THE RACE TO BUILD THE ATOMIC BOMB

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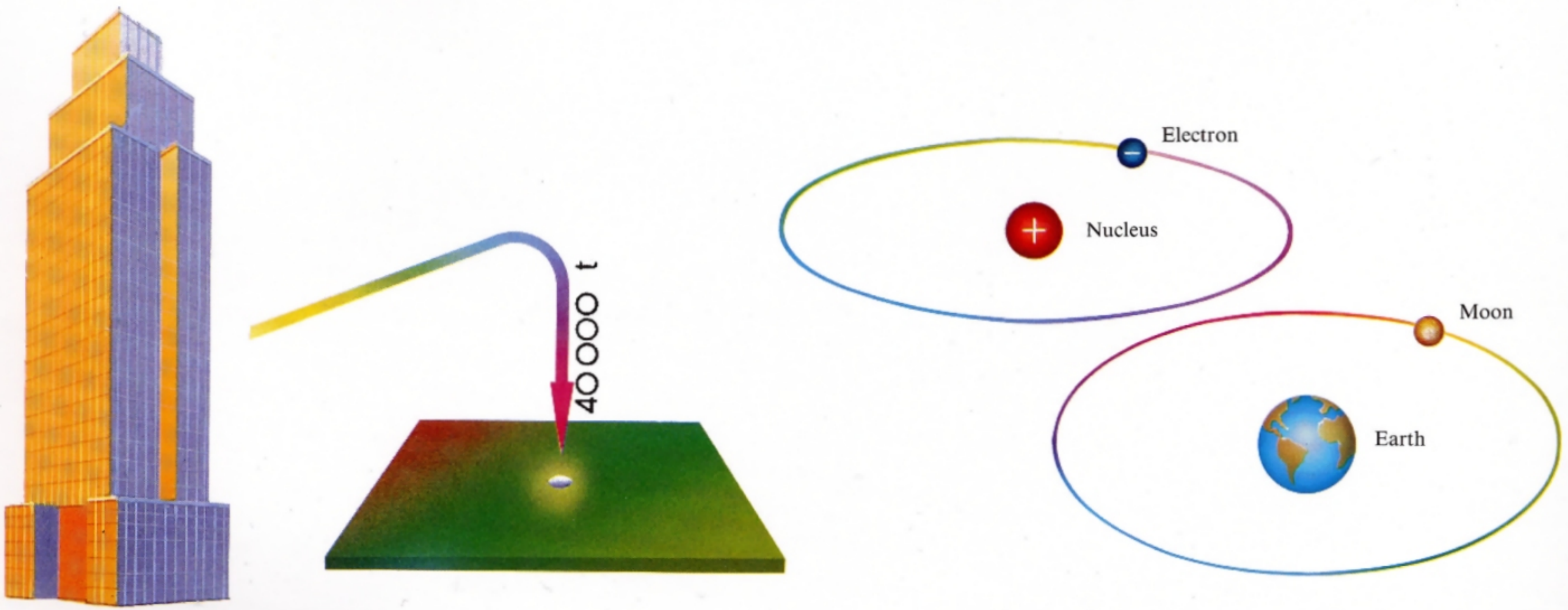
Mysteries of Atomic Structure and Radioactivity

If we took away all the empty spaces inside the atoms of a skyscraper, it would be reduced to the size of a grain of rice, weighing tens of thousands of tons!

The simplest atom is the HYDROGEN atom whose nucleus is formed by a positively charged PROTON, around which a negatively charged electron rotates. This model is similar to the Earth with its satellite, the Moon.



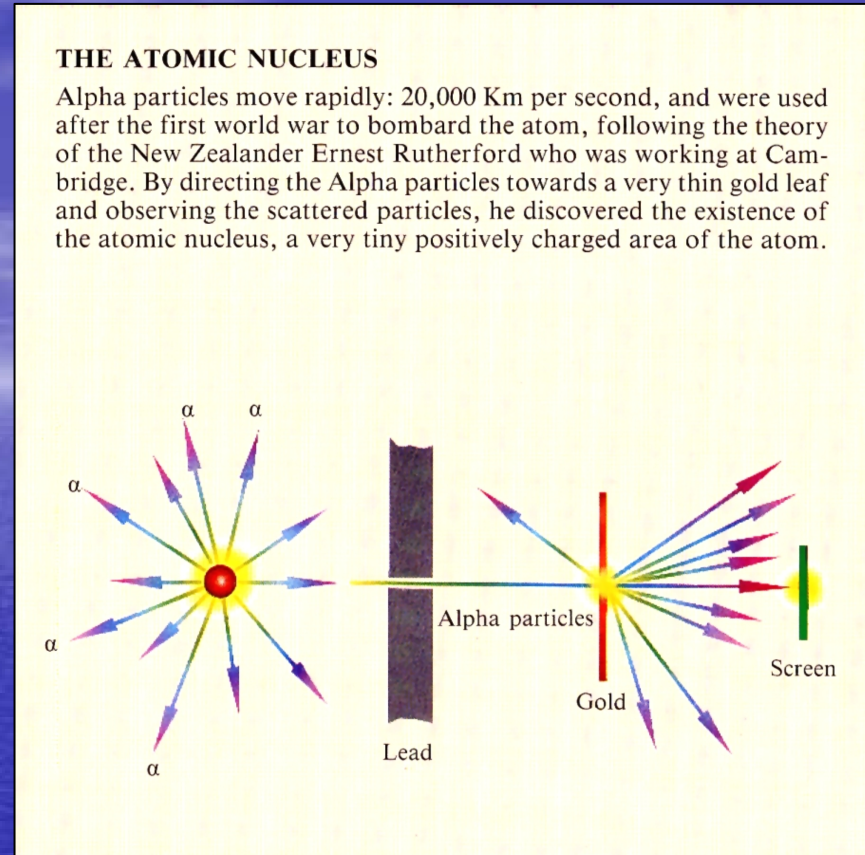
- **The scale of atomic structure made it one of the last mysteries of science to be unraveled, during the first half of the 20th Century.**

RADIOACTIVITY

Unstable elements known as RADIOACTIVE exist: their nucleus usually "explodes" after a long time (centuries or millenia), emitting particles and radiations, and changing into an atom of another lighter element.
In this way RADIUM, discovered by the French Pole Marie Curie, emits Alpha particles (nuclei of Helium), Beta particles (electrons) and Gamma rays (electro-magnetic radiations of the same nature as light, X rays and radio and TV waves).

- In 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.

Ernest Rutherford (1871-1937)



THE ATOMIC NUCLEUS

Alpha particles move rapidly: 20,000 Km per second, and were used after the first world war to bombard the atom, following the theory of the New Zealander Ernest Rutherford who was working at Cambridge. By directing the Alpha particles towards a very thin gold leaf and observing the scattered particles, he discovered the existence of the atomic nucleus, a very tiny positively charged area of the atom.

- **1906 – While working at the Cavendish 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.**

Albert Einstein (1879-1955)

THE FISSION DREAM

- 1907 - While working at the Swiss Patent Office in Bern, Albert Einstein publishes three articles in the German publication *Annals of Physics.* These included: 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.

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:

$$E = mc^2$$

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:

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

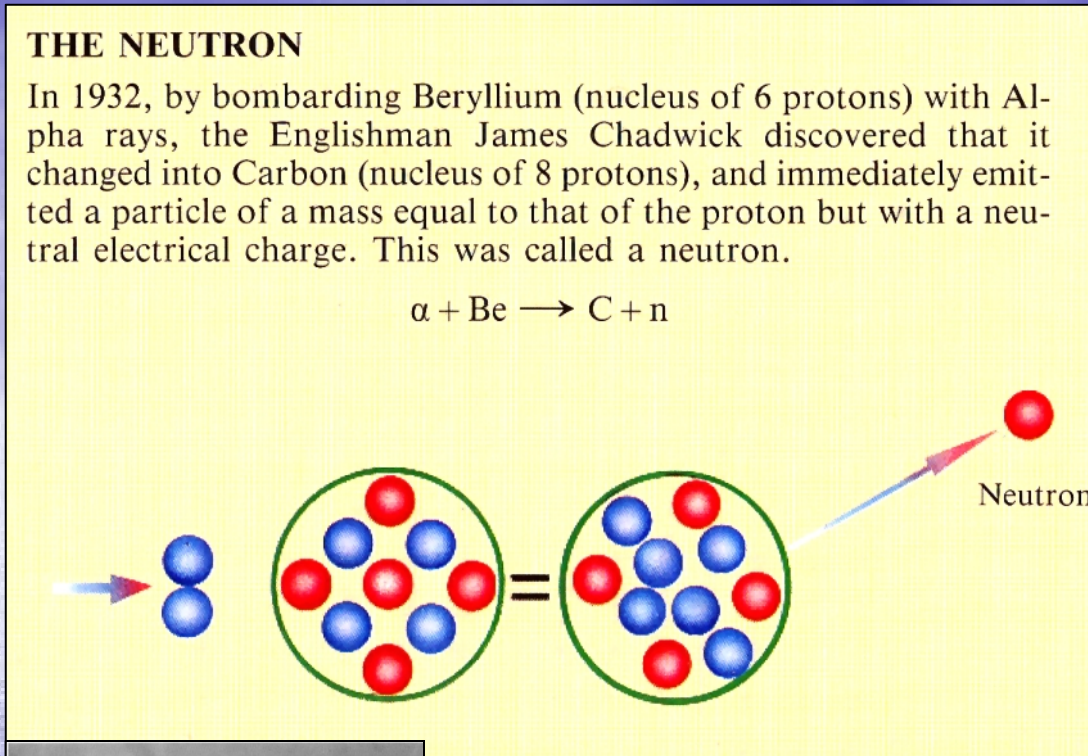
enough to light about thousand billion 100 Watt electric light bulbs for a second!

Albert Einstein
(1879-1955)

Nils Bohr
(1885-1962)

J. Robert
Oppenheimer
(1904-67)

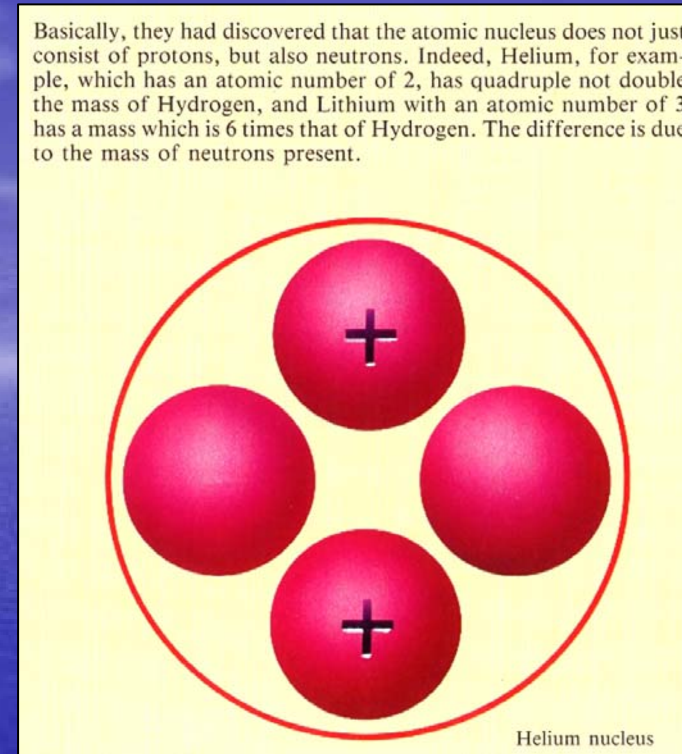
Albert Einstein is awarded the Nobel Prize in Physics in 1921, Nils Bohr of Denmark receives it in 1922. Experimental and theoretical physics is explored by many scientists working a major centers of learning in Europe and America. One of the most famous schools is the *University of Gottingen* in Germany,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



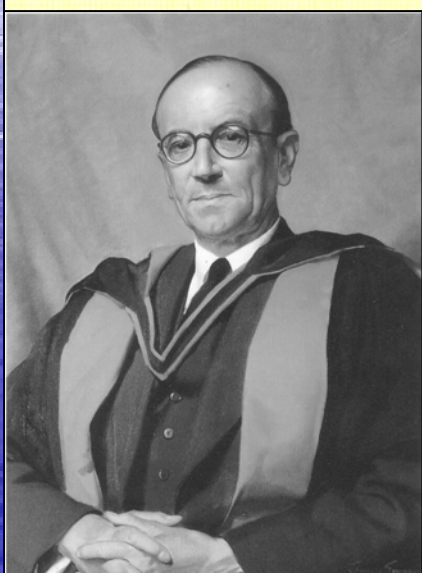
THE NEUTRON

In 1932, by bombarding Beryllium (nucleus of 6 protons) with Alpha rays, the Englishman James Chadwick discovered that it changed into Carbon (nucleus of 8 protons), and immediately emitted a particle of a mass equal to that of the proton but with a neutral electrical charge. This was called a neutron.

$$\alpha + Be \longrightarrow C + n$$



Basically, they had discovered that the atomic nucleus does not just consist of protons, but also neutrons. Indeed, Helium, for example, which has an atomic number of 2, has quadruple not double the mass of Hydrogen, and Lithium with an atomic number of 3 has a mass which is 6 times that of Hydrogen. The difference is due to the mass of neutrons present.

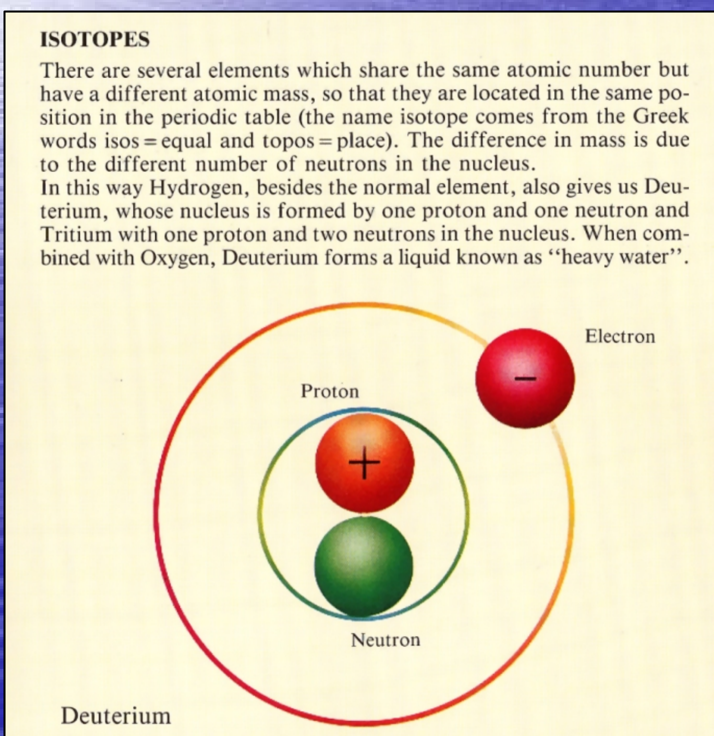


James Chadwick (1891-1974)

- **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 was of monumental significance in helping to unravel atomic structure.***

Discovery of Heavy Water

Harold Urey (1893-1981)

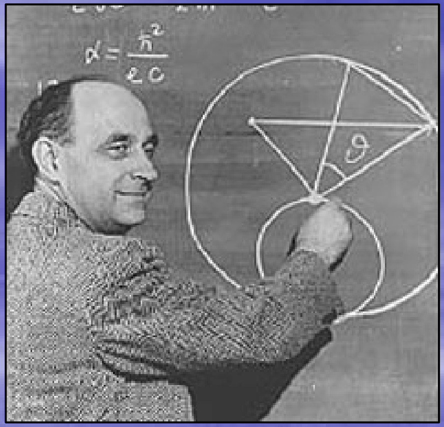


ISOTOPES

There are several elements which share the same atomic number but have a different atomic mass, so that they are located in the same position in the periodic table (the name isotope comes from the Greek words isos = equal and topos = place). The difference in mass is due to the different number of neutrons in the nucleus.
In this way Hydrogen, besides the normal element, also gives us Deuterium, whose nucleus is formed by one proton and one neutron and Tritium with one proton and two neutrons in the nucleus. When combined with Oxygen, Deuterium forms a liquid known as ''heavy water''.

- 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.

Irene and Frederick Joliot-Curie



Enrico Fermi (1901-54)

Leo Szilard (1898-1964)

Lise Meitner (1878-1968) and Otto Hahn (1879-1968)

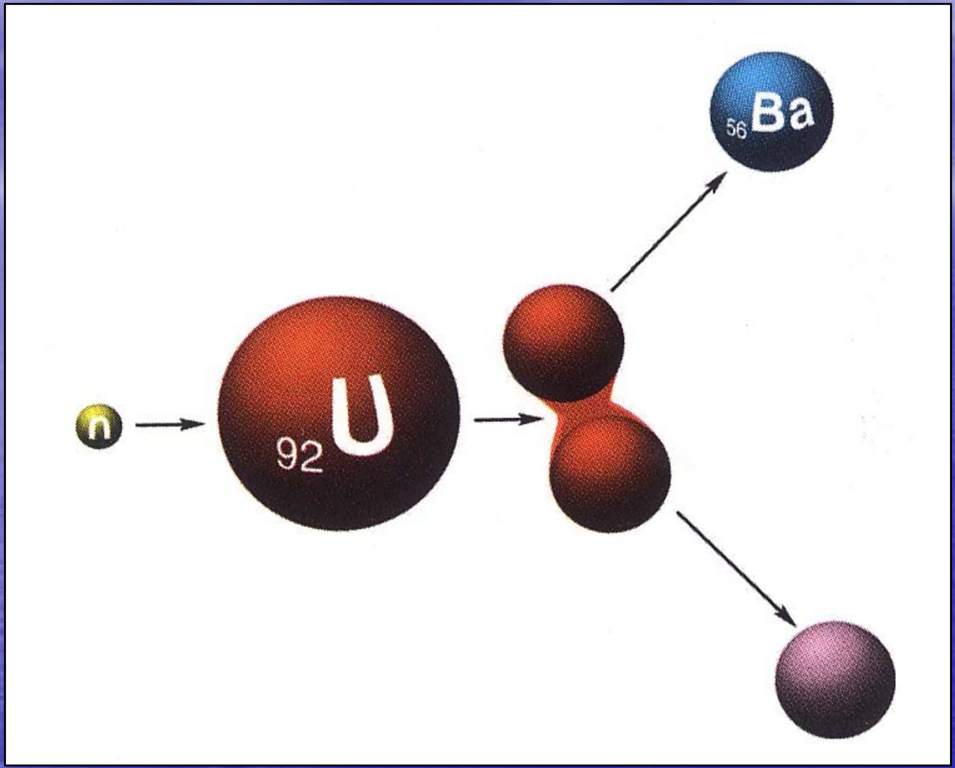
May 1935 – French physicist **Frederic Joliot-Curie** and his wife **Irene** (daughter of **Pierre** and **Marie Curie**) are awarded the **1935 Nobel Prize** in Chemistry for their discovery of artificial radioactivity.

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

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.**

SPLITTING AN ATOM



- *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.*

FISSION OF URANIUM - 1938

FISSION OF URANIUM

In 1938 the Germans Otto Hahn and Fritz Strassman discovered that when the Uranium atom was bombarded with neutrons, it absorbed them and split into lighter atoms like Barium. Some of their collaborators (Lisa Keitner, Otto Frisch) who worked in Sweden to escape racist persecution, developed the theory further by illustrating the FISSION of Uranium.

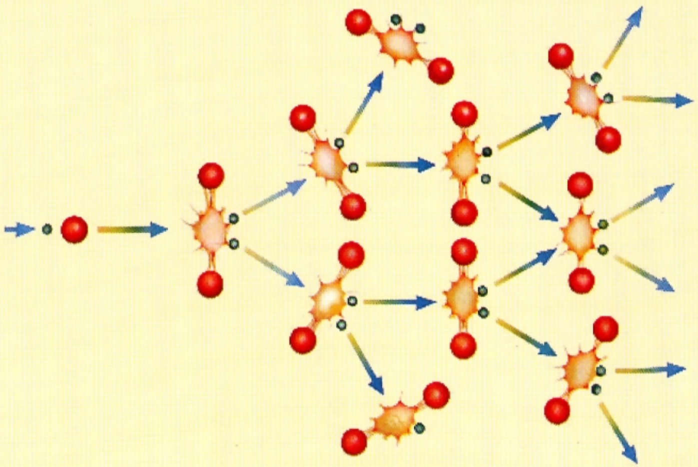
What happened was that, by absorbing one neutron, the isotope 235 of Uranium split in one of the following ways:

$$U^{235} + n \longrightarrow Ba^{139} + Kr^{95} + 2n$$

Uranium + neutron   Barium + Kripton + 2 neutr.

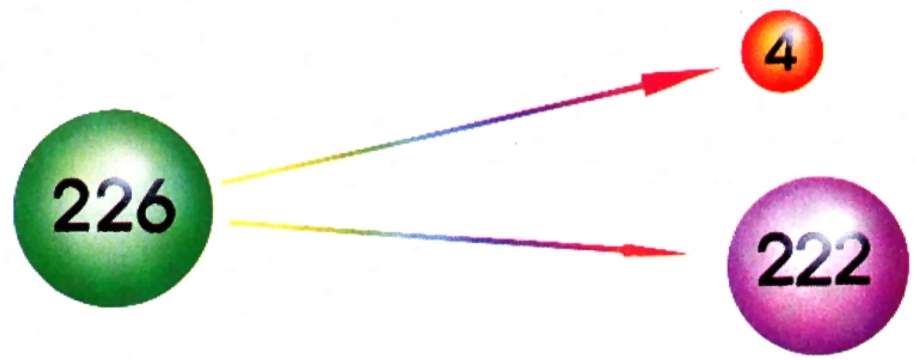
$$U^{235} + n \longrightarrow La^{144} + Br^{89} + 3n$$

(Lanthanium, Bromine)



An extremely interesting fact was that energy was produced and 2-3 neutrons were also generated which could hit other atoms of Uranium and produce a CHAIN REACTION.

- ***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.*** .



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.

- **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.

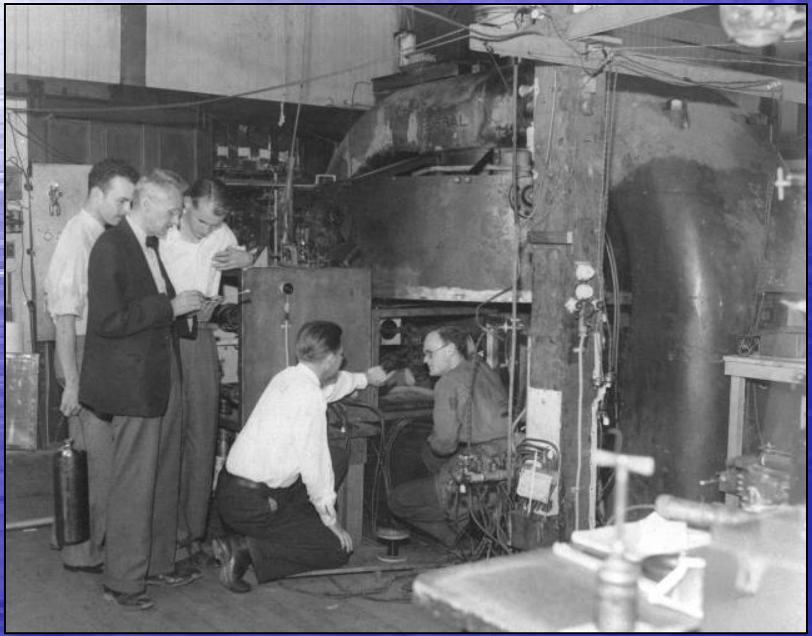
- On the eve of World War II **Nils Bohr** of Denmark, **Yakov Frenkel** of the Soviet Union, and **John Wheeler** of the USA publish papers describing the process of fission. **The war erupts on September 1, 1939, when Germany and the Soviet Union jointly invade Poland.**
- Hastened by recent German 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.

The Germans begin designing a reactor

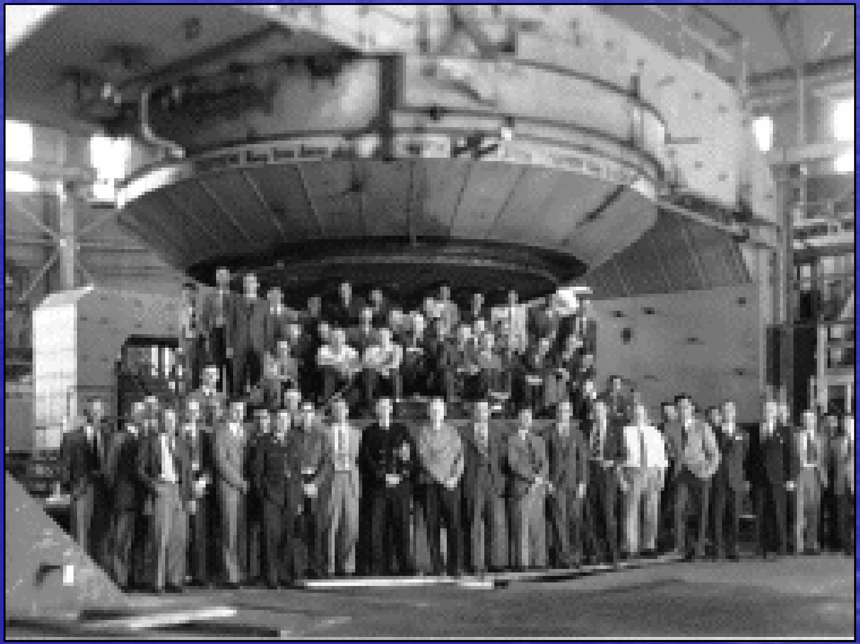
- In January 1940, before invading western Europe, the Germans convened a governmental conference on heavy water in Berlin.
- Paul Harteck and Han Suess of the *University of Hamburg* felt that deuterium could be an effective moderator for a nuclear reactor, thereby facilitating a chain reaction.
- Harteck makes a prophetic warning about uranium fuel and the deuterium moderator not being mixed in a reactor chamber, but 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.

Ernest Orlando Lawrence and his Berkeley Cyclotrons

Ernest O. Lawrence came to the University of California, Berkeley in 1928 and built an 5” cyclotron for accelerating atomic particles using 80,000 electron volts.



Lawrence’s 27” cyclotron in December 1932



184” cyclotron built for the Manhattan Project in 1942

The Discovery of man-made elements at Berkeley

Edwin McMillan (1907-91)

Philip Abelson (1913-2004)

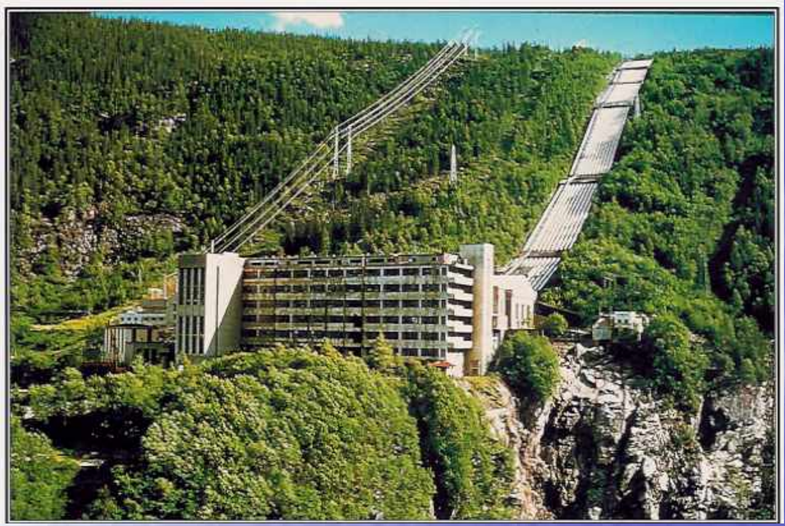
Glenn Seaborg (1912-99)

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

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.

Vemork hydroelectric plant

- 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.



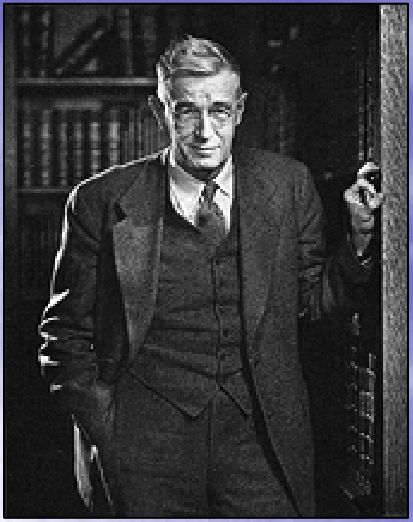
The Germans triple production of heavy water at Vemork

- 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).

Unexpected Source of Uranium from the Congo

Union Minière du Haut Katanga mine superintendent **Edgar Sengier (1879-1963)**

- **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.**
- **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 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.**

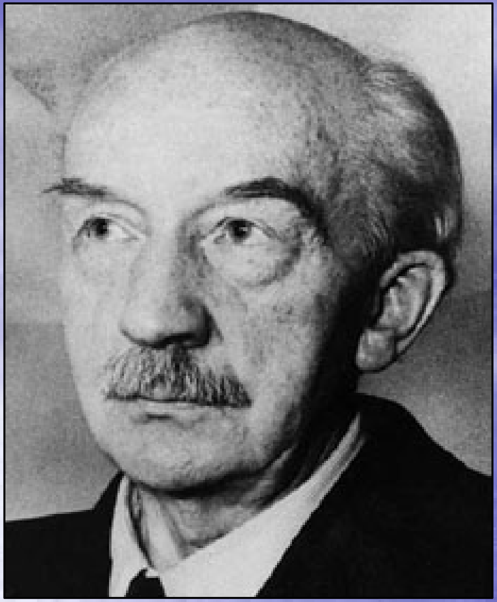


The Americans begin to react to reports of a German atomic reactor, emanating from Vemork

- **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, but would cost upwards of $100 million, and could not be completed prior to July 1944.

HEAVY WATER AS A NEUTRON MODERATOR FOR THE GERMAN ATOMIC REACTOR

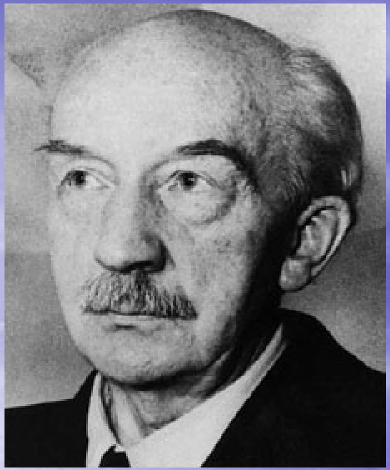
- The extra weight of deuterium oxide (heavy water) served as a slow motion mechanism, moderating the speed of neutrons set free in a nuclear reactor (atomic pile), and thereby allow the neutrons to split uranium atoms in a chain reaction to produce P-239 plutonium – the fissionable element that could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



Walther and Ingeborg

Walther Bothe (1891-1957) was the scientist responsible for calculating the efficiency of deuterium as a neutron moderator for the German reactor

- 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.



The Love Affair that Changed the Course of History

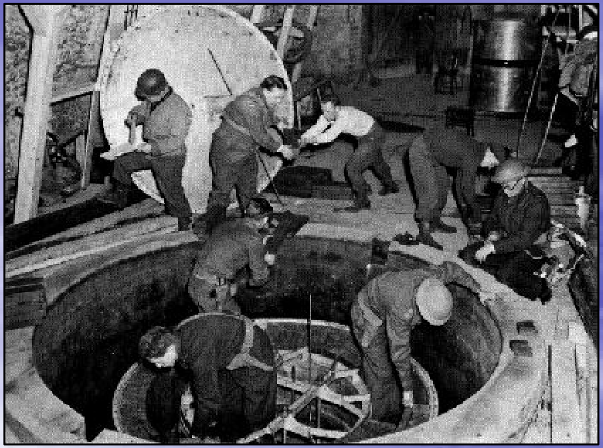
- Walther Bothe's (1891-1957) affair with Ingeborg Moerschner may have changed the course of the Second World War.
- Upon his return to Germany he made uncharacteristic mathematical errors in calculating the potential of graphite as an effective neutron moderator.
- These errors were not discovered for 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.

The Germans Build a Reactor

- In 1939 the German government agreed 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 in Berlin-Dahlem to determine priorities for war production. Heisenberg, the country's leading nuclear physicist, described 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 German Reactor Experiences a Meltdown on June 23, 1942

- 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.
- The pile 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.



Turning Point in the Atomic Arms Race

- 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.

Unsuccessful Raids on Vemork Powerplant

- 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.

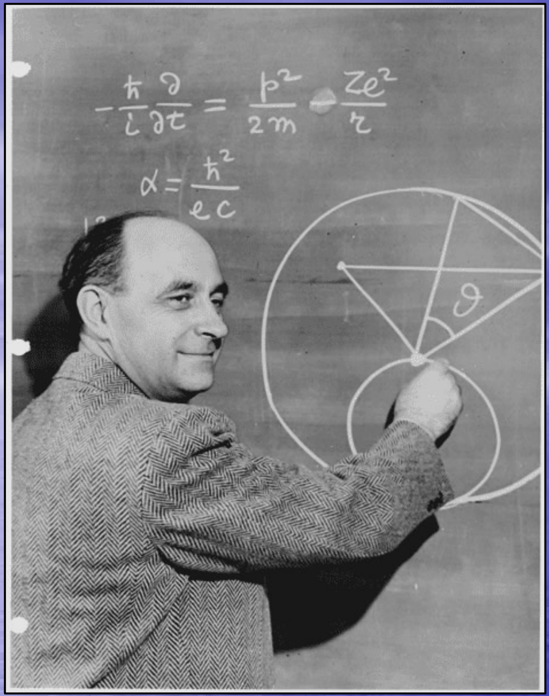
The Americans Bomb Vemork


Amerikansk flyangrep mot
Rjukan og Vemork i går.
Hittil er det fastslått at 20 mennesker er drept.
Mange hus ødelagt som følge av angrepet.

- The American 8th Air Force sent 388 heavy bombers on a raid to the Vemork plant at Rjukan on November 16, 1943
- The raid 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.

Heavy Water stocks sunk

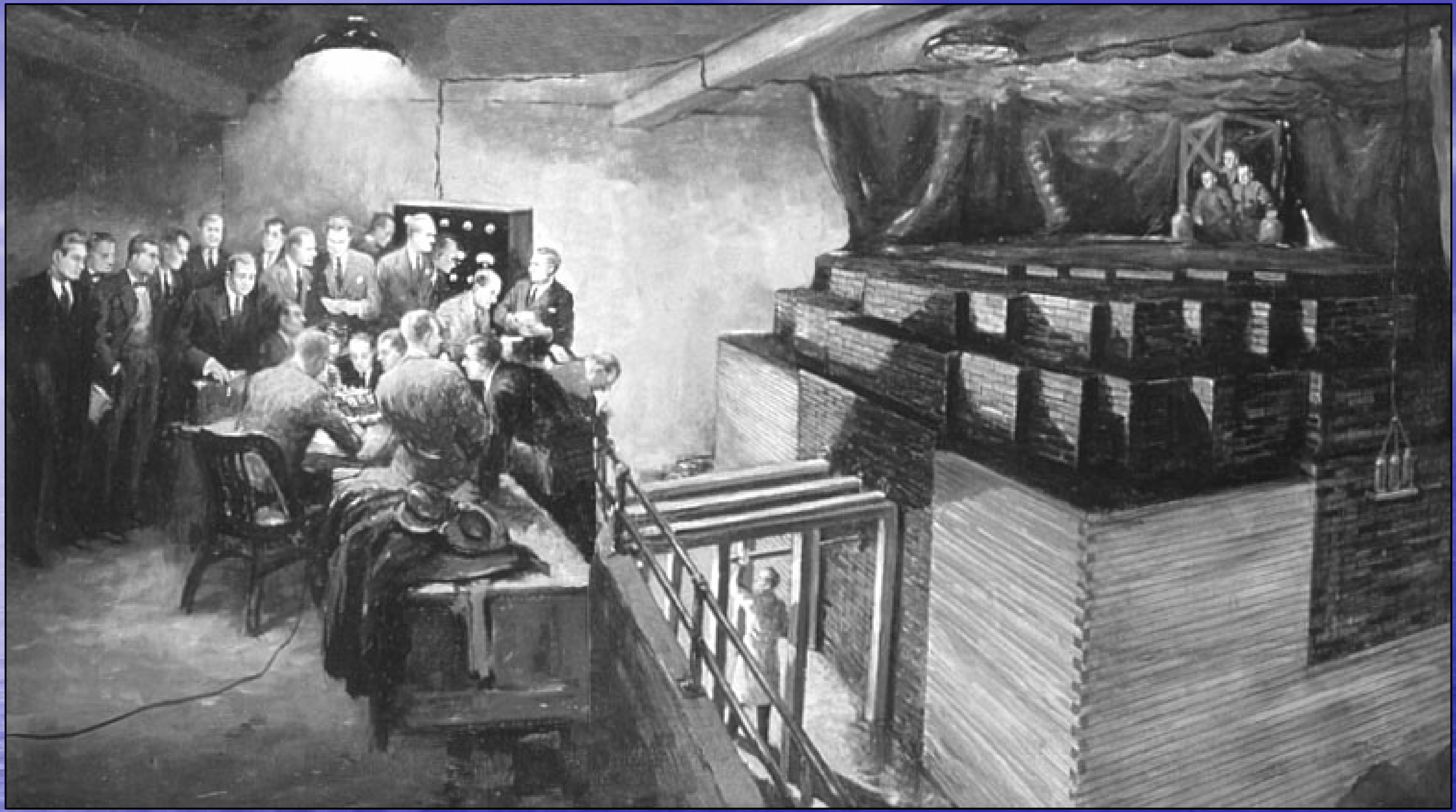
- On Feb 19-20, 1944 – Norwegian resistance saboteurs planted plastic explosives charges in the bilge of the Norwegian ferry *Hydro,* which was transporting railcars and passengers across Lake Tinn. The commando stole aboard at Mael on a Saturday night. The ferry exploded around 11 AM Sunday morning, when ¼ mile from its destination at Tinnoset, on the opposite shore, where the lake was 1,300 feet deep. 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

- 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.



- 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.

MAXIMUM EFFORT: THE AMERICAN'S MANHATTAN PROJECT 1942-45

Professors Bush and Compton

- In **June 1942 Arthur H. Compton** (at left), 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. **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.

Colonel James C. Marshall

Lt Colonel Kenneth D. Nichols (1907-2000)

- 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*.

The Chaplain's Son

Leslie R. "Dick" Groves, Jr. (1896-1970) was born in August 1896 in Albany, NY, the 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, where he graduated 4th in the 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, not promoted to Captain until 1934, then Major in 1940.
- Groves was consistently recognized in the Corps of Engineers as a capable officer and organizer, being 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 to provide more aggressive leadership 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. He insisted on being promoted to Brigadier General when he took command, and was subsequently elevated to Major General in 1944.

The Communist Sympathizer

J. Robert Oppenheimer (1904-67) was born in New York City of German-Jewish immigrants in April 1904.

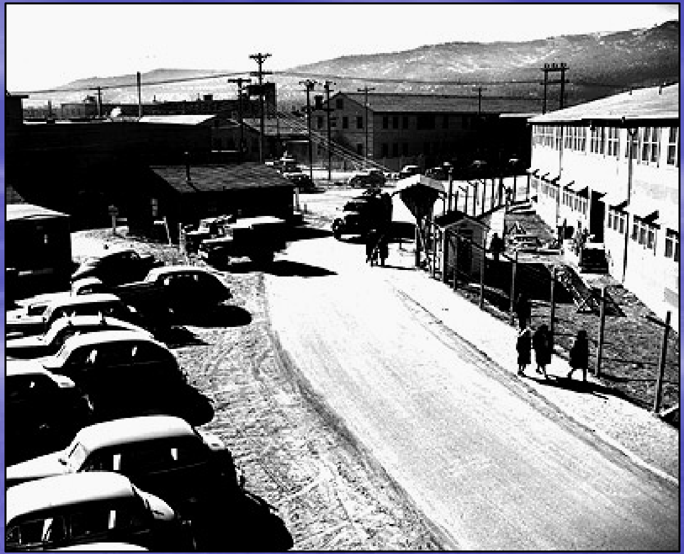
- Oppenheimer completed a 4-year course in chemistry at *Harvard* in three years, then heading for the famous *Cavendish Physics Laboratory* at *Cambridge* in the summer of 1925, where he went to work for English physicist (and later, Nobel Laureate) J.J. Thompson.
- He then accepted an offer from Max 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, where he 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 *Cal Tech*, 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 *Cal Tech* each spring. At Berkeley he began collaborating with experimentalist Ernest O. Lawrence and gained a reputation as an adored intellectual and fascinating lecturer, who "*could charm the pants off most anyone*."

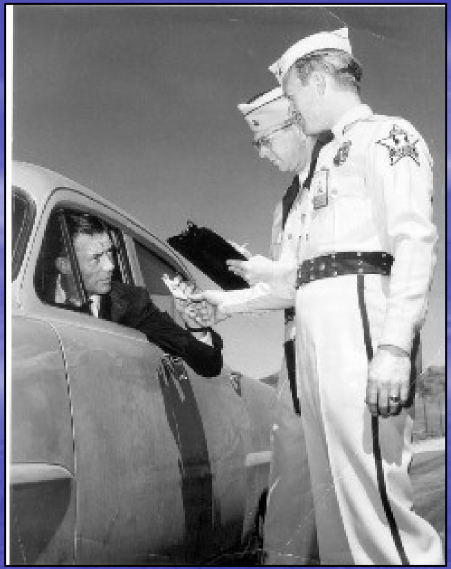
Oppenheimer's Jump Start from theoretical physicist to mega problem solver Sept 1941-Oct 1942

- Oppenheimer began working on nuclear fission research in the fall of 1941 through E. O. Lawrence. In January 1942 Arthur Compton asked Oppenheimer to work 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. That group was making impressive progress when BGEN Dick 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 on a train with Groves, Nichols and 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.

Oppie and Groves: The Consummate Odd Couple

- Groves chose Oppenheimer to be the Manhattan Project's Chief Scientist, even though the FBI recommended against granting him a top secret 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.

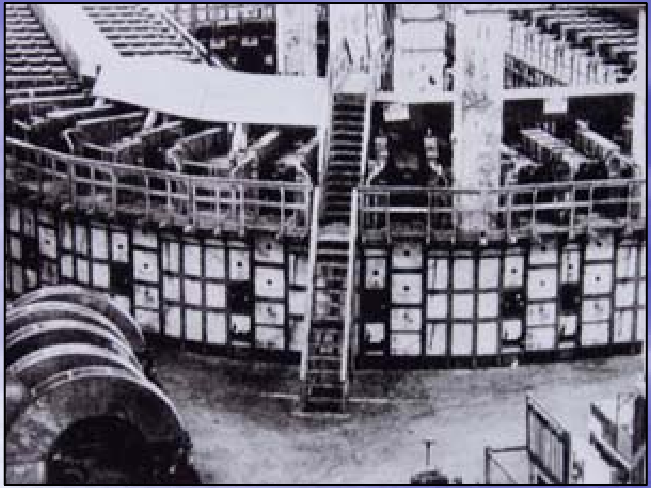




- **Oppenheimer** and **Groves** agreed that a central research facility should be established where scientists could gather to work out the methods of constructing an atomic bomb. The big problem was how to make a sub-critical mass within a bomb container and suddenly cause it to go critical.
- On November 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.

RUBE GOLDBERG MACHINES

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



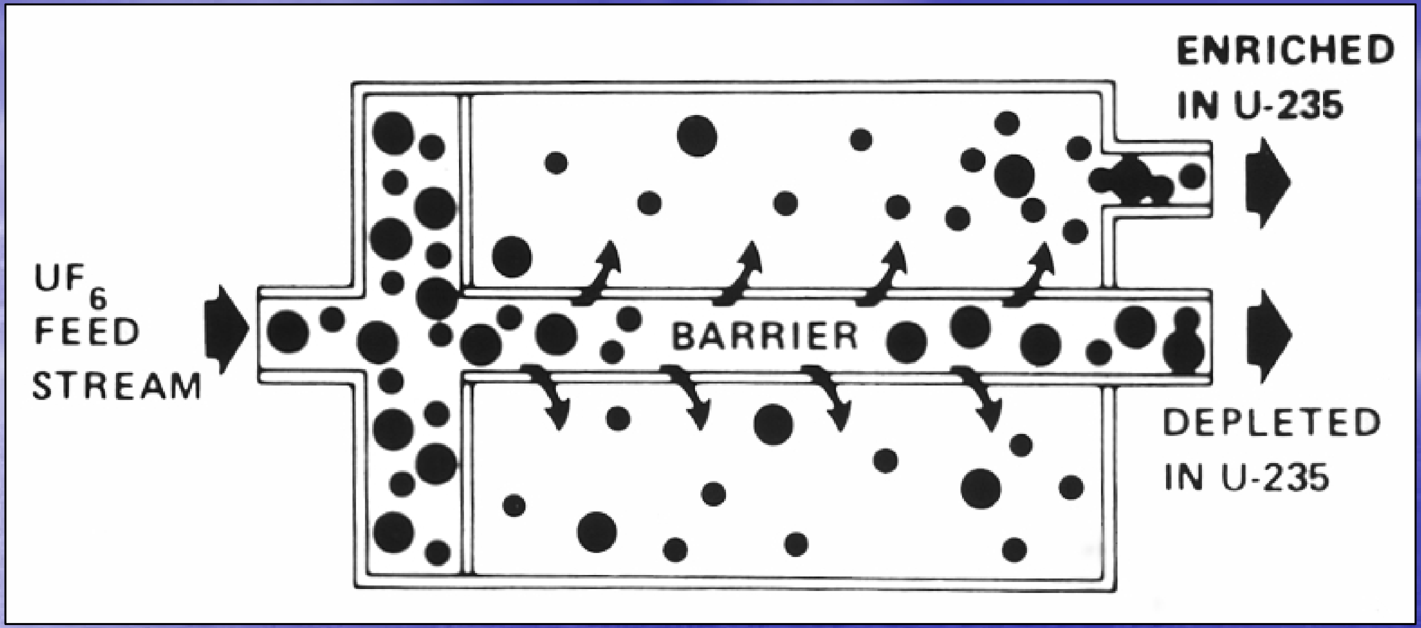
CALUATRONS

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.

- 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.
- Five “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.

K-25 Gaseous Diffusion Plant at Oak Ridge

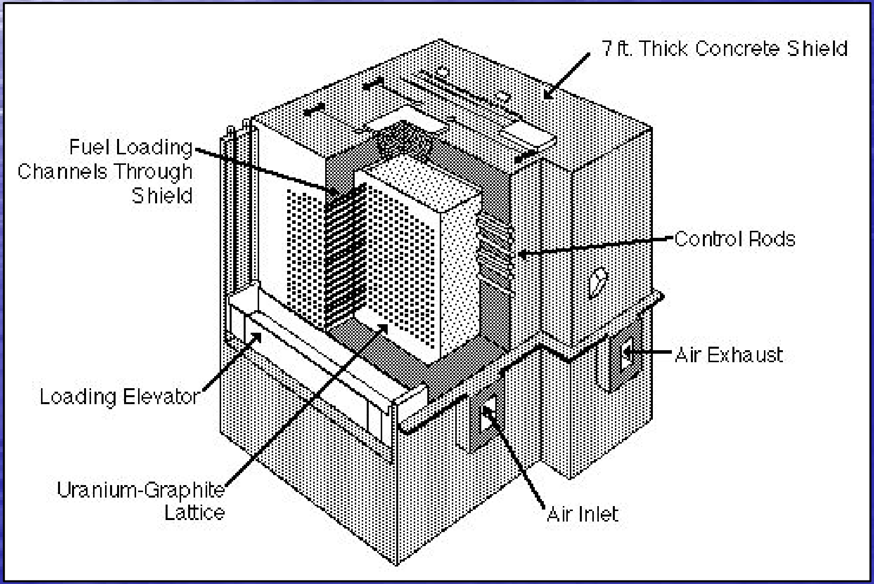
- The **K-25 Plant** at Oak Ridge. This U-shaped facility was 2,500 feet long on each side, 450 feet wide, and 60 feet high, occupying 44 acres.
- Here uranium hexafluoride (HF6) was forced through 3,000 stages in a continuous cascade, to slowly filter out the lighter U-235 atoms.

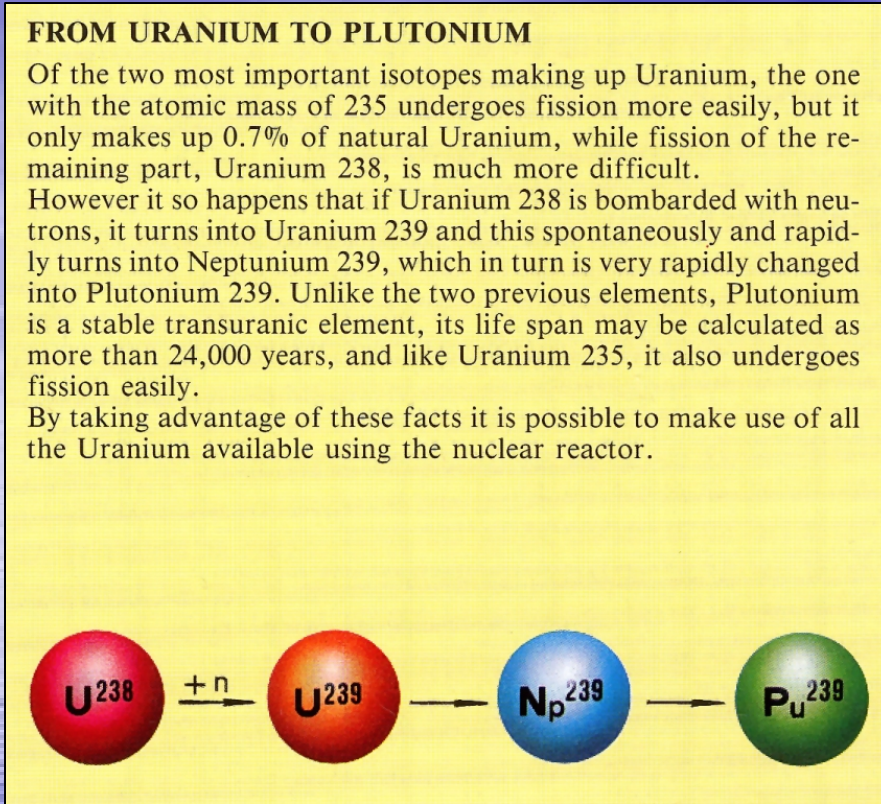


- The HF6 had to pass through 3,000 stages in a continuous cascade, to slowly filter out the lighter U-235 atoms. The diffusion holes were two millionths of an inch in diameter (using a secret and patented process).
- The plant did not enter operation until February 20, 1945 and the resulting U-235 only had a purity of 1.1%. This material was then fed into the Y-12 plant for final enrichment.

X-10 Graphite Reactor

- The X-10 graphite reactor at Oak Ridge opened Nov 4, 1943 as the prototype reactor for plutonium production at Hanford, 11 months after the successful reactor test at Chicago.
- 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.





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.

Plutonium shows itself to be a much more stable fissionable material than U235

- 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 BECOMES THE PLUTONIUM CAPITOL

- The B Reactor complex was the first constructed at Hanford, Washington, coming on-line in September 1944. It used 2,000 tons of graphite as the moderator. Plutonium production fell to near zero on several occasions due to build-up of Xe135 gas
- Enrico Fermi and his team had to troubleshoot these problems and develop workable protocols to maintain output in 1945, when plutonium was being produced for the first P239 bombs.

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

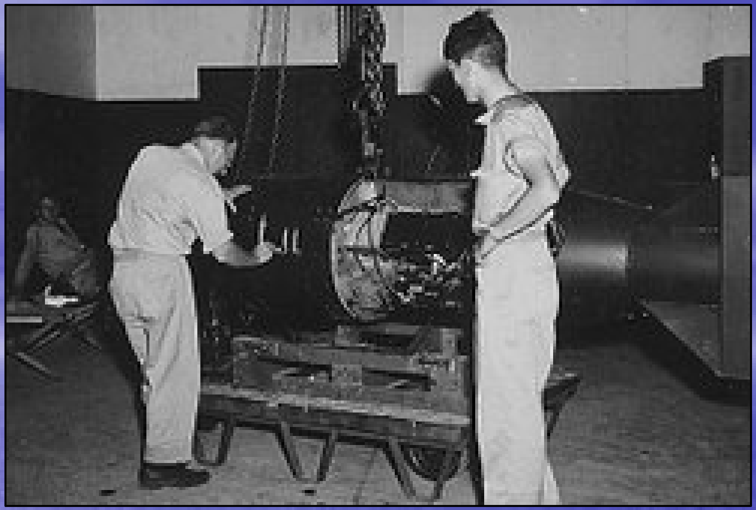
- Separation and enrichment of the resulting plutonium was handled at two huge installations, called the B and T Plants, located 3 miles apart, and about 5 miles from the B Reactor.
- Separation from the enriched slugs was achieved using bismuth phosphate, an excellent carrier of plutonium.
- The first 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.

Hanford T Plant in 1944

- 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

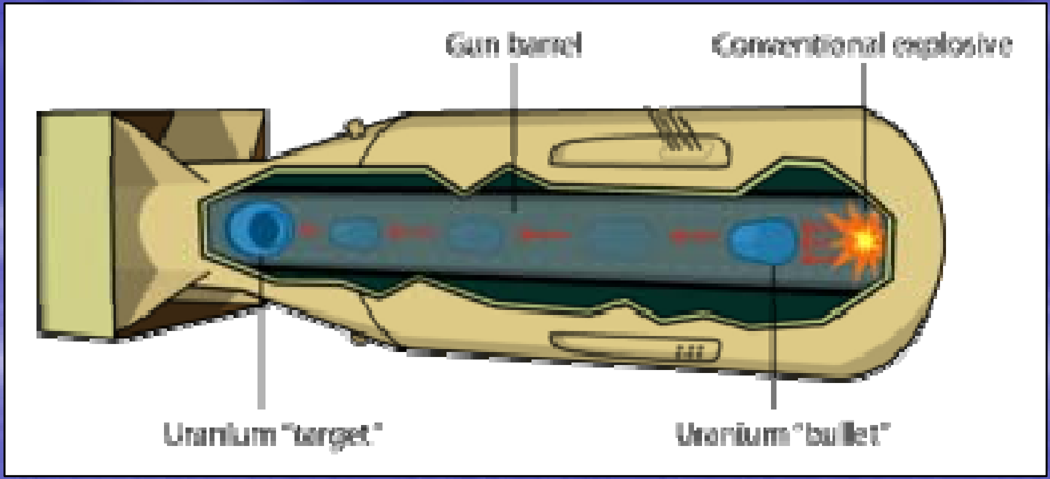
Fred Ashcroft



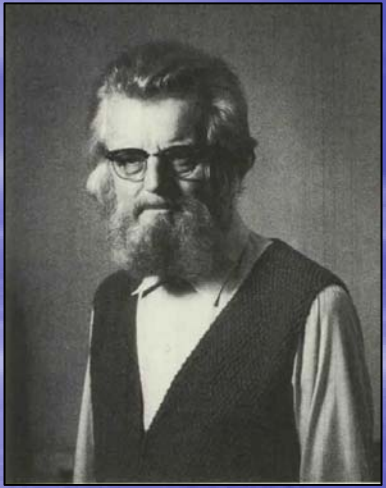
Francis Birch and Norman Ramsey

Deak Parsons

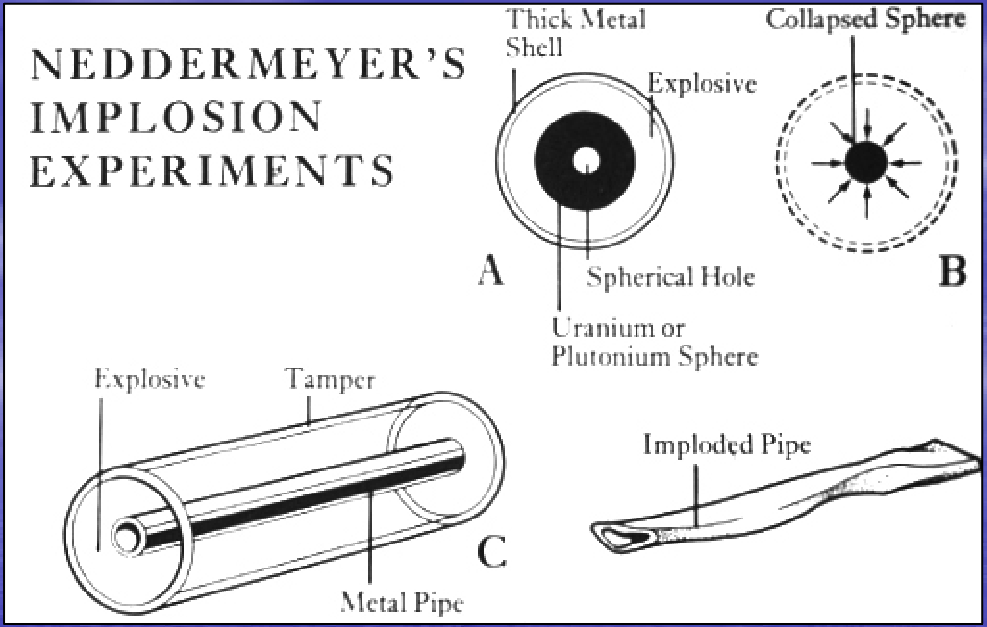
- Work originally centered around the idea of firing one piece of fissionable material into another, using a sort of gun barrel. This technique was deemed workable for U-235, and the details were worked out under the guidance of three Navy ballistics experts, CDR William S. "Deak" Parsons, CDR Fred Ashworth and LCDR A. 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.



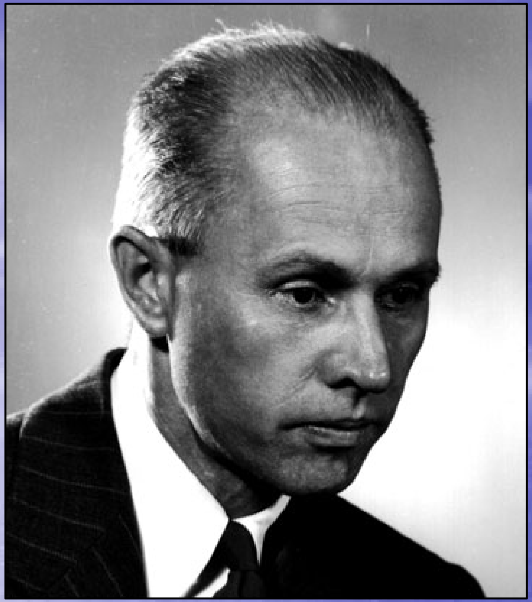
- The **Mk I "Little Boy" atomic bomb** was 10 feet long, 28 inches in diameter and weighed 8,900 pounds. The design used the gun method to explosively force a sub-critical mass of fissionable Uranium-235 and three U-235 target rings together into a super-critical mass, initiating a nuclear chain reaction. This was accomplished by simply shooting one piece of the uranium into the other by means of chemical explosives. The bomb core contained 140 pounds of U-235, of which only 1.5 pounds underwent nuclear fission.
- No full scale test of a gun-type nuclear weapon was carried out prior to the "Little Boy" device being dropped on Hiroshima.



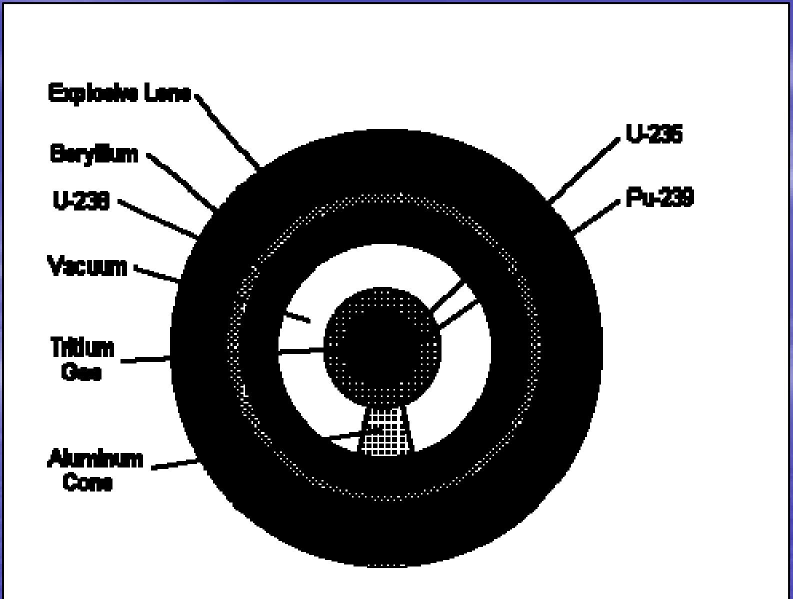
Seth Neddermeyer (1907-88)



- In **July 1943** one of Project Y's scientists, **Seth Neddermeyer**, 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.

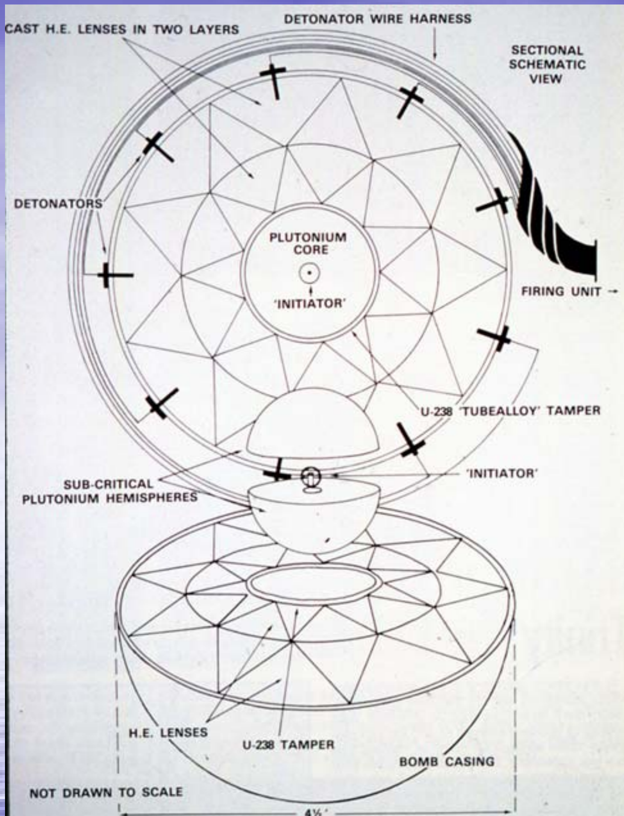


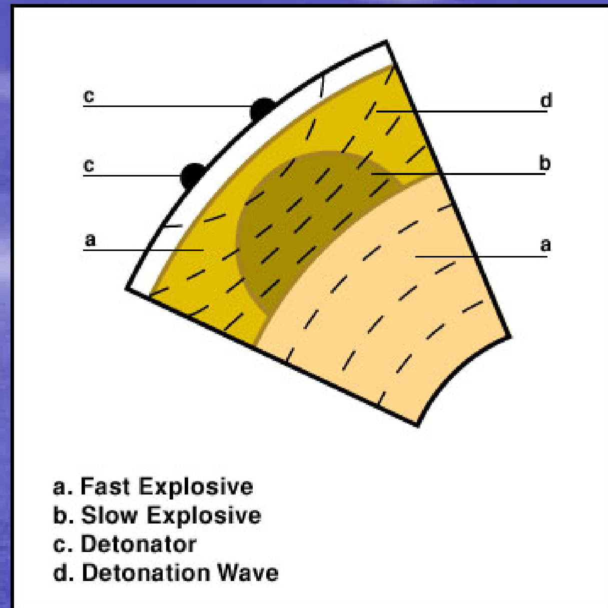
George Kistiakowsky



Schematic of the implosion device

- In September 1944, Oppenheimer placed Russian-born scientist George B. Kistiakowsky (1900-82) 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.

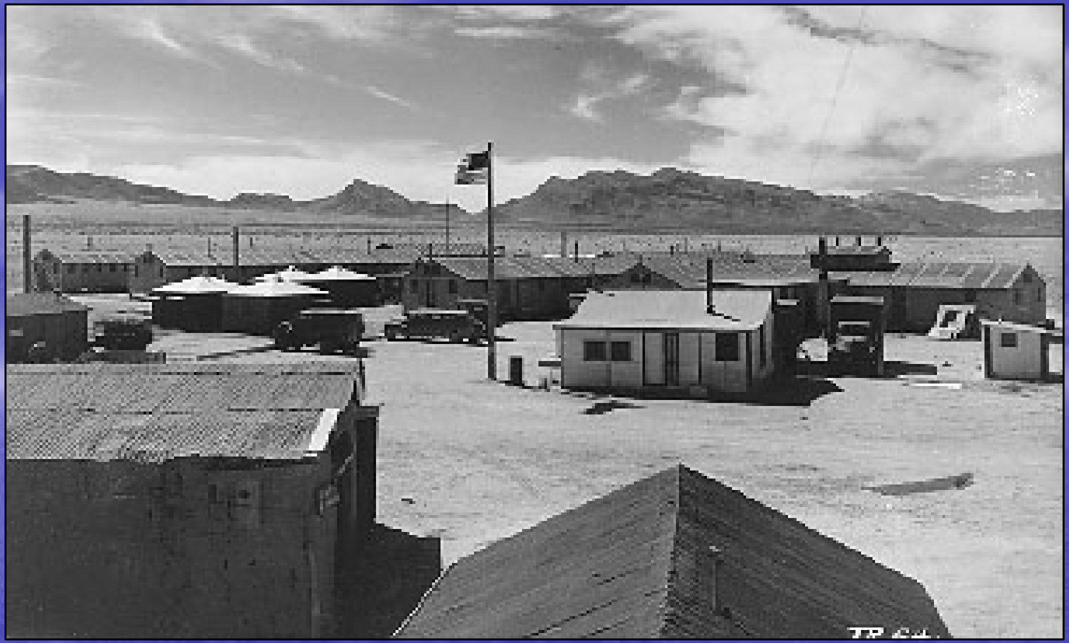




James Tuck

- 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.

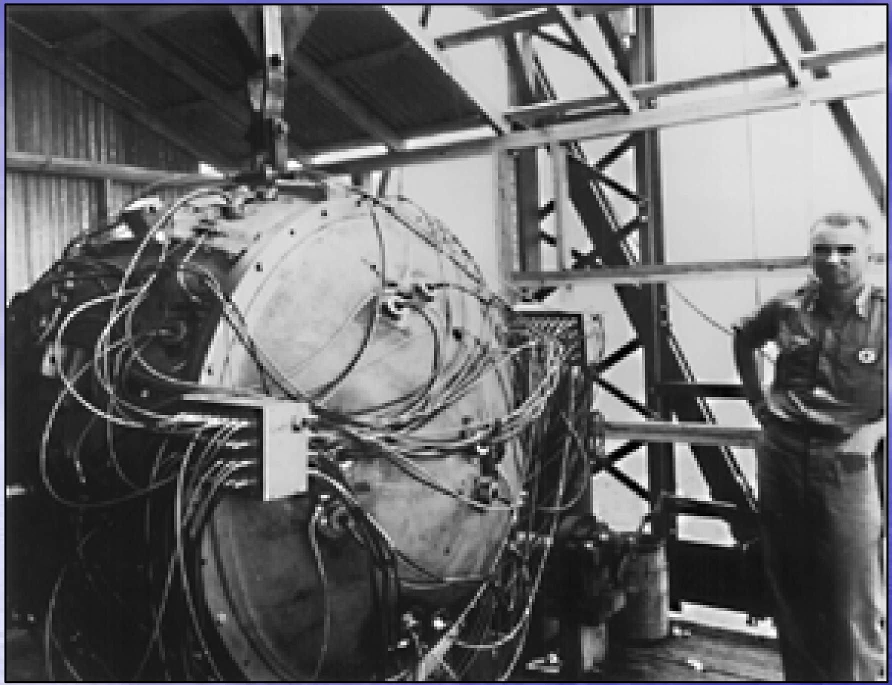
THE DUDE RANCH

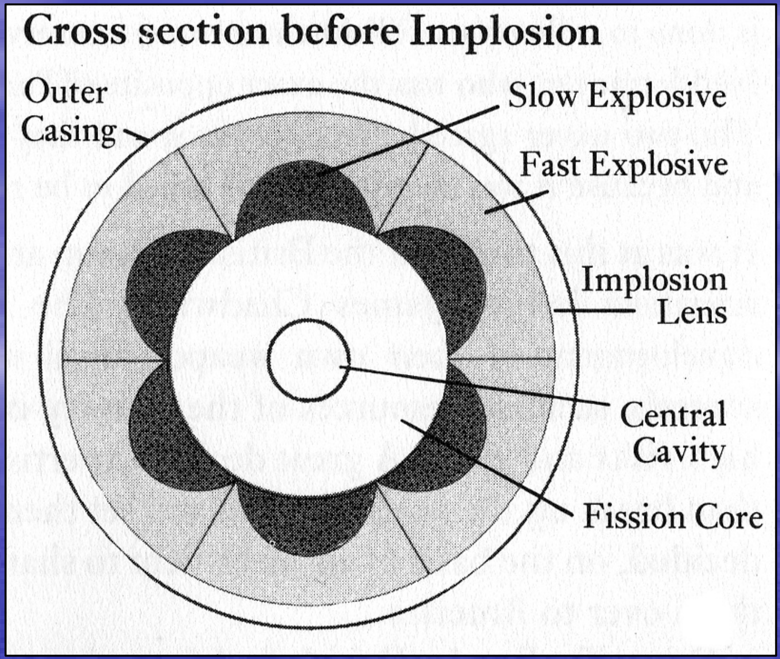


- The Los Alamos scientists began looking for a remote location to test an atomic bomb. They settled on the White Sands area south and east of Albuquerque, and west of Alamagordo. The government purchased the taciturn McDonald Ranch.
- The initial batch of enriched plutonium was shipped to Los Alamos 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. 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.

JUMBO

- Jumbo was the code name for a 214 ton steel cylinder fabricated by Babcock & Wilcox near Cleveland, Ohio and carefully transported to White Sands, New Mexico to contain precious plutonium in case the first atomic test was a dud.
- Jumbo was suspended on a steel frame about 800 feet from 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 Atomic Age is born July 17, 1945

- 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 fitted with lead shielding.

The secret notification given to Stalin

- One of the political goals of testing the atomic bomb at White Sands during the Potsdam Conference in Berlin was the supposed chilling effect the news of such a super weapon would have on Soviet dictator Josef Stalin, hopefully curbing Soviet post-war expansion and aggression. This was to be the opening salvo in America's post-war policy of containment.
- The announcement was quietly made to Stalin by Truman on July 19th, 16 hours after the successful detonation, 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.

LAYING WASTE TO AN EMPIRE

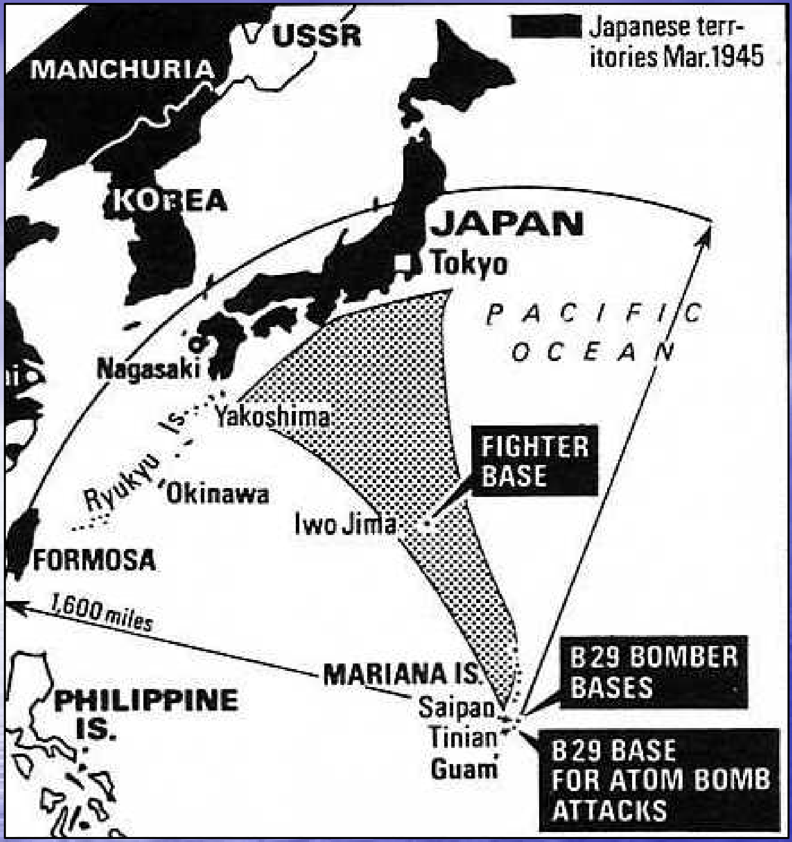
  

- The Doolittle Raid on Japan in April 1942 was a terrible embarrassment and loss of face for Japan’s wartime leaders
- They took revenge by killing 250,000 Chinese civilians who allegedly witnessed the escape of the American fliers through their villages
- They tried the captured fliers as war criminals in uniform, then publicly executed three of them
- 40% of documented Allied POWS died in Japanese captivity, compared with only 1% in German POW camps.
- These factors affected American thinking about strategic bombing of Japan, carried out between late October 1944 and early August 1945.

The Boeing B-29 Superfortress was a quantum leap in technology

- 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 combat 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 employed 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.**



PACIFIC BASES FOR AMERICAN BOMBERS

The Marianna Islands were invaded in the summer of 1944 to provide air bases on Saipan, Tinian and Guam within combat range of B-29s, 1,700 to 2,200 miles from most Japanese cities.

- **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.**

- North Field at Tinian had four great runways, 8,500 feet long, and sported 250 hard stands. 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.
- 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.

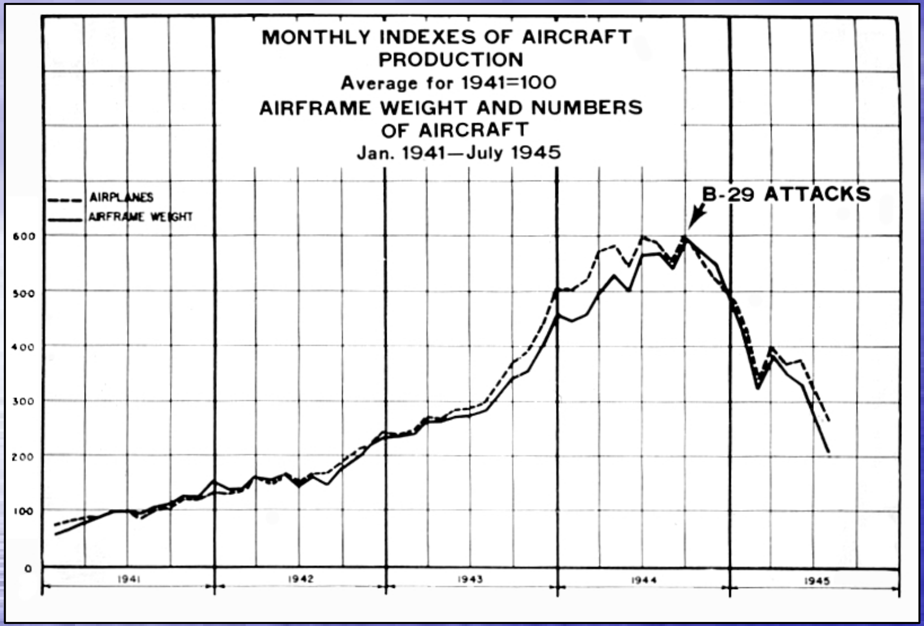
Fire Bombing

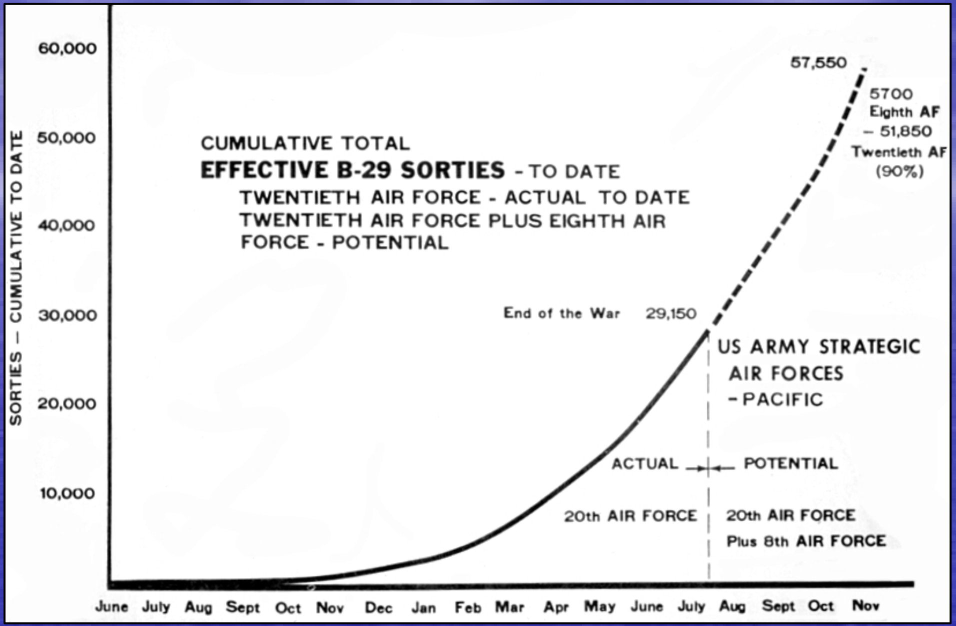
- Virtually every city in Japan with more than 35,000 people was destroyed in area-wide bombing by B-29s between November 1944 and July 1945. The tactics were changed in early March 1945, when incendiary bombs were dropped on Tokyo. The aircraft were strung out at altitudes between 6,000 and 8,000 feet.

Complete Destruction

- 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”.
- More people were killed in single fire raids on Tokyo and Osaka than in either of the atomic bomb attacks

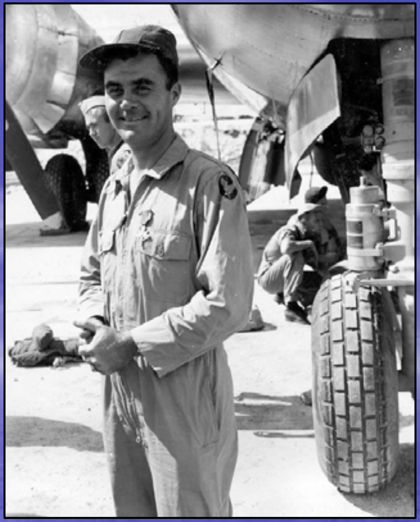
Systematic Program of Destruction





- By war's end 3,895 B-29s had been built, accounting for 29,150 combat missions against Japan.
- 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.

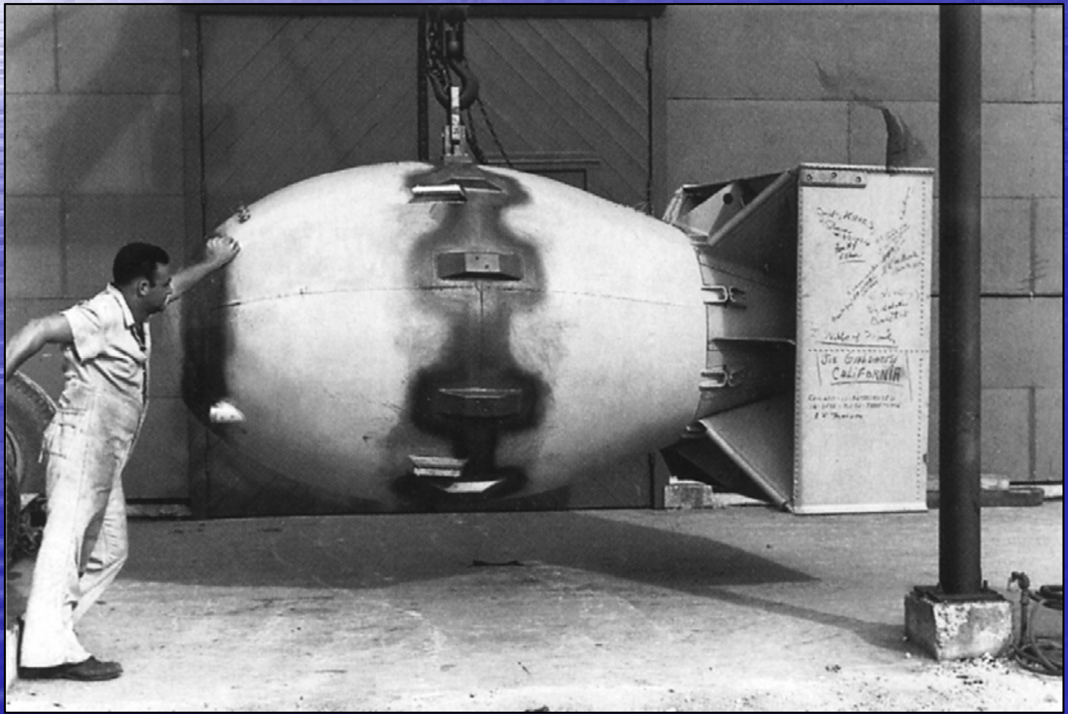
SILVERPLATE – The 509th Composite Group



LCOL Paul W. Tibbets, Jr. given command of 509th

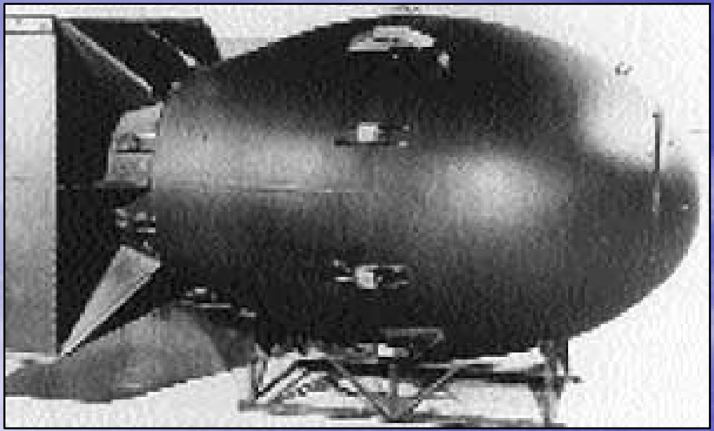
- **Capt Paul Tibbets** had led some of the first American bombing missions of the war flying a B-17 named the *Red Gremlin* from bases in England and North Africa between **Aug 1942** and **Feb 1943**.
- In May 1943 he became the Air Corps' Chief Test Pilot for the troubled B-29 flight test program, amassing more hours in B-29s than another other person by mid-1944.
- In September 1944 LCOL Tibbets was selected to command a special Army Air Corps unit charged with dropping 10,000 lb 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.

- After experimenting with removing the gun turrets at a rework facility, Tibbets ordered specially-built B-29Bs 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.



10,000 lb "pumpkin" bomb filled with conventional explosive TORPEX

- Upon their arrival, the 509th B-29s carried a distinctive tail code of a forward arrow in a circle.
- 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. In all the 509th flew 51 bombing sorties in 16 missions dropping torpex filled "pumpkins".

Tail Codes

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*.

Target Cities

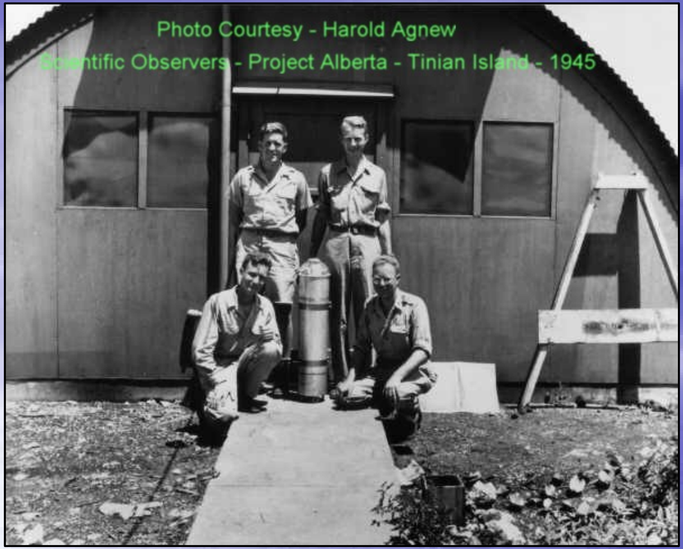
- MGEN Groves selected four potential target cities in Japan, which were taken off the B-29 target lists, and thereby spared for the time being. The purpose of this was to provide a more reliable indicator of how effective each atomic blast might be, if and when such attacks occurred.

- 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.

- **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."**

THE HIROSHIMA MISSION

- 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. Tibbets had a Circle R tail code, simulating 6th BG 313th Bomb Wing aircraft, also based on Tinian's North Field.
- The *Enola Gay* 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.



Project Alberta scientific observers on Tinian. Alvarez was the only person to observe the first three atomic missions first hand, at the Trinity Test, Hiroshima, and Nagasaki, from orbiting B-29s.

- The 509th aircraft pre-flight ops 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.

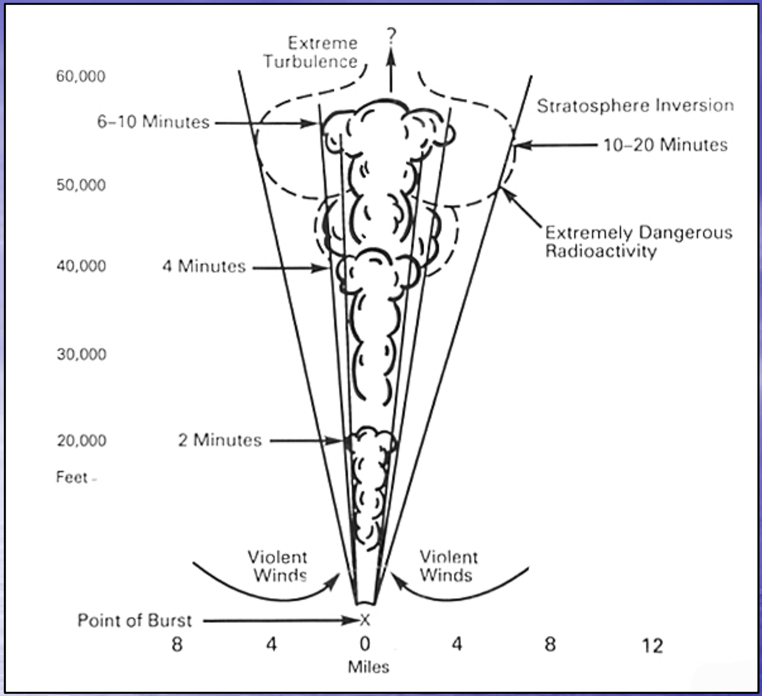
Prudent Precautions

- 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.

- *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.

Clear skies over Hiroshima and an on-time delivery of a deadly cargo

- 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).



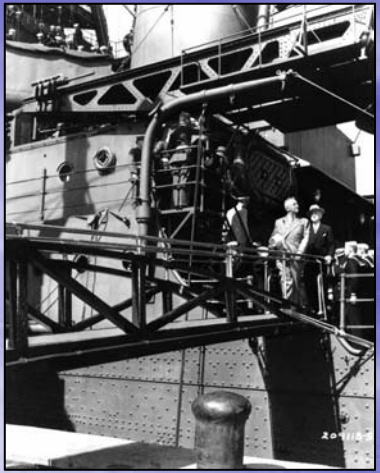
- Because of the low lying topography, the blast energy was able to sweep over a broad area.
- The bomb killed everyone within 1 km of ground zero, destroying houses up to 2.6 km away, and inflicting severe skin burns on people up to 3.9 km away. All structures within 2 km were incinerated by the fire 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 was dispatched to record the devastation. Aerial photos revealed that 4.7 square miles of Hiroshima was destroyed, about 68.5% of the city.

Most accurate bombing of the war

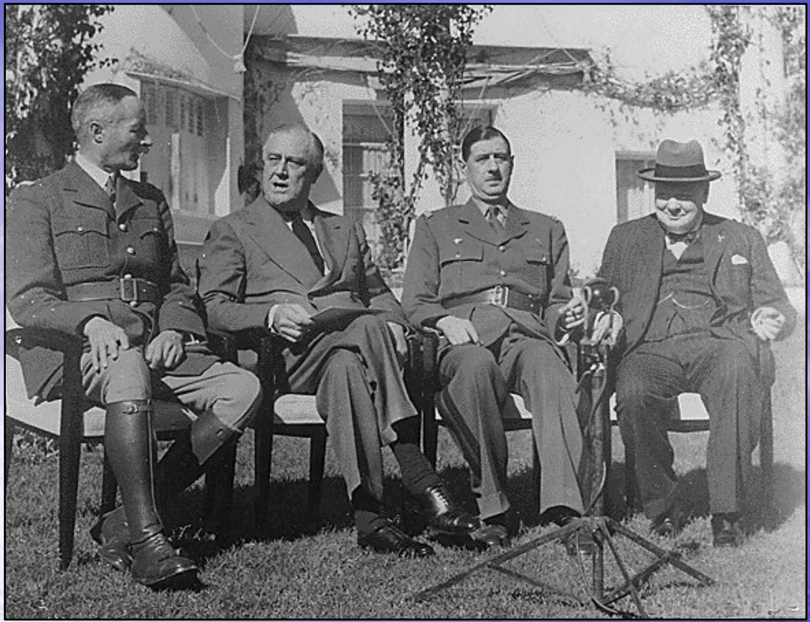
- Before and after images of Hiroshima attest to utter destruction of the Little Boy atomic bomb.
- The bomb detonated at an **altitude of 1740 feet** on a precise trajectory, within 7 feet of the primary aiming point on the **Aioi Bridge** (a 500 foot ground separation because of the parabolic trajectory).

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.
- 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.

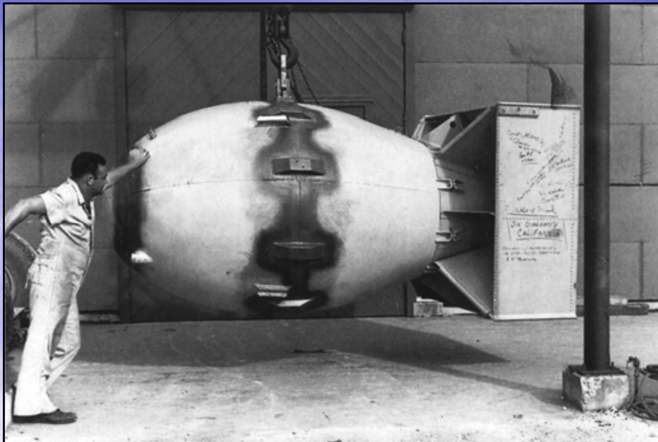
- On **Monday August 6th**, **President Harry S. Truman** was aboard the Navy cruiser *USS Augusta* in the North Atlantic, on his way home from the Potsdam Conference near Berlin. **16 hours** after the Hiroshima explosion, Truman announced via radio (from the *Augusta*) that the United States had dropped 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.



Demand of Unconditional Surrender

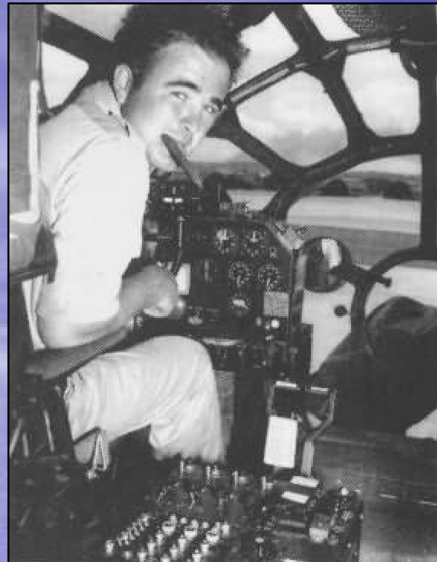
Giraud, Roosevelt, DeGaulle, and Churchill at the Casablanca Conference in January 1943

- President Roosevelt had pledged to demand the unconditional surrender of all Axis forces at the Casablanca Conference between the USA, Great Britain, and free France in January 1943.
- 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.



Nagasaki Mission

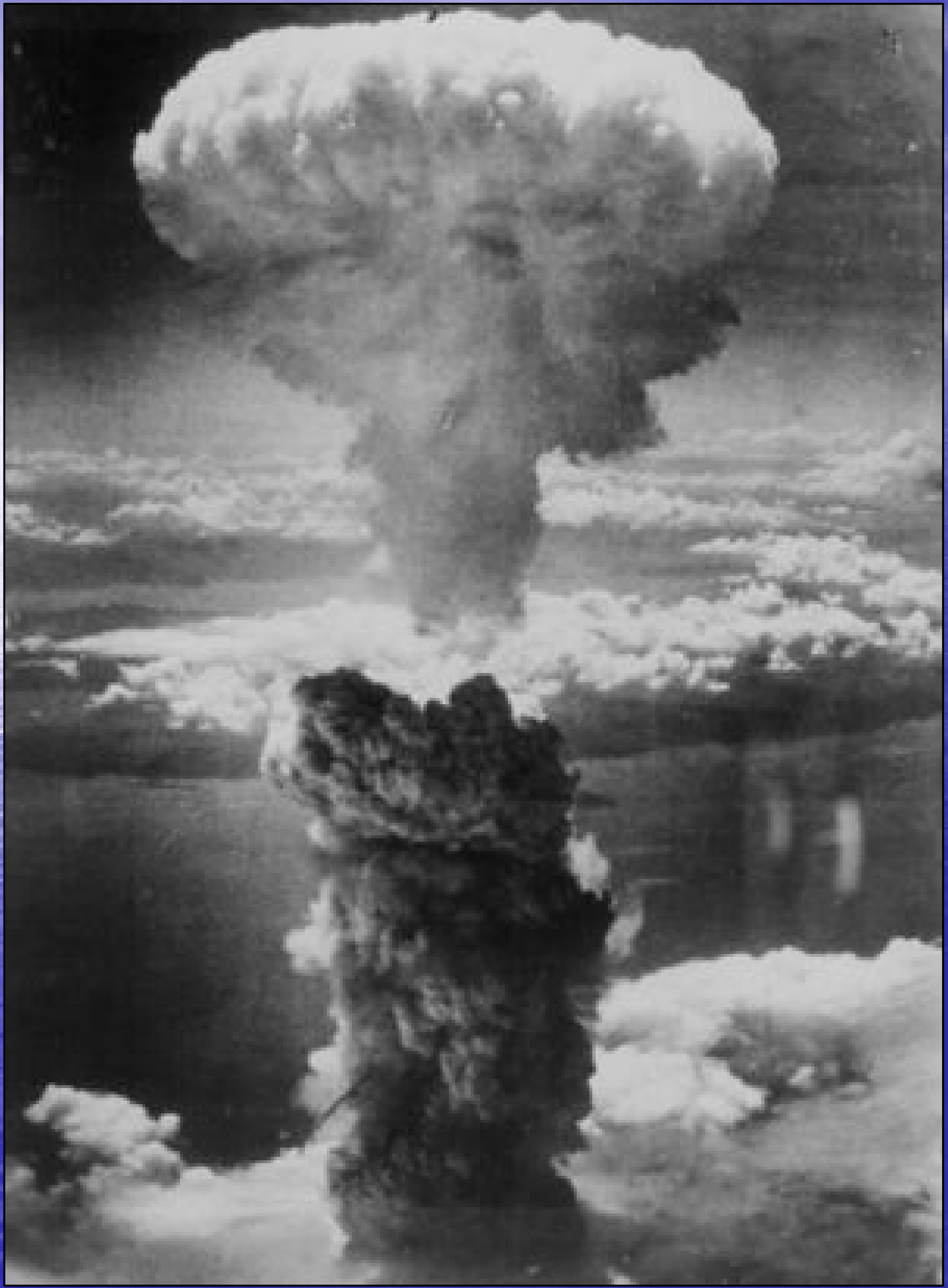
- **The second atomic bomb used 11 pounds of plutonium Pu239 (about the size of an orange) and was dubbed "*Fat Man*". The bomb was 128 inches long , with a diameter of 60 inches, and weighed 10,300 pounds. It would be fitted with four sets of redundant fuses, including barometric, timing and radar.**
- **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.**
- **Major Charles Sweeney was selected 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.**
- **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.**



- 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 atomic bombers were fitted with two 640 gallon auxiliary tanks, enabling them to carry 8,860 gallons of fuel.
- 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 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.



Nagasaki mushroom cloud

- 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.

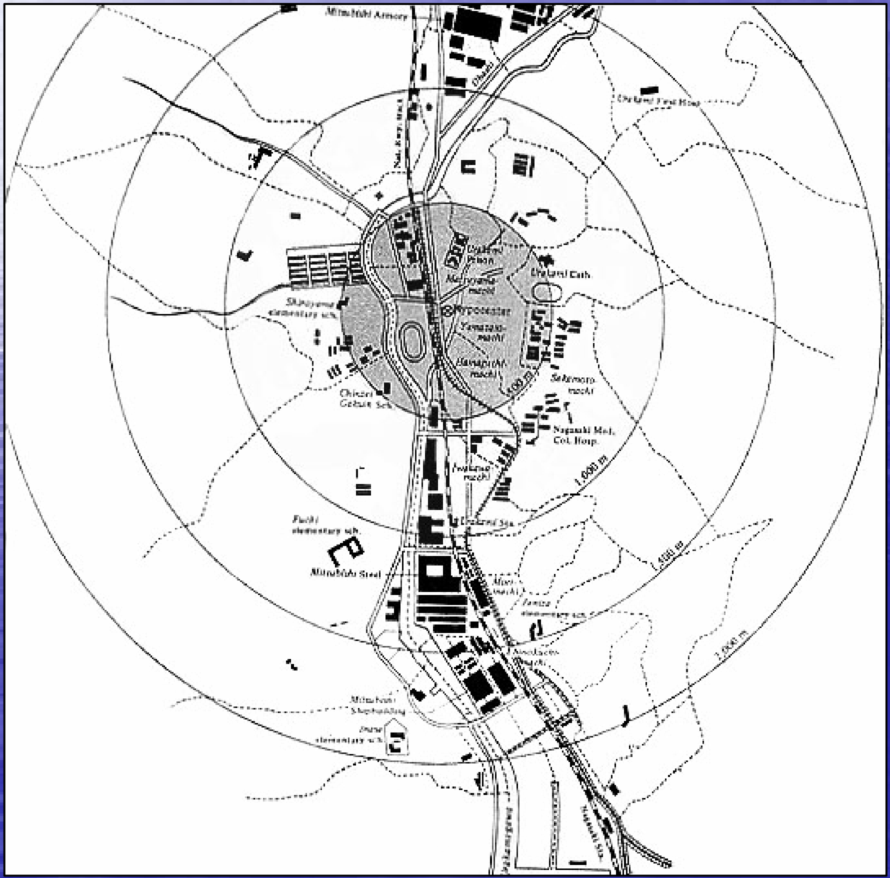
With only 300 gallons of accessible fuel remaining, *Bock's Car* (with *Great Artiste* in trail) made haste for the nearest airfield, at Yontan on Okinawa, almost 350 miles away. There was theoretically insufficient fuel to travel more than about 250 miles.

- 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.

Nagasaki damage assessment



- 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 mi2 of the 3.86mi2 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.

- 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.

Foreign Minister Togo

Kantaro Suzuki

Emperor Hirohito

Togo Shigenori

- A battle to end the war raged in the Japanese capital, with numerous mutinies and attempted coups. The militarists wanted to continue fighting to the last man and the diplomats became 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 had his longest working day of the war. The War Council had only one concern left, the preservation of the national polity - the Throne.

- **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.**
- **<u>The Japanese pronouncement came just 194 hours after the Hiroshima drop</u>. 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.**

- The difficult task of bringing the war to a close fell upon Foreign Minister Togo Shigenori (left), 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.
- Emperor Hirohito (middle) made his first 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.

Surprise Ending

- 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.