GET1024 / GEC1036 Lecture 14

Radiation from Nuclear Weapons and Past Tests

- History of Atomic Bombs
  - Manhatten Project, Trinity, Hiroshima & Nagasaki
- Effects of the Atomic Bombs
- Development of Nuclear Weapons and Tests
  - Hydrogen & Neutron Bombs
- Radioactive Fallout and Test Bans

Introductory Remarks

- Module meant to discuss the peaceful use of radiation but it would be incomplete to leave out nuclear weapons completely
- The topic itself can be emotional and controversial, e.g., of the necessity of using atomic weapons to end World War II (especially the second bomb), and the use of “neutron bombs”, nuclear stockpile for MAD, etc.
- Objectives of this lecture:
    - Provide some historical background on nuclear weapons
    - Understand some basic science of the nuclear weapons
    - Discuss the effects of nuclear weapons including its testing over the years
    - Understand how government, scientists and citizens are involved

Einstein's Letter

Albert Einstein
Old Grove Rd.
Nassau Point
Peconic, Long Island

August 2nd, 1939

F.D. Roosevelt,
President of the United States,
White House
Washington, D.C.

Sir:

Some recent work by E.Fermi and L. Szilard, which has been communicated to me in manuscript, leads me to expect that the element uranium may be turned into a new and important source of energy in the immediate future. Certain aspects of the situation which has arisen seem to call for watchfulness and, if necessary, quick action on the part of the Administration. I believe therefore that it is my duty to bring to your attention the following facts and recommendations:

In the course of the last four months it has been made probable - through the work of Joliot in France as well as Fermi and Szilard in America - that it may become possible to set up a nuclear chain reaction in a large mass of uranium,by which vast amounts of power and large quantities of new radium-like elements would be generated. Now it appears almost certain that this could be achieved in the immediate future.

This new phenomenon would also lead to the construction of bombs, and it is conceivable - though much less certain - that extremely powerful bombs of a new type may thus be constructed. A single bomb of this type, carried by boat and exploded in a port, might very well destroy the whole port together with some of the surrounding territory. However, such bombs might very well prove to be too heavy for transportation by air.

The United States has only very poor ores of uranium in moderate quantities. There is some good ore in Canada and the former Czechoslovakia, while the most important source of uranium is Belgian Congo.

In view of this situation you may think it desirable to have some permanent contact maintained between the Administration and the group of physicists working on chain reactions in America. One possible way of achieving this might be for you to entrust with this task a person who has your confidence and who could perhaps serve in an inofficial capacity. His task might comprise the following:

a) to approach Government Departments, keep them informed of the further development, and put forward recommendations for Government action, giving particular attention to the problem of securing a supply of uranium ore for the United States;

b) to speed up the experimental work,which is at present being carried on within the limits of the budgets of University laboratories, by providing funds, if such funds be required, through his contacts with private persons who are willing to make contributions for this cause, and perhaps also by obtaining the co-operation of industrial laboratories which have the necessary equipment.

I understand that Germany has actually stopped the sale of uranium from the Czechoslovakian mines which she has taken over. That she should have taken such early action might perhaps be understood on the ground that the son of the German Under-Secretary of State, von Weizsäcker, is attached to the Kaiser-Wilhelm-Institut in Berlin where some of the American work on uranium is now being repeated.

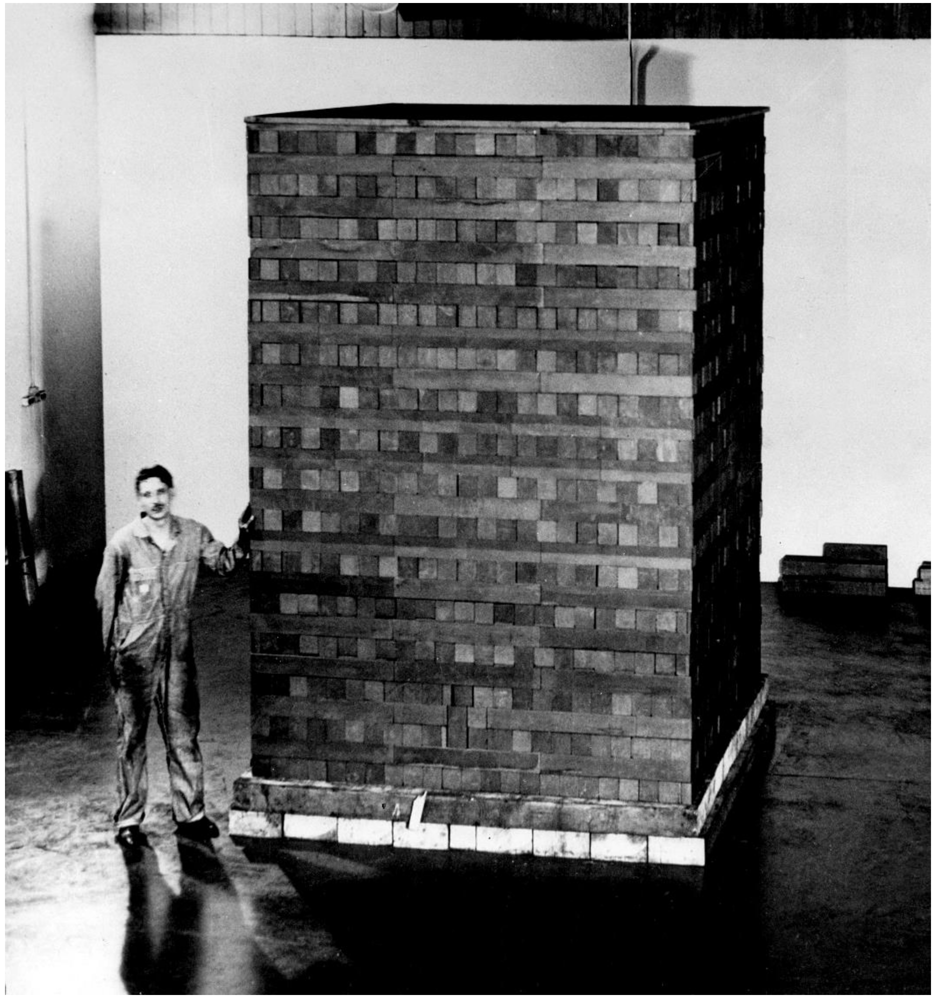
Yours very truly,
A. Einstein
(Albert Einstein)

Manhattan Project

- Started slowly from 1939 – investigation of uranium and chain reaction in various universities: Chicago (Fermi), Columbia (Szilard), UC Berkeley, etc.
- On Dec 7, 1941, Japanese attack at Pearl Harbor - United States entered into WWII.
- 1942 - The Army Corps of Engineers under BG Leslie Richard Groves took over & consolidated various atomic research projects – Manhattan Project. Later, physicist Robert Oppenheimer appointed as the scientific director.
- Chicago U – Dec 1942 – first sustained control chain reaction
- Los Alamos National Lab – bombs designed, built and tested
- Hanford, Washington – B Reactor – production of Pu-239 from U-238
- Oak Ridge National Lab – gaseous diffusion for enriched uranium
- Produced 4 bombs – including Gadget (tested at Trinity), Little Boy (Hiroshima), Fat Man (Nagasaki).

Chicago Pile - 1: World's 1st Chain Reaction

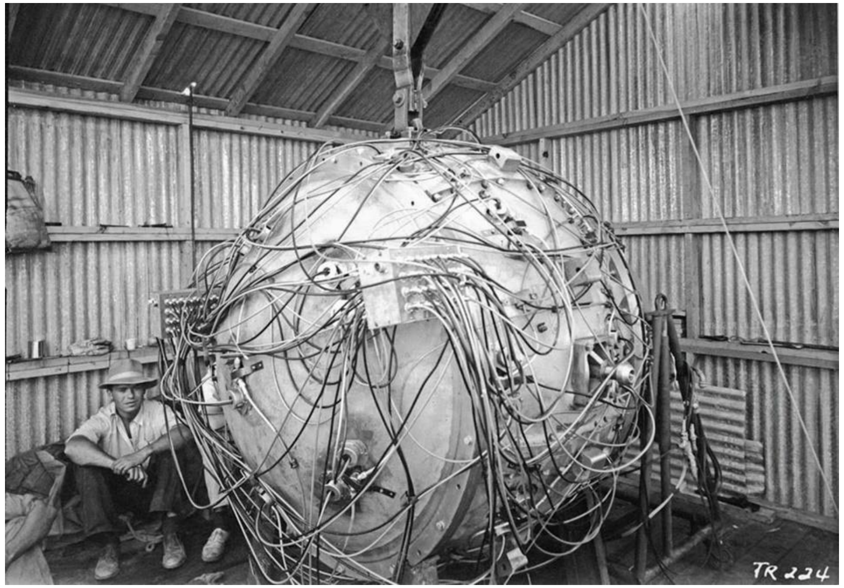
- Date: Dec 2, 1942
- Location: Abandoned rackets court underneath Stagg Field in the middle of the University of Chicago campus
- Materials:
    - 350,000 kg of graphite – in 57 layers (moderator)
    - 36,000 kg of uranium oxide + 5,600 kg of uranium metal
    - Cadmium used as control rods
- Cadmium rods were lifted slowly one by one until system went critical as measured by neutron detectors
- Thermal power: 0.5 W (ultimately 200 W max)
- Led on to Chicago Pile – 2 (Argonne National Lab) and Hanford B-reactor (for plutonium production)

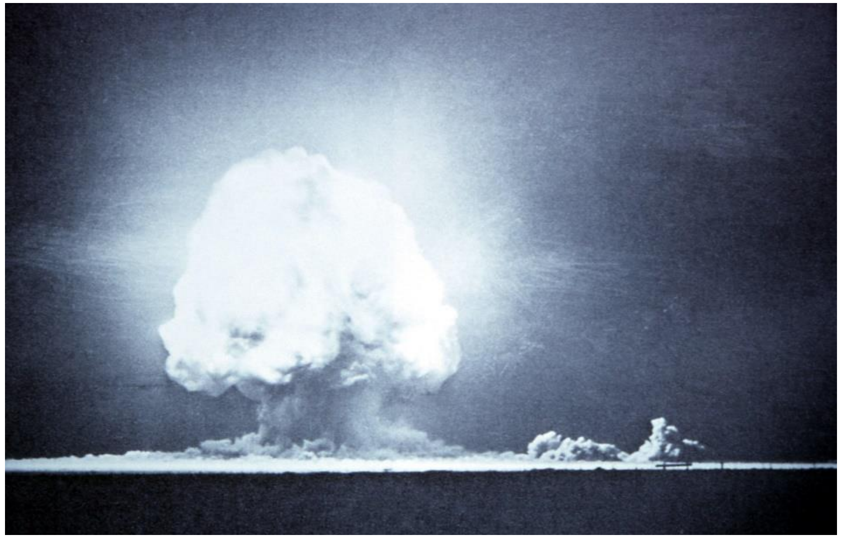


https://www.atomicheritage.org/history/chicago-pile-1

Trinity: World's First Atomic Bomb Explosion

- Date: July 16, 1945
- Location: Jornada del Muerto desert about 56 km southeast of Socorro, New Mexico, US.
- Material: Plutonium (bomb was code-named "Gadget")
- Method: Implosion (compression of the plutonium core to several times its original density by explosive – core becomes supercritical). Also activate neutron initiator to start process.
- Blast Yield: 22 kilotons of TNT (92 TJ)



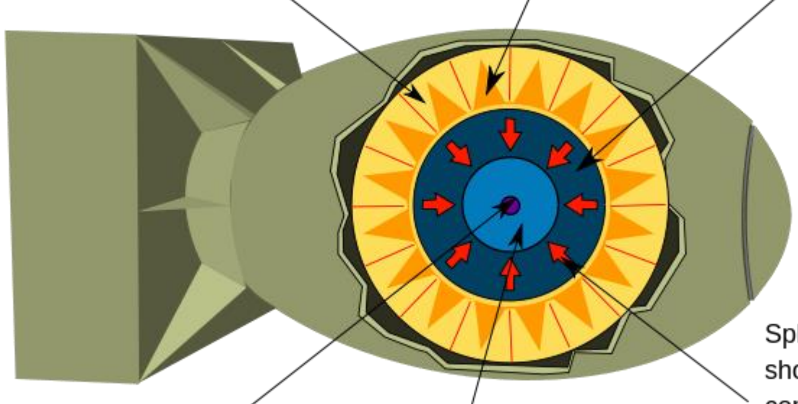


Neutron Initiator

Polonium-Beryllium

$$^{210}_{84}\mathrm{Po} \rightarrow {}^{206}_{82}\mathrm{Pb} + {}^{4}_{2}\alpha$$

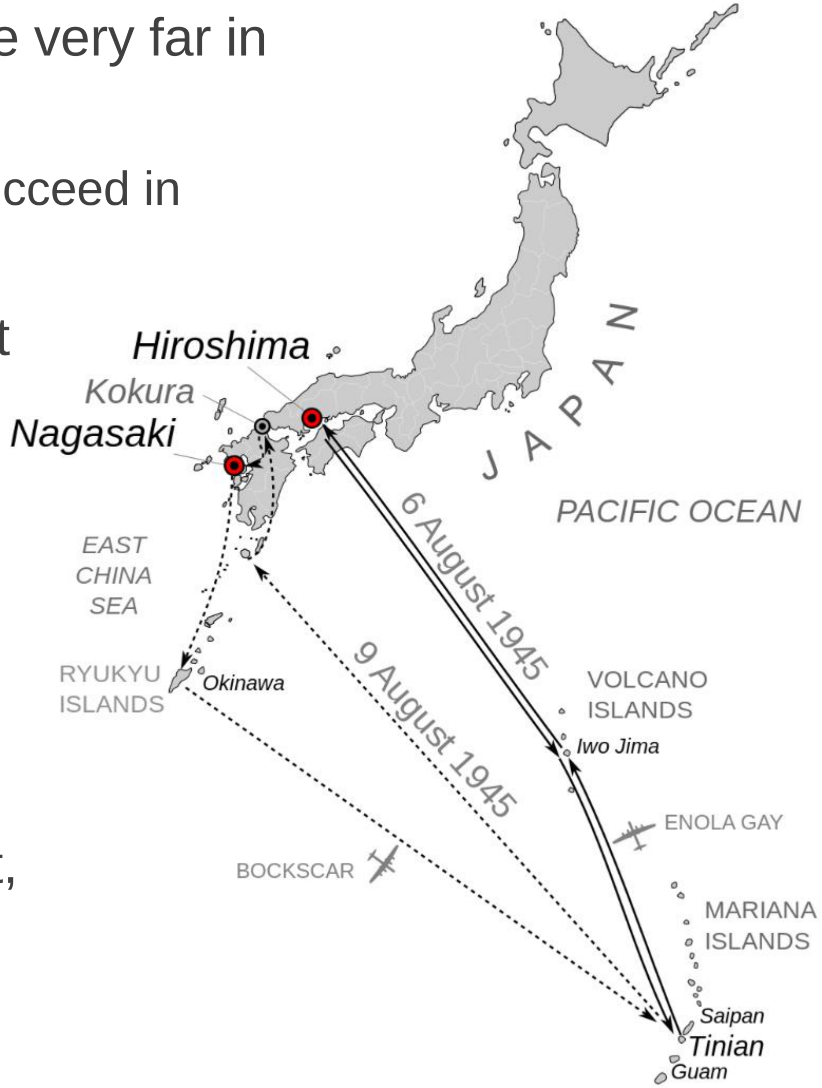
$$^{4}_{2}\alpha + {}^{9}_{4}\mathrm{Be} \rightarrow {}^{12}_{6}\mathrm{C} + {}^{1}_{0}\mathrm{n}$$



https://en.wikipedia.org/wiki/Trinity_(nuclear_test)

Atomic Bombing of Hiroshima and Nagasaki

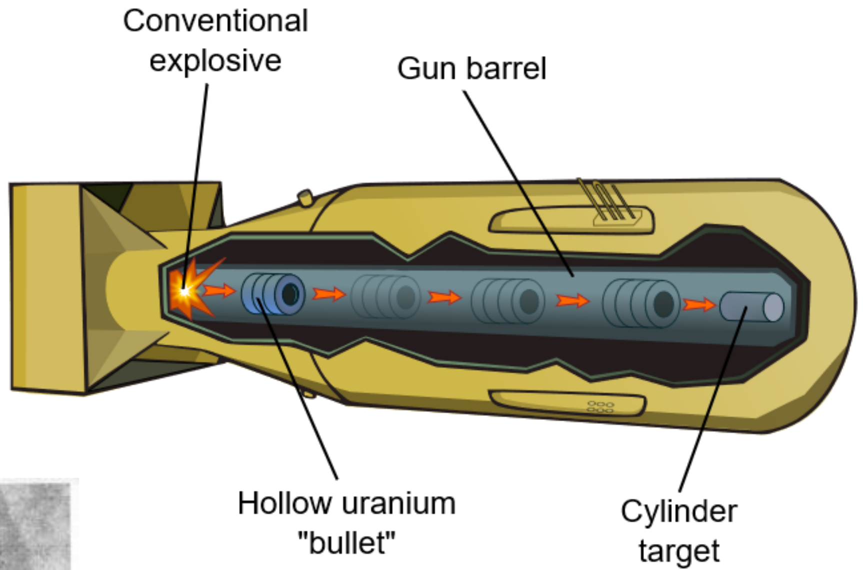
- In May 1945, Germany surrendered. Germany in fact had not gone very far in development of nuclear weapons.
  - Einstein later in life said, "had I known that the Germans would not succeed in developing an atomic bomb, I would have done nothing."
- Allies demanded an unconditional surrender of Japan with a threat of a new powerful weapon.
- Commanders and scientists debated over the use of atomic bomb over a city or a demonstration.
- 6 August 1945, first atomic bomb dropped on Hiroshima – an important army depot and port of embarkation. Japan did not surrender.
- 9 August 1945, second atomic bomb dropped on secondary target, Nagasaki.
- Japan surrendered on 15 August 1945.

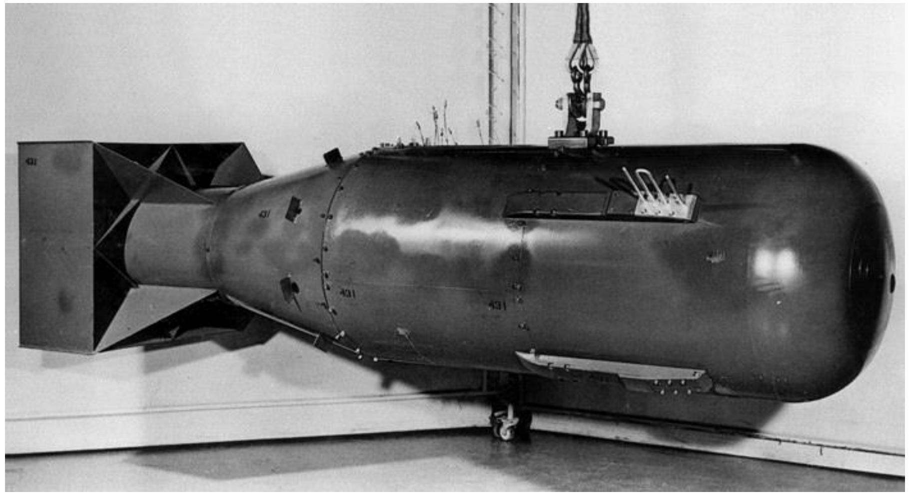


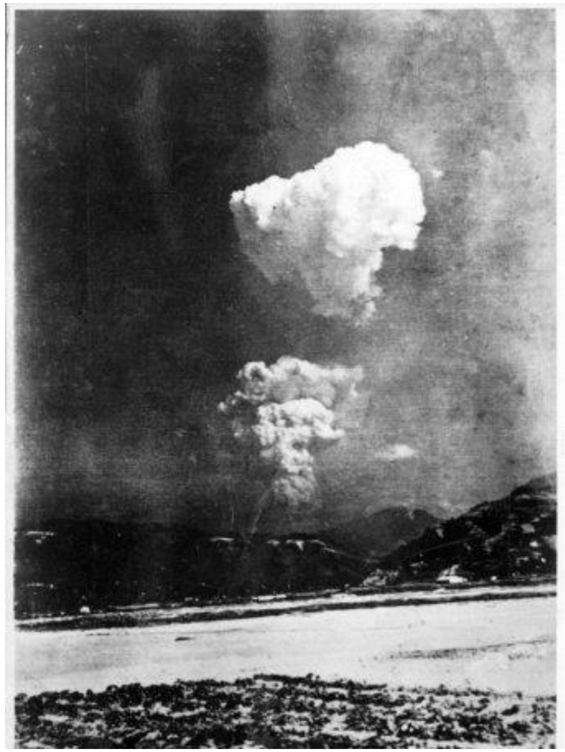
https://en.wikipedia.org/wiki/Atomic_bombings_of_Hiroshima_and_Nagasaki

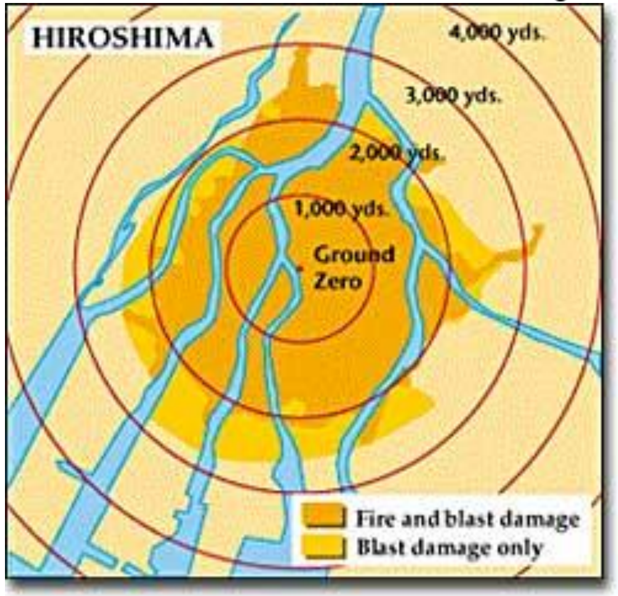
Little Boy: First Atomic Bomb on Civilian Population

- Date: August 6, 1945
- Location: Hiroshima – at 600 m altitude
- Material: 64 kg Enriched Uranium (Uranium-235)
- Method: Gun Type Assembly (hollow uranium bullet pushed by explosive toward cylinder target achieving critical mass)
- Dimension: 71 cm (diameter) x 3.0 m length
- Blast Yield: 15 kilotons of TNT (63 TJ)





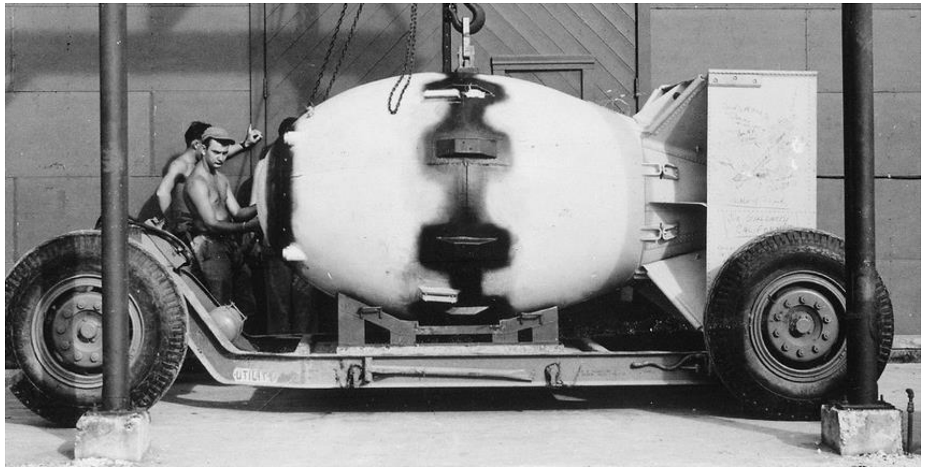


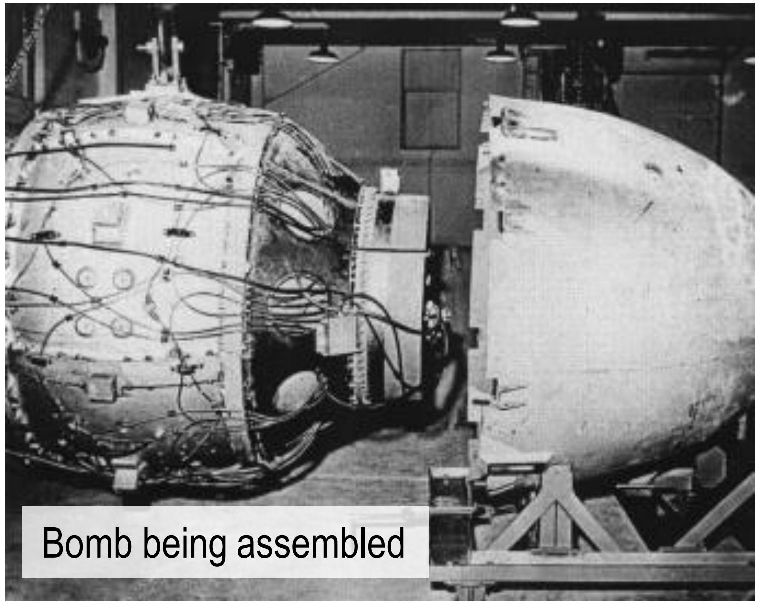


https://en.wikipedia.org/wiki/Little_Boy

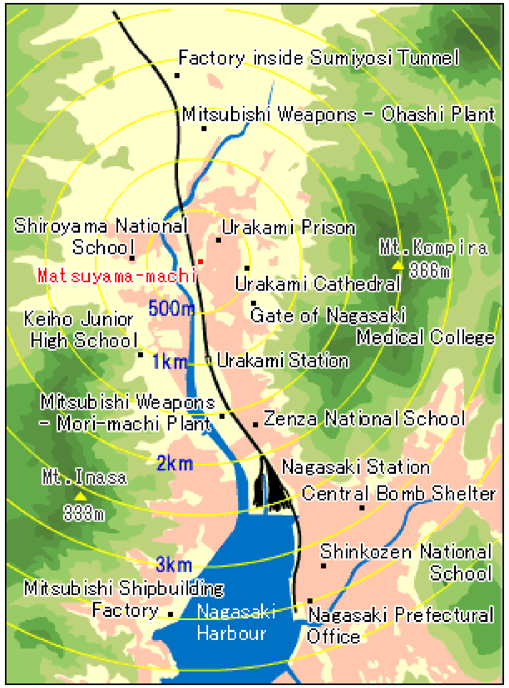
Fat Man: Atomic Bomb that ended World War II

- Date: August 9, 1945
- Location: Nagasaki – about 3 km off target.
- Material: 6.4 kg of Plutonium
- Dimension: 1.5 cm (diameter) x 3.3 m length
- Method: Implosion Type
- Blast Yield: 21 kilotons of TNT (88 TJ)





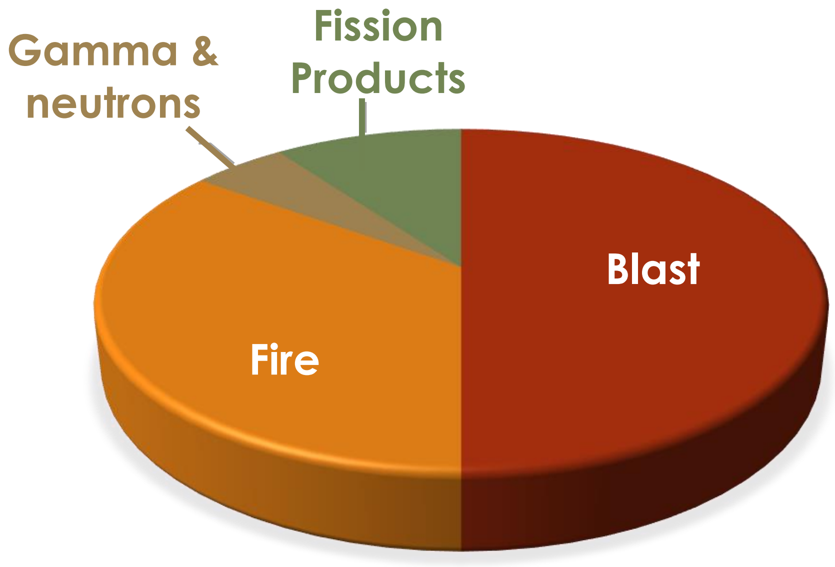
Bomb being assembled



http://www.nukefallout.com/nagasaki.html

Energy of Atomic Bombs

- **Blast Energy** (50%): Heat from the fireball causes a high-pressure wave to develop and move outward producing the blast effect.
- **Thermal Energy** (35%): 2 pulses of thermal radiation emerge from fireball.
  - The first pulse, which lasts about 0.1 s – radiation in the ultraviolet region.
  - The second pulse (several seconds) – 99% of the total thermal radiation energy. Causes skin burns and eye injuries suffered by exposed individuals and combustible materials to break into flames.
- **Nuclear Radiation** (15%):
  - Immediate (5%) – γ-rays and neutrons, within first minute of explosion. Decreases rapidly with distance from explosion.
  - Residual Radiation – Fallout (10%): > 300 different fission products that may result from a fission reaction. Many of these are radioactive with widely differing half-lives.



http://www.atomicarchive.com/Effects/index.shtml

Damages to Physical Structures

- The damages to man-made structures and other inanimate objects were the result in both cities of the following effects of the explosions:
  - Blast, or pressure wave, similar to that of normal explosions.
  - Primary fires – instantaneously by the heat radiated from the atomic explosion.
  - Secondary fires – resulting from the collapse of buildings, damage to electrical systems, overturning of stoves, and other primary effects of the blast.
  - Spread of the original fires (above) to other structures.

Pic from http://www.dailymail.co.uk

Note: Gamma Radiation did not produce damage to the physical structures

Injuries to Inhabitants

- "Flash" burns, caused directly by the almost instantaneous radiation of heat and light at the moment of the explosion.
- Burns resulting from the fires caused by the explosion.
- Injuries caused by collapse of buildings, flying debris, and hurling-about of persons struck by the blast pressure waves.
- Radiation injuries caused by the instantaneous penetrating radiation from the nuclear explosion; all these radiations occurred during the first minute after initiation of the explosion, and nearly all occurred during the first second of the explosion.

http://www.atomicarchive.com/Effects/index.shtml

Casualties in Hiroshima and Nagasaki

- Figures vary somewhat depending on sources and how they are classified as well as whether immediate or over a longer period of time.
- Following are based on Report by Manhattan Engineer District of the United States Army (who visited the cities in Sep 1945) under the direction of Major General Leslie R. Groves in http://www.atomicarchive.com/Docs/Hiroshima/index.shtml.

	Hiroshima	Nagasaki
Pre-raid population	255,000	195,000
Dead	66,000	39,000
Injured	69,000	25,000
Total Casualties	135,000	64,000

Distance (feet)	Mortality %
0 - 1000	93.0%
1000 - 2000	92.0
2000 - 3000	86.0
3000 - 4000	69.0
4000 - 5000	49.0
5000 - 6000	31.5
6000 - 7000	12.5
7000 - 8000	1.3
8000 - 9000	0.5
9000 - 10,000	0.0

Note: 1000 feet = 304 m

http://www.atomicarchive.com/Effects/index.shtml

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Distance (km)	Killed	Injured	Missing	Total Casualties	Killed per square km
0.0 – 0.5	7,505	960	1,127	9,592	9,500
0.5 – 1.0	3,688	1,478	1,799	6,965	1,600
1.0 – 1.5	8,678	17,137	3,597	29,412	2,200
1.5 – 2.0	221	11,958	28	12,207	48
2.0 – 3.0	112	9,460	17	9,589	8

Cause of Death	% of Total
Burns	60%
Falling debris	30
Other	10

Note: Original data have been converted to metric equivalent.

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Nuclear Weapons after WWII

- It is generally agreed that the use of atomic bombs ended World War II and probably prevented many more times casualties both on the Japanese side (mainly civilians) and for the Allies who were planning for the invasion of Japan.
- Many scientists who have helped to develop the atomic bombs were horrified with the devastating effects of the bombs. However, the end of WWII did not mark the end of the atomic bombs.
- More powerful bombs (> 1000 times more powerful than Little Boy and Fat Man) were designed and made ready for use in wars. More countries developed this capability.
- Energy from fusion of the atoms (which is the energy produced in the Sun) was finally achieved on Earth in 1952 with hydrogen bombs.
- Thousands of such devices was stockpiled in both US and former USSR (now Russia) through a deterrence strategy known as Mutually Assured Destruction (MAD).

Hydrogen (Thermonuclear) Bomb

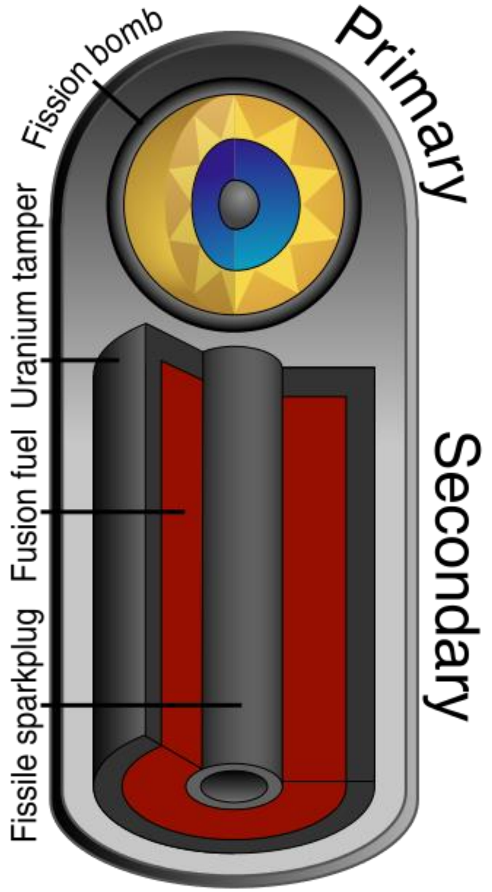
- The hydrogen bomb is a 2- (or more) stage bomb.
- The primary stage may be a standard implosion method fission bomb. It provides energy for compression in the secondary stage.
- Compression causes the fission sparkplug to become critical providing (1) neutrons and (2) high temperature for fusion.
- These neutrons produces tritium in the fusion fuel which contains lithium deuteride:

$$^{6}_{3}\mathrm{Li} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{3}_{1}\mathrm{H}\ (+\ 4.8\ \mathrm{MeV})$$

- At high enough temperature (300,000,000°C), tritium fuses with deuterium:

$$^{2}_{1}\mathrm{H} + {}^{3}_{1}\mathrm{H} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{1}_{0}\mathrm{n}\ (+\ 17.6\ \mathrm{MeV})$$

- The uranium tamper holds (and compresses) the contents. It will also undergo fission producing a significant amount of the yield.
- There are other designs and much of the details are still classified.



https://en.wikipedia.org/wiki/Thermonuclear_weapon

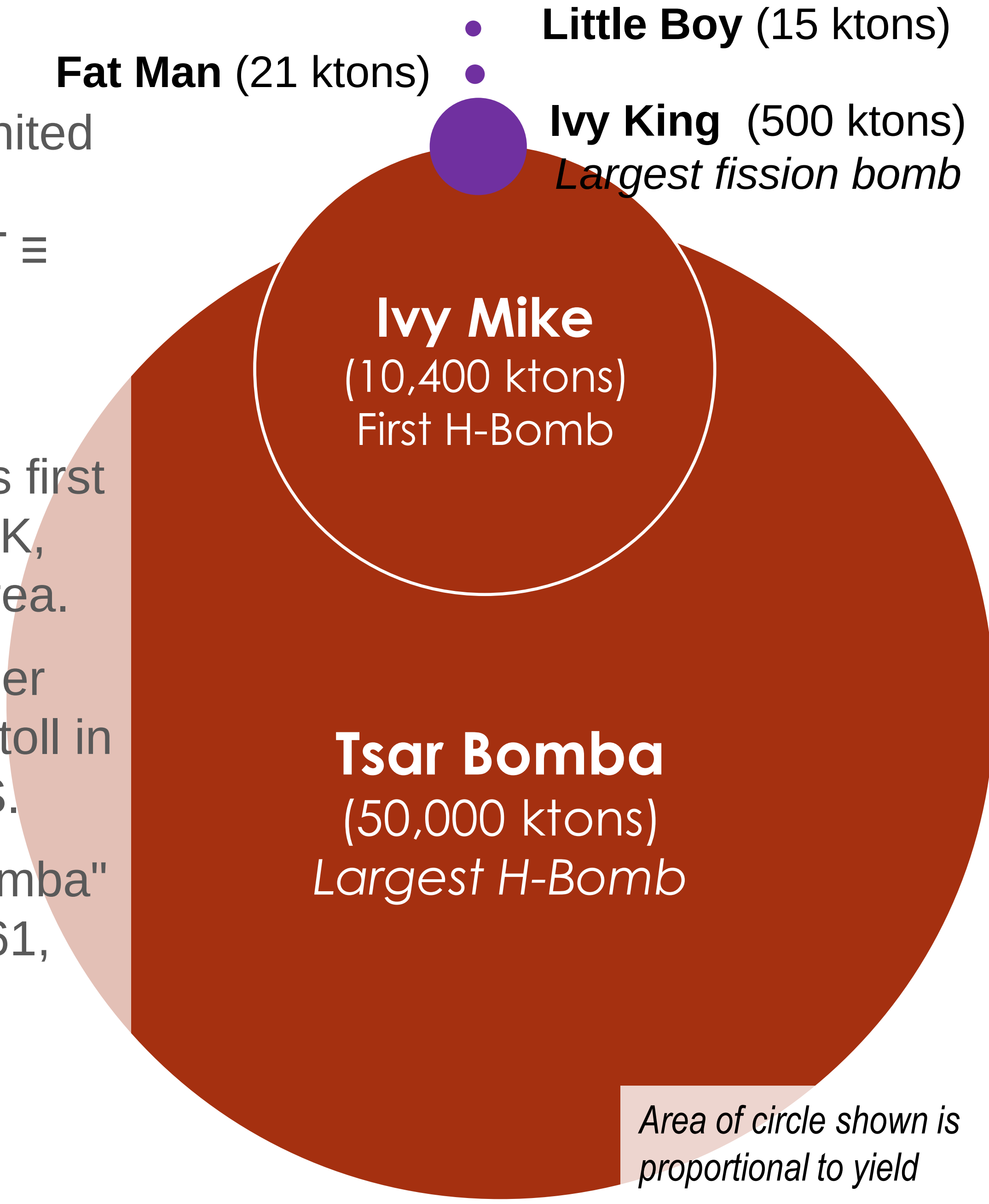
Neutron Bombs (Enhanced Radiation Weapons)

- Enhanced Radiation Weapons (ERW) or **neutron bombs** are small hydrogen bombs designed with reduced blast and thermal energy but with more energy carried away by neutrons which are allowed to escape from a specially designed casing.
- Originally meant to be a tactical weapon for tank warfare, it was met with a firestorm of protest as the growing anti-nuclear movement gained strength through the 70s and 80s.
- US government was forced to retire them.

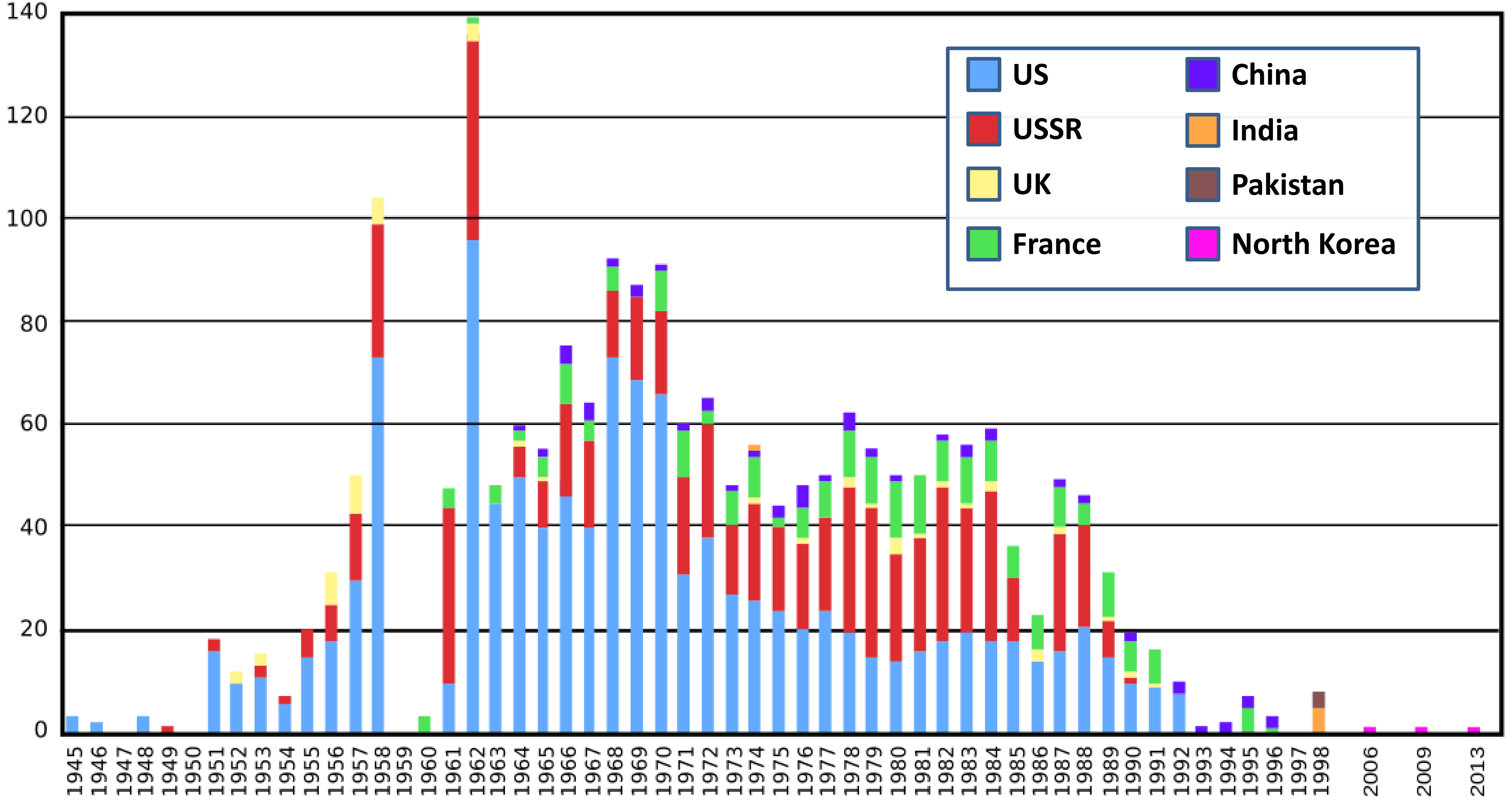
Energy type	Standard %	Enhanced %
Blast	50	30 – 40
Thermal	35	20 – 25
Prompt radiation	**5**	**30 – 45**
Residual radiation	10	5

Nuclear Weapon Tests

- The first nuclear device was detonated as a test by the United States at the Trinity site on July 16, 1945, with a yield approximately equivalent to 20 kilotons of TNT (1 ton TNT ≡ 10^9 calorie = 4.18×10^9 J)
- Two nuclear bombs were used in WWII.
- US conducted a few more tests before USSR exploded its first atomic bomb in 1949. The arms race started. Joined by UK, France and China. Later by India, Pakistan and North Korea.
- The first thermonuclear weapon technology test of engineer device, codenamed "Mike", was tested at the Enewetak atoll in the Marshall Islands on November 1, 1952 also by the US.
- The largest nuclear weapon ever tested was the "Tsar Bomba" of the Soviet Union at Novaya Zemlya on October 30, 1961, with the largest yield ever seen, an estimated 50–58 megatons.



Nuclear Weapon Tests by Various Countries



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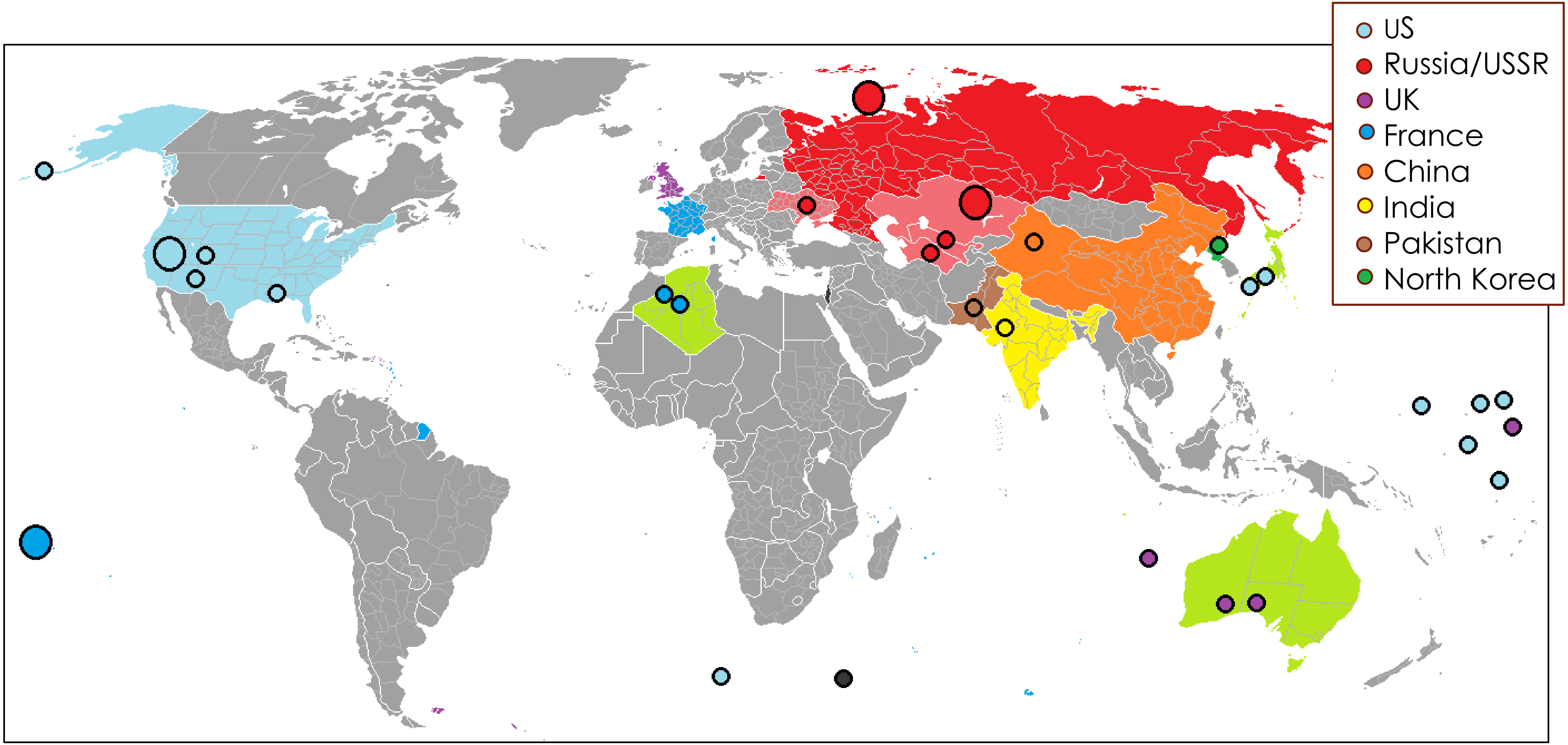
Nuclear Weapon Tests by Various Countries



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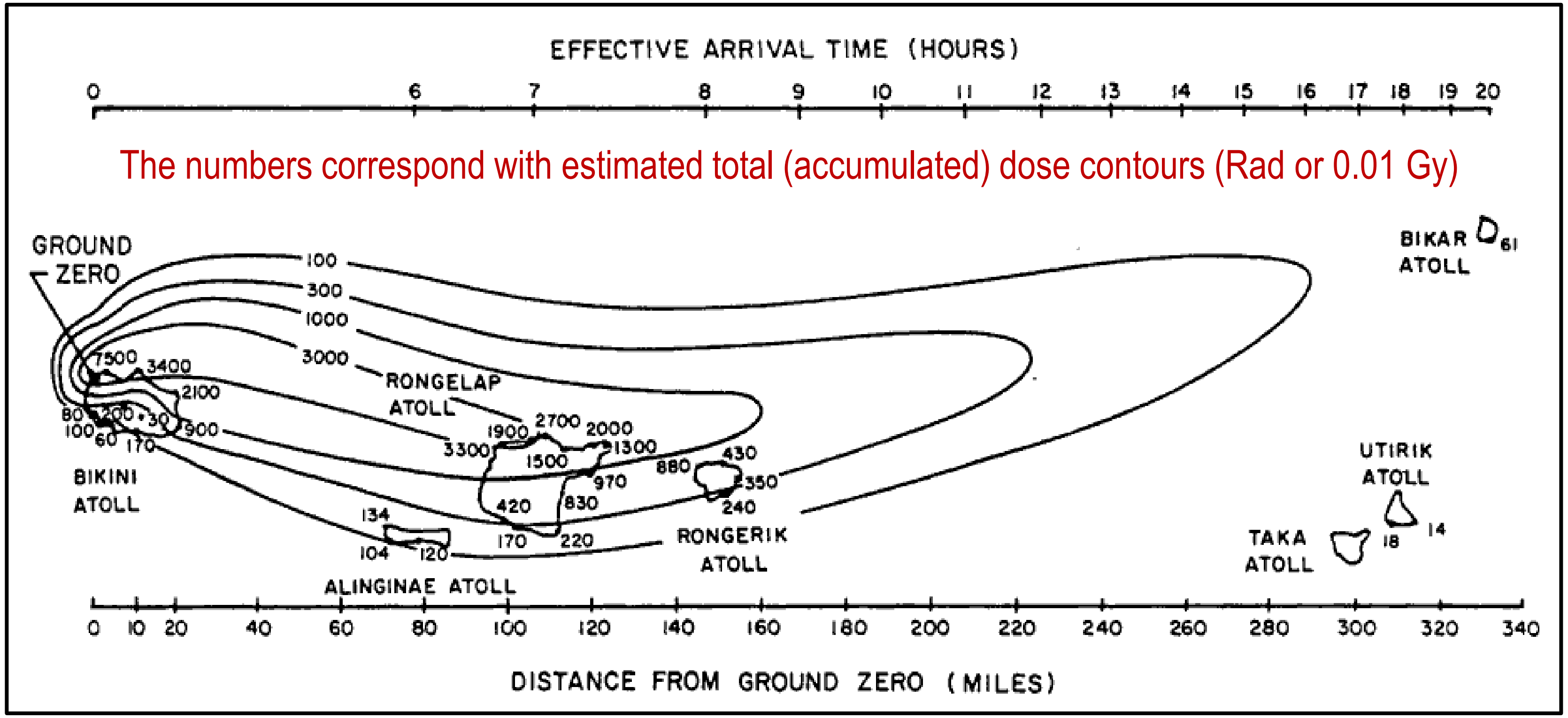
Nuclear Countries and Number of Tests

Country	Tests	Devices fired	Devices w unknown yields	Peaceful use tests	Non-PTBT tests	Yield Range (kilotons)	Total Yield (kilotons)	% (by tests)	% (by yield)
USA	1032	1132	12	27	231	0 to 15,000	196,514	48.7%	36.3%
USSR	727	981	248	156	229	0 to 50,000	296,837	34.4%	54.9%
UK	88	88	31	0	64	0 to 3,000	9,282	4.15%	1.72%
France	217	217	0	4	57	0 to 2,600	13,567	10.2%	2.51%
China	47	48	7	0	23	0 to 4,000	24,409	2.22%	4.51%
India	3	6	0	1	0	0 to 60	68	0.141%	0.0126%
Pakistan	2	6	0	0	0	1 to 32	51	0.107%	0.0094%
North Korea	6	6	0	0	0	1 to 250	197.8	0.2836%	0.024%
Totals	**2121**	**2476**	**294**	**188**	**604**	**0 to 50,000**	**540,849**		

https://en.wikipedia.org/wiki/List_of_nuclear_weapons_tests

Radiation Effects of Nuclear Tests

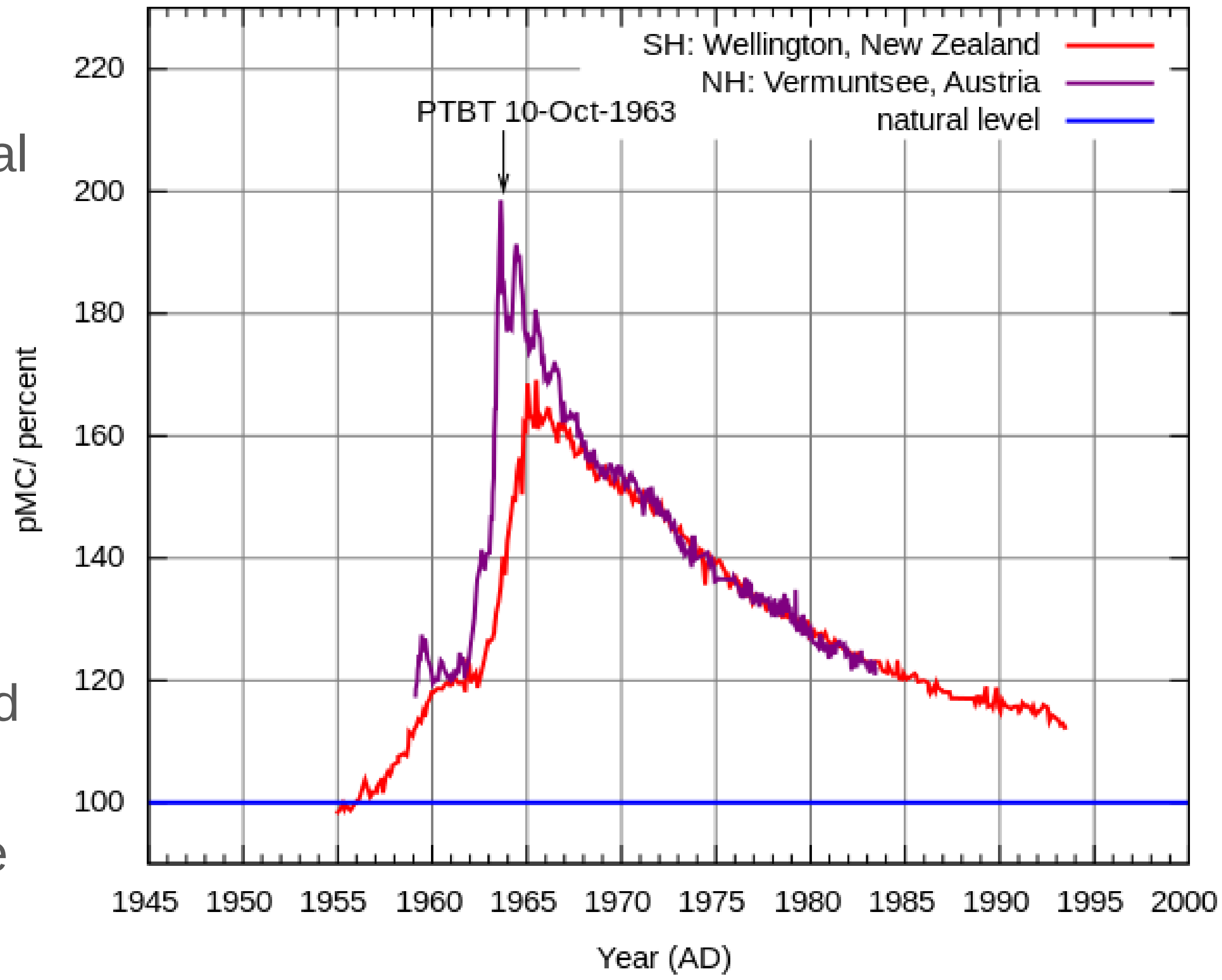
- Due to the neutrons and gamma rays emitted by a nuclear weapon, anyone in the vicinity would be exposed, e.g., in some of the early tests. Note, for a 1 megaton explosion, it was estimated that at distance of 2 km away, the dose would be 5 Sv.
- More importantly, the radioactive fallout may affect a much larger area.
- One example is fallout during the nuclear weapons test Bravo (yield 15,000 ktons) on Bikini Atoll on Mar 1, 1954 during Operation Castle. The plume spread dangerous levels of radioactivity over an area over 160 km long, including inhabited islands.



https://en.wikipedia.org/wiki/Nuclear_weapons_testing#/media/File:Bravo_fallout2.png

Radioactive Fallout

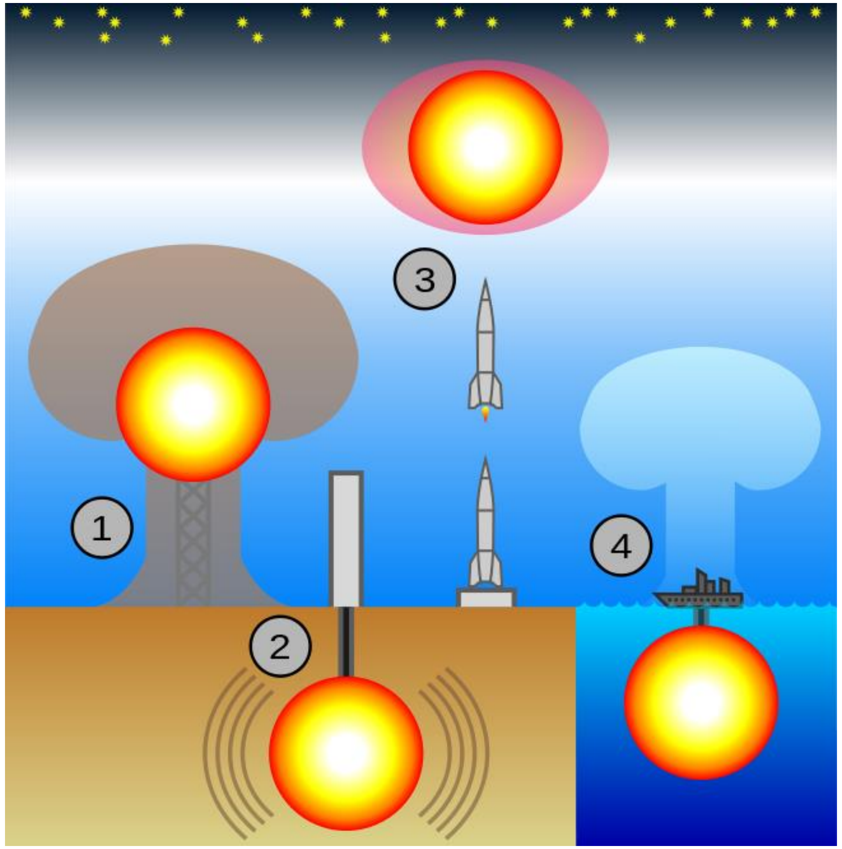
- The nuclear explosions between the 1945 and 1960s scattered a substantial amount of radioactive contamination. Some of this material is dispersed worldwide.
- The increase in background radiation due to these tests peaked in 1963 at about **0.15 mSv** per year worldwide, or about 7% of average background dose from all sources.
- The Partial Test Ban Treaty of 1963 prohibited above-ground tests, thus by the year 2000 the worldwide dose from these tests has decreased to only 0.005 mSv per year.
- The graph on right show the ratio of radioactive C-14 to stable C-12 from 1955 to 1995.



https://en.wikipedia.org/wiki/Background_radiation#/media/File:Radiocarbon_bomb_spike.svg

Test Ban Treaties

- Mounting public pressure both domestically and in the international arena against nuclear testing due to increased awareness of the implications for health, environment and global security, as well as concern over the escalating nuclear arms race
- 1963: **Partial Test Ban Treaty (PTBT)**: Ban testing in atmosphere, space and underwater. Underground still allowed. Signed by US, USSR and UK.
- 1974: **Threshold Test Ban Treaty (TTBT)** – <150 kilotons.
- 1996: **Comprehensive Nuclear-Test-Ban Treaty (CTBT)** – Ban all nuclear explosions on Earth whether for military or for peaceful purposes



Four major types of nuclear testing:
1. atmospheric, 2. underground,
3. exoatmospheric, 4. underwater

https://www.ctbto.org/the-treaty/

Nuclear Stockpile

- **Megatons to Megawatts** programme – convert nuclear weapons to nuclear fuel
- United States and Soviet Union (Russia) have reduced significantly the number of warheads in their nuclear stockpiles but …