft. On **July 29th** the 509th flew their last "practice" missions to Japan, hitting targets in Koriyama, Osaka, Kobe, Shimoda, Ube, Nagoya, Wakayama and Hitachi (a few more torpex missions were flown on **August 14th**, after the Nagasaki mission). In all the 509th flew 51 bombing sorties in 16 missions dropping "pumpkins". **Tibbets** was prohibited from flying any of these missions because of his intimate knowledge of the Manhattan Project.

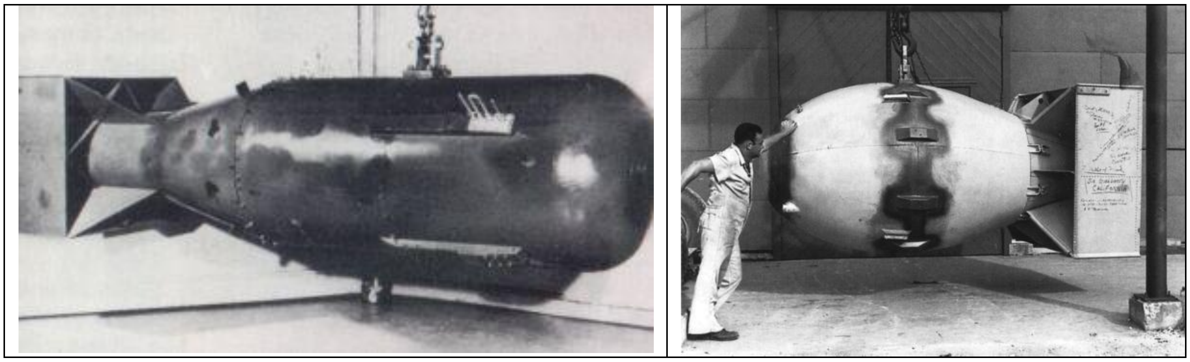
Shortly before the atomic missions, **COL Tibbets** decided to alter the B-29's tail codes because they had been noticed and singled out in several radio broadcasts by **Tokyo Rose**. The Japanese knew the 509th were at North Field, but not what their mission was. The tail codes were altered over the weekend of August 4-5 to represent four different bomb groups operating in the Marianna Islands (four with Circle R; four with Triangle N; three with Square P; and four with an un-bordered A). The circled arrows were repainted on 509th aircraft after the cessation of hostilities. No aircraft names were carried on any of the 509th's B-29s during the atomic missions, with the exception of the *Enola Gay*.

MGEN Groves selected four potential target cities in Japan, which were taken off the B-29 target lists, and thereby spared for the time being. The purpose of this was to provide a more reliable indicator of how effective each atomic blast might be, if and when such attacks occurred. The four cities were: Kokura, Niigata, Hiroshima and Nagasaki (Kyoto had been on the original list, but was removed). All contained "legitimate" military targets, such as heavy industries or railroads.

The 509th used specially built B-29B aircraft without defensive gun turrets, which saved 7000 pounds. Only the tail guns were retained. This shows the Enola Gay wearing the arrow-in-circle tail code that was noted by Tokyo Rose in her radio broadcast a few days before the mission to Hiroshima. The 509th tail codes were immediately changed to mimic those of regular bomb groups operating out of the Mariannas, to shield their identity.

<u>Hiroshima Mission</u>

Seven B-29s of the 509th Group were actually involved in the world's first atomic mission, carried out on Monday **August 6, 1945**. One was positioned at Iwo Jima as a spare aircraft, in case one of the others had to abort. At 1:37 AM three of the 509ths B-29s took off to scout the weather ahead of the strike force. These included *Jabitt II* bound for Nagasaki; *Straight Flush* to Hiroshima; and *Full House* was sent to Kokura. **Colonel Tibbets** was given aircraft Victor 82 to fly the mission, which he named the "*Enola Gay," after his mother.* This aircraft would carry the U-235 bomb, dubbed "*Little Boy*". The bomb was 10 feet long, 28 inches in diameter and weighed almost 9,700 pounds.



The U235 atomic bomb Little Boy (left) and the Pu239 bomb Fat Man (right). The imploding Fat Man became the prototype nuclear weapon after the Second World War, with all the plutonium being manufactured at Hanford, WA.

Pre-flight briefing of the Enola Gay, Straight Flush and Great Artiste aircrews on Tinian. Colonel Tibbets is sitting in the second row smoking a pipe.

Tibbets had *Enola Gay* painted with Circle R tail code, simulating 6th BG 313th Bomb Wing aircraft, from Tinian's North Field. The aircraft's pre-flight operations were well documented by Army photographers, using klieg lights to illuminate the aircraft. *Enola Gay* was packed with 7,000 gallons of high octane aviation fuel and a 9,000 lb. bomb. She lifted off from Runway A on North Field at 2:45 AM local time. She was followed by the instrument aircraft *The Great Artiste* on Runway B, piloted by **MAJ Sweeney**, which included Project Alberta scientists **Luis Alvarez**, **Lawrence Johnson** and **Harold Agnew**. Bringing up the rear on Runway C was the photographic plane, *Necessary Evil*, piloted by **CAPT George Marquardt.** The three aircraft were spaced about 2 minutes apart.

Scientific observers with Project Alberta on Tinian included Luis Alvarez, Lawrence Johnson, and Harold Agnew, shown here. Alvarez had the distinction of being the only person to fly and observe the first three atomic missions: the Trinity Test, Hiroshima, and Nagasaki, from orbiting B-29s.

Enola Gay being backed on over arming pit at North Field on Tinian, where the U235 atomic bomb Little Boy was hoisted into her forward bomb bay. Note the revised Circle R tail code of the 6th Bomb Group, also based at North Field.

Since arriving on Tinian Navy **CAPT Deak Parsons** became increasingly concerned about the safety of the bomb in flight. On Saturday evening August 4th four B-29s crashed while attempting takeoff from North Field, causing **Parsons** to suddenly change his mind about attempting to arm the U-235 bomb after takeoff, in order to avoid any possibility of destroying the enormous North Field B-29 base. **Parsons** resurrected a 2-month old plan by his assistant **LCDR Birch**, which used a "double plug" system of arming the bomb in the bomb bay, after takeoff. **Parsons** practiced the procedure all day long, in preparation for takeoff. *Enola Gay* began the 7+ hour trip to Japan at an altitude of 4,700 feet until the bomb was armed, because the bomb bay was unpressurized. **Parsons** and his assistant **LT Morris Jepson** managed to arm the bomb 25 minutes after takeoff, and *Enola Gay* gradually climbed to 8,000 feet for the lonely trip to the rendezvous above Iwo Jima cruising at a speed of 250 mph at an altitude of 9,300 feet. The accompanying aircraft were each two minutes behind. The three plane echelon gathered at 6 AM and departed Iwo at 6:07 AM, and began the long climb to 30,000 feet.

The nose art of Enola Gay (left), Straight Flush (middle) and The Great Artist (right) of the 509^{th} Group. No aircraft names were carried on any of the 509^{th}'s B-29s during the atomic missions, with the exception of the Enola Gay. The nose art shown here was added shortly after hostilities ceased. The Enola Gay is preserved at the Smithsonian's Udvar-Hazy facility at Dulles International Airport and Bock's Car is preserved at the Air Force Museum in Dayton, Ohio.

The reconnaissance aircraft (*Straight Flush*) arrived over Hiroshima around 7:07 AM local time, triggering an air raid alarm warning at 7:09. She cleared the area by 7:31, and the alarm was terminated. Upon their departure, *Straight Flush* radioed that Hiroshima had clear skies (using an encrypted code). At this time the *Enola Gay* and her escorts were about 40 minutes from the Japanese coast, inbound at a speed of 328 mph.

The three plane element split up, with the photographic plane hanging back, while *Enola Gay* and *Great Artiste* drove on to the target, with just 30 feet separating their wingtips. *Enola Gay* dropped her deadly cargo at 9:15 AM (8:15 AM local time). At the same instant *Great Artiste* dropped instruments to record heat, blast and radiation, which deployed parachutes at 14,000 feet (these were seen by many of Hiroshima's survivors). After loosing their cargoes from an altitude of 32,700 feet, the bombers immediately split apart, on orthogonal tracks: *Great Artiste* turning to starboard and *Enola Gay* to port, in 160-degree diving turns. By banking sharply (50 to 55 degrees) into a gradual dive (they lost 1700 feet of altitude), the planes were 10-1/2 miles away (slant range) from ground zero by the time the bomb's initial blast reached them (the blast traveled at a speed of 1100 feet per second and delivered a jolt of 2.5g's). It took the bomb approximately 43 seconds to fall and another 58 seconds for the blast to reach them, after detonation.

The radar altimeter on the bomb was set for altitude of 1,890 feet, and appears to have detonated at a height of 1,740 feet, directly over the Shima Hospital. The precise position of ground zero was subsequently determined to be 550 feet from the T-shaped Aioi Bridge. The bomb was loosed at an altitude of 31,600 feet at an initial forward velocity of 270 mph. Ignoring wind resistance, the time-to-detonation should have been 43.85 seconds, while theoretical time-to-ground impact would have been 45.07 seconds. If the bomb's trajectory were taken to the ground surface, it would have hit within 7 feet of the aiming point! This was probably the most precise high altitude bombing mission of the Second World War.

The explosive energy of the U235 bomb was estimated to have been equivalent to about 12,500 tons of TNT. Of this, 35 % was expended as thermal radiation, 17% as radioactive radiation, and 48% as blast energy. About 40 seconds after detonation (1 minute and 23 seconds after dropping the bomb) the aircraft received a 2g initial blast wave, which traveled outward at a speed of approximately 1,100 feet per second. This concussion was followed by a second one, which was the reflection of the first compressive wave off the ground (since the bomb exploded almost 2000 above ground). After several minutes **Tibbets** re-assembled the three-plane element and circled Hiroshima till 8:40 AM (local time), to document the bomb's effects. *Enola Gay* landed at North Field at 2:58 PM, after being airborne for a little over 12 hours. Her crew was met by every Army Air Corps dignitary in the Pacific, and **Col. Tibbets** was given the Distinguished Service Cross by **Gen. Carl A. Spaatz**, Commander of U.S. Strategic Air Forces-Pacific (who had only arrived on July 29th, to oversee reorganized aerial operations for the invasion of Japan).

Impacts on Hiroshima

Located 1,700 miles from Tinian, Hiroshima capital of Hiroshima prefecture in the Chugoku region of Japan. In **1945** it was Japan's 7th largest city, with a pre-war population of 380,000 people. About 240,000 were residing there in early **August 1945**. Hiroshima was home to Japan Steel Company and the headquarters of the Japanese 2nd Army Group, responsible for the defense of Kyushu and southern Japan, which the Americans intended to invade in **October 1945**. The city was a communications center, a storage point, and an assembly area for troops. The alternate targets of Kokura (100 nm SW) and Nagasaki (200 miles SW) were within easy flying distance of Tinian as well.

The city was located on a delta, dissected by a series of distributaries of the Ota River. Because of the low lying topography, the blast energy was able to sweep over a broad area. The bomb killed everyone within 1 km of ground zero, destroying houses up to 2.6 km away, and inflicting severe skin burns on people up to 3.9 km away. All structures within 2 km were incinerated by the fire that followed. Flash burns were recorded up to 3.9 km away (2-1/2 miles). . Five hours later, a 20th AF F-13 reconnaissance aircraft (a modified B-29) was dispatched to record the devastation. These photos revealed that 4.7 square miles of Hiroshima was destroyed, about 68.5% of the city.

Before and after images of Hiroshima attest to utter destruction of the Little Boy atomic bomb. This was the most accurate bombing of mission of the Second World War, with the bomb detonating at an altitude of 1740 feet on a precise trajectory, within 7 feet of the primary aiming point on the Aioi Bridge (a 500 foot ground separation because of the parabolic trajectory).

At the time, 71,379 were listed as dead or missing, with 68,023 injured. The Japanese government has monitored post-event deaths believed to be related to effects of radiation (which assume all forms of cancer are likely attributable to radiation exposure), and the final toll was officially set at 118,661 killed with 30,524 severely injured. The Hiroshima Commercial Display Building (about 800 feet from Ground Zero) was retained in its damaged condition as a mute monument to the attack's ferocity.

The Days Between Hiroshima and Nagasaki


President Harry S. Truman (1884-1972) and the heavy cruiser USS Augusta (CA-31). The only president who served in the First World War, Truman always maintained that the decision to drop the atomic bombs was not a difficult one for him to make, as his primary concern was to conclude the conflict with Japan as soon as possible, hoping to avert an Allied invasion of the Japan that would have cost 500,000 to more than 1 million American casualties.

On Monday August 6th, **President Harry S. Truman** was aboard the Navy cruiser *USS Augusta* in the North Atlantic, on his way home from the Potsdam Conference near Berlin. 16 hours after the Hiroshima explosion, **Truman** announced via radio (from the *Augusta*) that the United States had dropped a new atomic bomb on Japan, and called for the Japanese to capitulate, or face prompt and certain annihilation. Armed Forces Radio immediately began broadcasting to the Japanese mainland the fact that an atomic bomb was used to destroy Hiroshima and that more would soon follow if Japan refused to capitulate. On **August 7th** and **8th**, 21st Bomber Command dropped 4-1/2 million leaflets on major Japanese cities, bluntly informing the Japanese as to the destructive power of atomic bombs and encouraging them to inquire about what had occurred at Hiroshima. It implored the Japanese people to besiege their Emperor to end the war, and accept the 13 consequences of an honorable surrender.

One of the 4.5 million leaflets dropped by 21st Bomber Command on Hiroshima, Nagasaki, and 33 other Japanese cities on 1 August 1945. The Japanese text on the reverse side of the leaflet carried the following warning: "Read this carefully as it may save your life or the life of a relative or friend. In the next few days, some or all of the cities named on the reverse side will be destroyed by American bombs."

On Tuesday **August 7th** 21st Bomber Command sent 152 B-29s to Japan, hitting a variety of smaller targets. On **August 8th** they sent 375 B-29s to Japan. 224 of these dropped firebombs (napalm) on the industrial city of Yawata, the neighboring city to Kokura. The fires ignited during the evening **of August 8th** would spare Kokura the following morning, when *Bock's Car* would make three aborted attempts to drop the second atomic bomb.

<u>Nagasaki Mission</u>

The second atomic bomb used 11 pounds of plutonium Pu239 (about the size of an orange) and was dubbed "*Fat Man*". It was painted bright yellow and was the same type of implosion device that had been detonated **July 17th** in New Mexico. The bomb was 128 inches long , with a diameter of 60 inches, and weighed 10,300 pounds. It would be fitted with four sets of redundant fuses, including barometric, timing and radar. Each of these systems was also duplicated, to insure the bomb exploded well above ground. Unlike the Little Boy U235 bomb, Fat Man could not be armed after takeoff, it had to be carried "live." The second atomic mission was carried out on Thursday **August 9th, 1945**. The 393 BS commanding officer **Major Charles Sweeney** was selected by **Tibbets** to lead the mission. **Sweeney's** regular aircraft was *The Great Artiste*, which remained filled with monitoring equipment used on the Hiroshima mission, so he selected *Bock's Car*, normally commanded by **Capt. Fred Bock**, while **Bock's** crew flew *The Great Artiste* as the instrument plane. *Bock's Car* was painted with a Triangle N tail code, simulating a 444th BG 58th Bomb Wing aircraft from Tinian's West Field. The other aircraft was to be the photographic plane, piloted by **LCOL James T. Hopkins** (in *Big Stink*). The senior officer aboard was Navy **Commander Frederick L. Ashworth**, the bomb armorer (who had extensive combat experience), but Sweeney was the aircraft commander.

Left: Crew of Bock's Car on the Nagasaki mission, minus Commander Ashworth. Right: Nose art on Bock's Car. After Bock's Car dropped the Pu239 weapon on Nagasaki, the crew managed to make Yonton Field on Okinawa with just one engine turning and only 35 gallons of fuel by the time the plane stopped, unable to taxi off the runway. The probability of the crew getting the aircraft back to Okinawa safely was about 1-in-1000.

From the outset, things didn't go nearly as smooth on the second atomic mission. Just before take off, Sweeney discovered that the fuel pump attached to the 640-gallon auxiliary tank in the aft bomb bay of *Bock's Car* was not operating properly (the 509th's atomic bombers were fitted with two 640 gallon auxiliary tanks, enabling them to carry 8,860 gallons of fuel, 1280 gallons more than other B-29s). Scheduled for a 2:30 AM takeoff, **Sweeney** lost precious time trying to decide whether to scrub the mission, eventually asking **Col. Tibbets** to make the call. **Tibbets** reminded him that the bomb bay fuel tank was not essential, it was there as a counter weight for the heavy A- bomb in the forward bay and for use as a back-up (mission planners had provided for 1,000 gallons of reserve fuel). He suggested going ahead, but warned of not wasting fuel by circling at the rendezvous.

Bock's Car finally took off at 3 AM. She was carrying 7,000 gallons of gas, of which 6,400 would be accessible. The three plane element was diverted to a rendezvous point at Yakushima (off the southern coast of Kyushu) because a typhoon was threatening Iwo Jima. *Bock's Car* had to transit to Yakushima at 17,000 feet (instead of 8,000) to stay above the rough weather, and this expended additional fuel. *Bock's Car and The Great Artiste* rendezvoused at 30,000 feet over Yakushima at 7:45 AM, but there was no sign of **Hopkin's** photographic plane. **CDR Ashworth** encouraged **Sweeney** to remain orbiting, so that valuable data would be recorded. Sweeney spent 45 minutes circling, waiting for **Hopkins** to appear, but he never did. He was burning up about 500 gallons per hour of fuel at that altitude (it turned out **Hopkins** was flying at 39,000 feet instead of the prescribed 31,000). At this juncture both weather reconnaissance aircraft reported scattered clouds (20% cover) over Kokura and Nagasaki. **Sweeney** decided to press on for Kokura, attempting three bomb runs, without gaining visual recognition required for bomb release. In part, Kokura was obscured by smoke generated from B-29 raids on nearby Yawata the previous evening. After 55 minutes of frustration and dangerously low on fuel, **Sweeney** was forced to head for the divert target, Nagasaki.

The two aircraft arrived over Nagasaki just before 11 AM, but *Bock's Car* no longer had sufficient fuel to even reach Okinawa. They encountered 9/10th cloud cover over the city, well above the 20% cover reported several hours earlier. Sweeney decided they would have to drop the bomb using radar navigation, despite the "visual-only" policy that had been demanded by mission planners. On the way in to the Initial Point **Sweeney** asked for **CDR Ashworth's** concurrence, but never got it. They opened their bomb bay doors 30 seconds before the radar drop. At 25 seconds till drop bombardier **Kermit Beahan** found a small opening in clouds, between two large Mitsubishi armaments plants along the Urakami River and the bomb was released at 11:01 AM local time. The bomb exploded almost 1-1/2 miles wide (upstream) of the intended target, at an altitude of 1,890 feet, but obliterated the heavy industries along the Urakami River, sparing most of the residential district.

Carnage on the ground in the heart of Nagasaki.

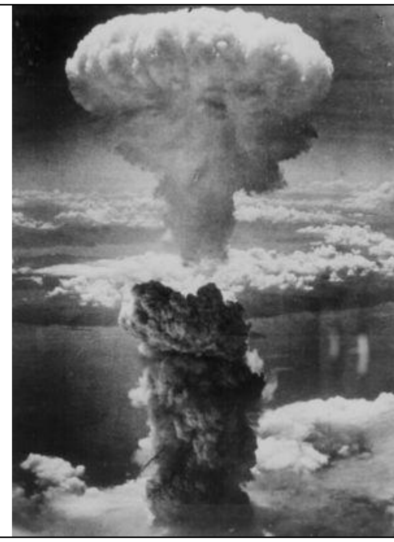
With only 300 gallons of accessible fuel remaining, *Bock's Car* (with *Great Artiste* in trail) made haste for the nearest airfield, at Yontan on Okinawa, almost 350 miles away. There was theoretically insufficient fuel to travel more than about 250 miles. They were going to have to ditch the aircraft somewhere 70 to 100 miles short of Okinawa. Flight engineer (Fred Kuharek) was able to transfer fuel from the 640-gallon auxiliary tank with the errant pump, but at a slow rate. **Sweeney** reduced his fuel consumption by turning the engine rpm's down to 1600 rpm (well below the recommended cruise setting of 2000 rpm) and "flying on the step", a technique developed by **COL Tibbets**. "Step flying" involved taking the plane into gradual descent without increasing engine power, thereby gaining airspeed without using additional fuel. In this way, the low power settings were supplemented, thereby conserving fuel. The method could only be used in a downward flight profile. On the way to Okinawa, **Sweeney's** crew tried raising Air-Sea rescue and Yontan Airfield tower, but neither responded (four B-29s had been launched as "dumbo" aircraft in case of a ditching, but had flown back to Tinian because it was believed **Sweeney** had aborted the mission, since **Hopkins** couldn't find him).

Unable to raise Yontan Tower by radio, Bock's Car fired 22 emergency flares to get the field's attention. She lost No. 4 engine on approach and hit the midpoint of the runway at 140 mph (instead of 110 mph), losing power to the No. 1 engine on touchdown. The pilots hit the brakes hard to bring the mammoth aircraft to a halt at the far end of the runway, when the No. 2 engine also quit! The plane had to be towed to a ramp suitable for refueling. Afterwards, it was learned the No. 3 engine only had 35 gallons of fuel (an insufficient amount to have kept the aircraft flying for another approach). It was one of the closest calls of any bomber mission in World War II. Yontan was headquarters for the newly transferred 8th Air Force, under **LGEN Jimmy Doolittle**. **MAJ Sweeney** was debriefed by **Doolittle**, who had flown the first mission against Japan on April 18, 1942. After towing Bock's Car to the fueling stand and re-fueling the plane, **Sweeney** rejoined his crew for the 5 hour flight back to Tinian. *Bock's Car* landed on Runway A at Tinian at 10:39 PM local time, and taxied into her hard stand 40 minutes later, without the fanfare or reception accorded *Enola Gay's* triumphant return a few days previous.

<u>Impacts on Nagasaki</u>

At that time Nagasaki had a population of approximately 212,000 people. The City was spread out along the Urakami River Valley, and housed two of Mitsubishi's largest wartime manufacturing plants, including the vast steel and armament works. The plutonium bomb exploded at an altitude of 1,650 feet, within 2000 feet of the steel and armament works. It released 22,000 tons of TNT blast energy, almost double that of the Hiroshima bomb. The bomb's blast leveled an area roughly 2.3 x 1.9 miles in size, destroying 38% of the City (1.45 mi^2 of the 3.86mi^2 area). The damage tapered off about 9,000 feet from ground zero.

Many parts of Nagasaki were protected by a series of low ridges, in particular the residential downtown area. The first undamaged buildings were noted about 4.6 km from ground zero. According to official statistics kept at the time, 25,680 were killed or missing, with 23,345 injured. Post-war statistics maintained by the Japanese list 73,884 deaths attributed to the bomb, with 74,900 injured. These include all post-war deaths from cancer, of any type.



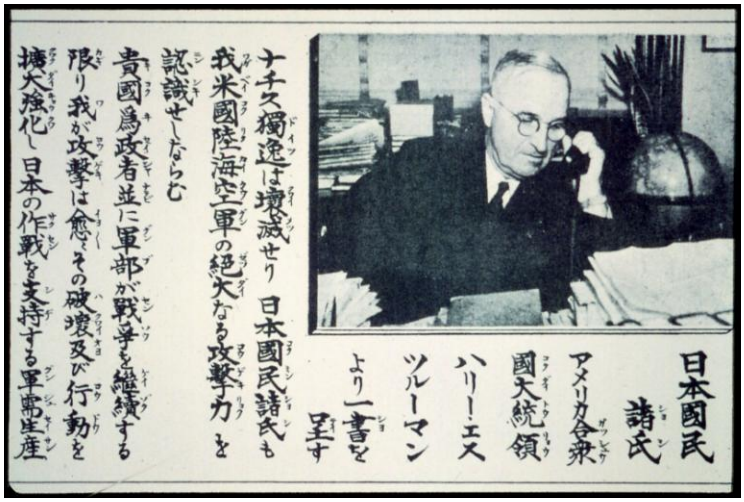
The sinister mushroom clouds of Hiroshima (left) and Nagasaki (right) were indelibly imprinted on the minds of all Americans throughout the Cold War, especially during the Cuban Missile Crisis in 1962.

Surprise Ending

A battle to end the war raged in the Japanese capital, with numerous mutinies and attempted coups. Worried about public panic, the militarists panned off the Hiroshima explosion as an unusual firestorm ascribable to unique atmospheric conditions, never mind the leaflets and radio transmissions broadcasting to the contrary. The diplomats were becoming increasingly frustrated. In the heat of the ongoing debate, things suddenly became even hotter.

On Thursday morning **August 9th** the Soviet government announced it was declaring war on Japan. At 11 AM *Bock's Car* dropped a second atomic device on Nagasaki. In Tokyo it was a day of nonstop conferences. The Supreme War Council was convened by **Foreign Minister Togo Shigenori** and by the afternoon Premier **Suzuki Kantaro** acceded to the previously unthinkable, stating *"Let us, the present Cabinet, take the responsibility of seeing the country through the termination of the war"*. The Emperor gave audiences from 9 AM till 11:30 that evening, his longest working day of the war. The War Council had only one concern left, the preservation of the national polity - the Throne.

Left: The difficult task of bringing the war to a close fell upon Foreign Minister Togo Shigenori, who was appointed in April 1945 after the militarists resigned. Shigenori had served as Foreign Minister in 1941-42, but was ousted because of his opposition to war with the United States. Middle: Emperor Hirohito inspecting bomb damage in Tokyo in 1945. His radio broadcast on August 14th calling for unconditional surrender was the first time Japanese soldiers or civilians ever heard his voice. Right: Post-war occupation commander General MacArthur and Emperor Hirohito, in early 1946. The Japanese wartime leadership never imagined that the National Polity would be preserved when the Americans conquered their country.



One of the 5-1/2 million special leaflets dropped on Japan on August 14, 1945, announcing Japanese peace overtures through the Swiss Embassy and the American's reply. It urged the Japanese people to encourage their leaders to cease hostilities to avoid unnecessary bloodshed. These revelations were an enormous embarrassment to the Suzuki government.

The next day the foreign ministry issued a note to the Americans through the Swiss consulate asking for peace, and dearly hoping to avert another atomic blast. At 4 AM the following day (**August 11th**) the Soviet Army struck out across the Manchurian frontier. Later that day the Americans responded to the Japanese peace overture by demanding they publicly accept the tenants of the Potsdam Declaration, which included the wording "unconditional surrender." Concerned about preservation of the **Emperor**, the Japanese cabinet stalled, again mired in a vicious internal fight. The Americans tipped the scales by dropping a record 5-1/2 million leaflets on the **13th** spelling out the Japanese surrender overtures to the Swiss embassy and the American reply. This exposed the cabinet's actions, and the Emperor was obliged to intercede, calling his people to lay down their arms and accept the unconditional surrender during a noontime radio broadcast on Tuesday **August 14th**, heard clearly by the allies. It was the first time the Japanese people ever heard their Emperor's voice over radio. The Japanese pronouncement came just 194 hours after the Hiroshima drop. Regardless of one's political views, it's difficult to separate the atomic bombs from the Emperor's sudden decision to intervene in the war and accept an unconditional surrender.

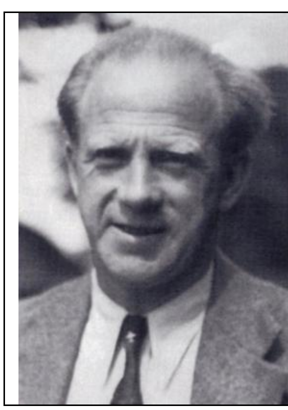
Two nuclear warheads had suddenly and irrevocably accomplished peace in a span of a week and a day. To those who were there and lived through those toilsome hours of agonizing how to end it, the connection between the events was as solid as an arc weld. The Japanese leadership, for their part, had reacted as the Americans had hoped, and numerous internal memos attest to their belief that the Americans had a sizable stockpile of nuclear bombs, and that certain and complete annihilation would ensue unless they acted quickly. It was one of the few times where American efforts to coerce a particular Japanese reaction were so successful. The American bombing campaign had continued nonstop through August 14th, when 828 B-29s were launched against targets at Hikari, Kumagaya, Isezaki and Tasuchizakiminato, while the 509th was even dispatched to drop seven of their 4-ton pumpkins.

Formal surrender ceremonies between the western Allies and the Empire of Japan were carried out on the battleship MISSOURI in Tokyo Bay on September 2, 1945, bring the Second World War to a close. The Japanese delegates wore dress uniforms and formal attire, while the Allies, on MacArthur's orders, wore their working khaki uniforms.

Revelations at Farm Hall

Two months after the war with Germany concluded, ten of the most prominent German physicists were interned for six months at Farm Hall, an estate near Cambridge, England. This group included Werner Heisenberg, a former student of Nils Bohr thought to be the leading nuclear physicist in Germany. The facility was bugged to record conversations between the German scientists. The purpose of this sequestering was to ascertain how close the Germans had come to developing an atomic bomb during the war. In early August the Germans were given newspaper announcing the detonations of atomic devices over Hiroshima and Nagasaki, which stirred considerable discussion and activity amongst the group, as hoped.

The Germans never came close to producing an atomic bomb for a number of reasons, which included poor leadership among the scientists, an absence of desire to take on so ambitious a project, and a number of technical errors. Within a few days of the Hiroshima announcement, the group completed calculations showing that an atomic bomb was possible, using a modest volume of fissionable material. But, the Germans never had sufficient fissile materials to experiment with, having never developed a suitable enrichment process for U235 or Pu239. Then, there were Walther Bothe's flubbed calculations in January 1941, when he erroneously concluded that graphite was not a suitable neutron moderator, causing their group to pursue heavy water instead. Then, there was the explosion and fire in the Leipzig laboratory in June 1942, from which many precious materials were lost, which took several years to recover.



The key factor that triggered America's efforts to produce atomic weapons were the urgent orders to increase heavy water production at Vemork, which came about, in large measure, from Bothe's erroneous calculations and the Leipzig lab fire! In his 1997 book *Blood and Water: Sabotaging Hitler's Bomb*, author Dan Kurzman eloquently summed this up: "Fatefully, if not for a laboratory explosion and the mistake of a lovesick scientist, Germany might have beat the United States to a reactor and perhaps a bomb."

Werner Heisenberg (1901-1976). After hearing of the atomic bomb being detonated over Hiroshima at Farm Hall, he performed the necessary calculations for designing the U235 bomb in a few days.

Epilogue

One of the political goals of using the atomic bombs was the supposed chilling effect their employment would supposedly have on Soviet dictator **Josef Stalin**. Our state department reasoned that the technological edge of possessing such terrible destructive power would impede Soviet post-war aggression, allowing the western powers to demobilize their military forces. Informing **Stalin** of America's successful detonation of an atomic bomb at the Potsdam Conference was the overture to our post-war policy of containment. The announcement was quietly made to **Stalin** by **Truman** on **July 19th, 1945**, but **Stalin** exhibited complete ambivalence. Later we learned that his network of spies had already apprised him of the Manhattan Project, right down to the last details of the successful Trinity Test at White Sands on **July 17th**.

Hungarian-émigré **Leo Szilard** had become concerned about using the atomic bomb once Germany surrendered, in early **May 1945**. He tried to circulate a petition among the scientists working with him in Chicago, but it never went beyond **Oppenheimer**. **Szilard** warned **Oppenheimer** that the military would use the awful weapon as they saw fit, and that soon thereafter, politicians would use the A-bomb for political coercion of the Soviets, leading inevitably to a nuclear arms race. The President's inner circle of advisors asked **Oppenheimer** how long it might take the Soviets to develop their own A-bomb. **Oppenheimer** had informed them that he thought it would take the Soviets about 10 years to "catch up" with our nuclear weapons program. In actuality, the "nuclear edge" lasted just 4 years. No one had imagined how much inside help the Soviets were getting out of Los Alamos. This set the stage for the "next war."

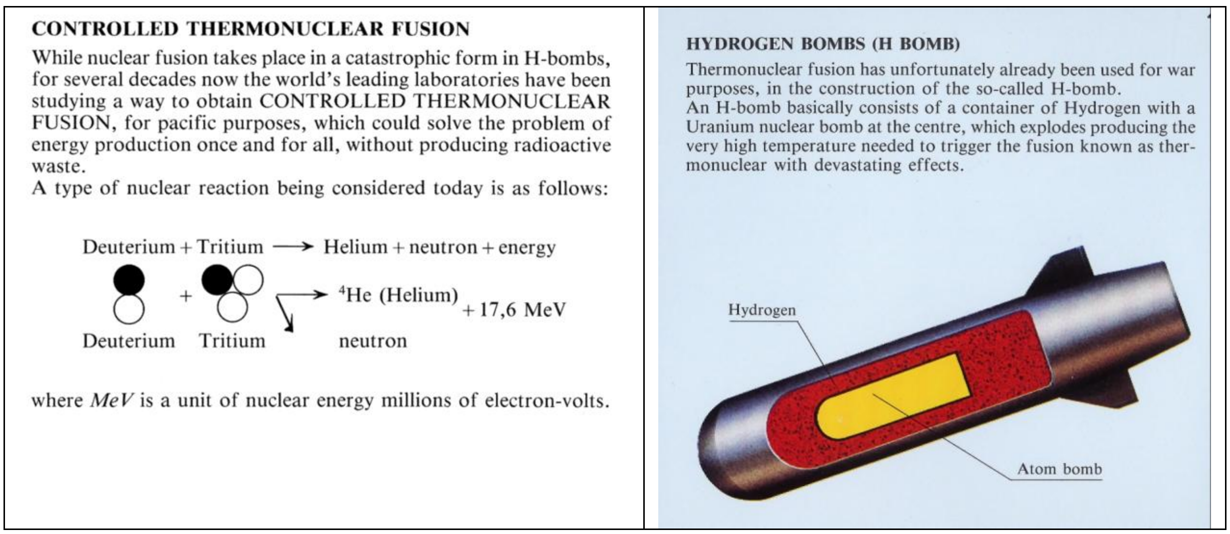
After the Second World War, American intelligence worked hard to decipher wartime Soviet communications codes, so encrypted messages collected during the war and afterwards might be examined, to see what espionage, if any, had been carried out in the United States. By **1949** the Americans succeeded and began deciphering messages sent from the Soviet Embassy in New York to Moscow during the war.

To their horror, they discovered the Soviets had penetrated the highly secretive Manhattan Project. By the fall of **1949**, British physicist **Klaus Fuchs** was revealed as one of the principal agents at Los Alamos, sending highly sensitive information to the Soviets via a small network of spies. This was especially troubling news because **Fuchs** had replaced **Edward Teller** at Los Alamos in **1944** on the committee working to develop the implosion device for the plutonium bomb, the standard nuclear weapon of the post-war era. **Fuchs** was a German-Jewish émigré who had defected to England, and was subsequently lent to the Manhattan Project during the war. No one seemed aware of his pro-Communist politics, and he was promoted to the Patent Committee at Los Alamos after the war, where he was privy to the innermost secrets about **Edward Teller's** pioneering work on "The Super", or thermonuclear (fusion) bomb, then under development.

Klaus Fuchs (1911-88) was found guilty of communicating information to the Soviets concerning atomic research on March 1, 1950 and sentenced to 14 years in prison. After serving nine years of his sentence, he was released (shown at right) and he illegally relocated in East Germany, where he resumed his academic career in physics.

At the same time we were learning about Fuchs (**September 1949)**, American B-29 reconnaissance aircraft overflying the Soviet Union detected radiation particles in the atmosphere, testifying to a successful Soviet detonation of their own bomb, on **August 29, 1949**. If American agents arrested **Fuchs**, it might betray our penetration of the Soviet codes, so the delicate job was left to Britain's Scotland Yard. In **October 1949**, **Fuchs** reported to British security that his father had accepted a teaching position in communist East Germany. Responding coyly, British counterintelligence agent **W.J. Skardon** gradually gained **Fuchs'** confidence, informing him that he had been suspected of espionage activity for some time. Thoroughly distracted, **Fuchs** pondered over how to proceed. He continued meeting with **Skardon** and eventually confessed. He was formally arrested on **January 27, 1950**, but was repatriated to East Germany in **1959**, after serving a 9- year sentence.

The revelations about communist spies in the highest levels of atomic weapons research and development, both during and after the war, had indescribable recriminations. The "Cold War" that developed between the western allies and the Soviet Union represented a psychological state of affairs, fomented by a number of key events, including: 1) The blockade of west Berlin by **Stalin** in **1948**; 2) the detonation of an atomic bomb by the Soviets in **September 1949**; 3) the **Fuchs** arrest and revelations, beginning in **January 1950;** 4) the trials of **Harry Gold**, **David Greenglass** and **Julius** and **Ethel Rosenberg** in America, which came soon thereafter; and 5) the communist invasion of South Korea in **June 1950**, and subsequent involvement of American and United Nations forces in armed combat with the communists.



Teller's thermonuclear bomb became the Cold War's premier weapon, with a destructive power as great as 100 megatons (8000 times that of the Hiroshima bomb). The arms race Oppenheimer and Szilard had feared came to pass, but, thankfully, were never employed in combat. After the collapse of the Soviet Union in 1991, the west learned that Josef Stalin was considering the employment of thermonuclear weapons when he suddenly died in 1953.

By **1952** these events created an atmosphere of intrigue and suspicion, the likes of which were unprecedented in the 20th Century. The arms race with the Soviets predicted by **Szilard** and feared by **Oppenheimer** came about faster than anyone had imagined. Each side began testing thermonuclear (fusion) weapons. The United States detonated a heavy 10.4 megaton device on Elugelab Island at Eniwetok Atoll on **November 1, 1952**. This bomb released 1000 times the destructive power of the Hiroshima fission bomb, but was too large to be carried in an airplane. The Soviets seized the lead in the evolving arms race on **August 12, 1953** when they detonated the first air-deployable thermonuclear bomb, which had a yield of 400 kilotons. The Russians were now ahead of the Americans in the arms race (six months later the Americans carried out their Castle Bravo test on Bikini Atoll, which had an explosive yield of 15 megatons, about 2.5X larger than expected. At 23,500 lbs, it was still too large to deploy operationally in any aircraft except a B-36).

Left: Cover of TIME magazine in late June 1954 announcing revocation of J. Robert Oppenheimer's security clearance by the Atomic Energy Commission's Personnel Security Board (shown at right). This hearing was orchestrated by AEC Chairman Lewis L. Strauss (above right foreground), shown with the AEC Commissioners who voted to deny Oppenheimer's security clearance (left to right) Thomas Murray, Eugene Zuckert, and Joseph Campbell. This was the darkest postscript to the Manhattan Project, which would never have succeeded by July 1945 if not for the leadership of Oppenheimer.

The high visibility trials of communist spies and revelations about Soviet weapons development quickly gaining par with our own created an atmosphere of paranoia, which spawned mandatory loyalty oaths and investigations of anyone suspected of having communist sympathies. No one was immune from suspicion, and **Robert Oppenheimer** soon became one of the victims. **Oppenheimer** had been retained as Chief Advisor to the newly created Atomic Energy Commission after the war, but was not supportive of **Edward Teller's** bombastic demands to develop the much more destructive thermonuclear weapons, which **Teller** zealously promoted as "the super." **Oppenheimer** was concerned about a spiraling arms race that, in the end, would be in the hands of mad men (like **Josef Stalin**) to decide, while western politicians would respond in-kind. His counter-establishment views were publicized in prominent newspapers like the *New York Times* and in journals like *Foreign Affairs* between 1950-54.



Left: Lewis L. Strauss (1896-1974) was a Wall Street millionaire and Naval reserve intelligence officer who rose to the rank of Rear Admiral by the end of the war, working for Navy Secretary James Forrestal. He was a hawkish member of the Atomic Energy Commission from 1946-50 and its Chairman from 1953-58. Middle: Upon retirement from the Army, Major General Kenneth D. Nichols (1907-2000) served as General Manager of the AEC from 1953-55. Right: Edward Teller (1908-2003). Teller's dream of a fusion weapon came to pass after the Soviets detonated their nuclear device in August 1949, years before it was expected. Believing the scientists at Los Alamos were too ambivalent about developing thermonuclear weapons, Teller lobbied Congress to create a separate laboratory for that research, which became the Lawrence Livermore National Laboratory in California. Teller went on to direct research activities at Livermore between 1958-1975.

These security hearings were orchestrated by AEC Chairman **Lewis L. Strauss**, who felt Oppenheimer was endangering national security because of his public opposition to thermonuclear weapons, and what he viewed as Oppenheimer's lapses in judgment in regards to security precautions over the years, because he had refrained from handing academic colleagues over to the FBI who had exposed their leftist tendencies and philosophies (though Oppenheimer never acted upon their suggestions). Strauss was also suspicious of Oppenheimer's previous flirtations with the American Communist Party on the west coast because he felt he might have been used by subversives, unknowingly. The case against Oppenheimer emanated from **William L. Borden**, the executive director of the Joint Congressional Committee on Atomic Energy, who took it upon himself to make a review of **Oppenheimer's** security files in **November 1950**. Just 30 at the time, in a report to the AEC and The FBI **Borden** would conclude that **Oppenheimer** was an "espionage agent" and was acting under a "Soviet Directive." Unfortunately, this radical viewpoint was supported by FBI Director **J. Edgar Hoover**.

In late 1953 the indictment against **Oppenheimer** was prepared by the AEC's new General Manager, retired Major General **Kenneth D. Nichols**, who had served as **Leslie Grove's** principal subordinate during the Manhattan Project. In the late spring of **1954**, a security hearing was convened by the AEC's Personnel Security Board, comprised of **Gordon Gray** (chairman), **Thomas A. Morgan**, and **Dr. Ward V. Evans**. The AEC hoped to convene the hearing in secret and avoid embarrassing media coverage, but a headline story in the New York Times sympathetic to Oppenheimer appeared after the first day of the hearings, and this infuriated **Strauss**, the AEC, and the Eisenhower Administration (Gray had served as Secretary of the Army under President Truman and President of the University of North Carolina). Most of the testimony focusing on his communist party sympathies in California in the **1930s and early 40s**, before he assumed his important role directing the scientific activities of the Manhattan Project. **General Groves** and fellow physicists **Luis Alvarez** and **Hans Bethe** provided defense testimony favorable to **Oppenheimer**, but this was insufficient to counter the sheer weight of adverse testimony, which, more than anything substantial, called **Oppenheimer's** patriotism and judgment into question because his views were at variance with those of the AEC, many in Congress, the Air Force, and the Eisenhower Administration.

The Personnel Security Board voted to strip **Oppenheimer** of his security clearance on **June 29, 1954.** Those who led the charge against **Oppenheimer** paid a price for their zeal. **Edward Teller** tarnished himself irrevocably by testifying against **Oppenheimer**, suggesting that **Oppenheimer's** opposition to his thermonuclear weapons research was probably linked to his "political views." This played into the "once a communist, always a communist" stereotype that **Lewis Strauss**, **William Borden**, **General Nichols**, and **J. Edgar Hoover** seemed to believe about **Oppenheimer**.

The scientific community never forgave **Teller**, feeling his actions were prejudiced by jealousy. His reputation suffered, and he was shunned by much of the scientific community for many years thereafter. **Lewis Strauss** also suffered repercussions for his role in the **Oppenheimer** hearings, four years later. After heading the AEC between 1953-58, **President Eisenhower** nominated **Strauss** to become Secretary of Commerce in October 1958. The Senate rejected his appointment by a vote of 49 to 46 in **June 1959**, making him the only cabinet appointment formally rejected by a Senate vote between **1925** and **1989**! It was an ignominious end to **Strauss'** many years of public service (which began in 1918, when he volunteered himself to become Herbert Hoover's personal secretary while he chaired the Allied efforts for European Relief).

Oppenheimer inherited **Einstein's** position as Director of *Princeton's Institute for Advanced Studies* in **1947**). He aged considerably through these proceedings, which seem shameful in retrospect. **Oppenheimer's** meteoric career in service of his country was over. Although he supervised 17 former or future Nobel Laureates during the Manhattan Project, he never received the Nobel Prize because his interests and contributions were spread over too wide of a spectrum to be recognized as the father or inventor of any significant discovery. His cigarette smoking caught up with him in **1966** when he contracted throat cancer and he died on **February 18, 1967**. **Leslie R. Groves** was promoted to Lieutenant General just before retiring from the Army in **February 1948** and he died of heart failure on **July 13, 1970**.

The proliferation of nuclear weapons typified the "balance of terror" between East and West during the Cold War, or détente, that ensued between **1950-1991**. This standoff ended in **August 1991**, with the dissolution of communist control of the Soviet Union, but thousands of nuclear warheads remain stockpiled in the independent Soviet states. More recently, China, India, Pakistan, and Israel have openly acknowledged their custody of nuclear warheads (though Israel has never tested one). Other "outlaw" nations, such as North Korea, Iraq, and Iran have been rumored to be working on developing their own nuclear warheads. In **1981** the Israeli Air Force attacked a nuclear power plant under construction in Iraq to curtail the possibility of uranium enrichment occurring there. As the memory of Hiroshima and Nagasaki fades, it seems likely that the world will witness the reemergence of nuclear weapons on the world stage, mostly likely employed by rouge nations or terrorists.