How The Atomic Bombs Were Made ?

A deep dive into the physics behind disaster of atomic bombs

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Introduction

- In 1942, before the Manhattan Project, Robert Oppenheimer held conferences where physicists discussed nuclear bomb design issues.
- A gun-type design was initially chosen, where two sub-critical masses of plutonium would be brought together by firing a "bullet" into a "target".
- The alternative implosion-type design, suggested by Richard Tolman, was considered far more complex and received scant consideration.

Thin Man

- In early 1943, Oppenheimer prioritized the gun-type weapon but created the E-5 Group at Los Alamos to investigate implosion as a hedge against predetonation.
- Implosion-type bombs were determined to be more efficient in terms of explosive yield per unit mass of fissile material due to compressed fissile materials reacting more rapidly and completely.
- However, the plutonium gun-type bomb received the bulk of the research effort due to less uncertainty involved, with the assumption that the uranium gun-type bomb could be easily adapted from it.

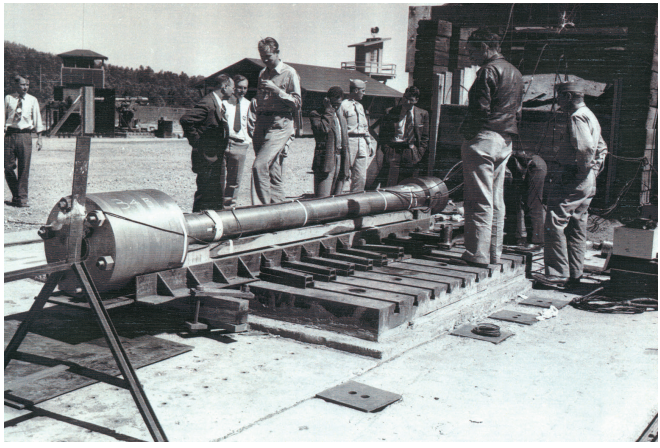

Figure 1: A prototype of the "Thin Man" gun being tested at Anchor Ranch, at Los Alamos.

- "Thin Man" was an early nuclear weapon design proposed before plutonium breeding.
- It assumed plutonium could be assembled by a gun-type method, requiring a "bullet" speed of at least 910 m/s.
- Dimensions: 5.2 m long, 0.97 m wide tail and nose, 0.58 m midsection.
- Weight: approximately 3,600 kg.
- No USAAF aircraft could carry it without modifications.
- Avro Lancaster (10 m bomb bay) or modified Boeing B-29 Superfortress were suggested.
- B-29 modification involved removing part of the bulkhead and oxygen tanks (Serial No. 42-6259).

Figure 2: A USAAF B-29 Superfortress. B-29s dropped the atomic bombs on Hiroshima and Nagasaki, the only aircraft ever to drop nuclear weapons in combat.

Predetonation

- Experiments in April 1944 by Emilio G. Segrè's group at Los Alamos showed reactor-produced plutonium contained the isotope plutonium-240.
- Plutonium-240 has a high spontaneous fission rate, increasing the risk of predetonation.
- This meant the plutonium would likely predetonate and blow itself apart during critical mass formation.
- The distance required to avoid predetonation would need an impractically long gun barrel for any bomber.

- The only viable option was the more difficult implosion method.[2]
- At a meeting on July 17, 1944, it was agreed that gun-type work would focus on the `Little Boy` uranium design.
- Almost all Los Alamos research was re-oriented toward solving the implosion problems for the `Fat Man` plutonium bomb.

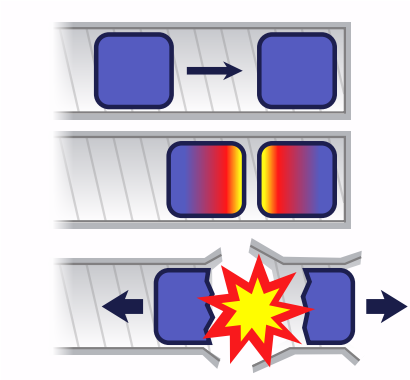

Figure 3: If two pieces of subcritical material are not brought together fast enough, nuclear predetonation can occur, whereby a smaller explosion than expected will blow the bulk of the material apart.

Pu-239 Production

$$^{238}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \longrightarrow {}^{239}_{92}\mathrm{U} \xrightarrow[23.5\ \mathrm{min}]{\beta^-} {}^{239}_{93}\mathrm{Np} \xrightarrow[2.3565\ \mathrm{d}]{\beta^-} {}^{239}_{94}\mathrm{Pu}$$

Neutrons from the fission of uranium-235 are captured by uranium-238 nuclei to form uranium-239; a beta decay converts a neutron into a proton to form neptunium-239 (half-life 2.36 days) and another beta decay forms plutonium-239.[1]

Isotope	Decay mode	Half-life (years)	Spontaneous fission n $(1/(g{\cdot}s))$
^{238}Pu	alpha to ^{234}U	87.74	2600
^{239}Pu	alpha to ^{235}U	24100	0.022
^{240}Pu	alpha to ^{236}U	6560	910

Little Boy

- The gun-type uranium bomb, code-named "Little Boy", was much simpler than the plutonium implosion design.
- Its smaller size allowed it to fit into the B-29 bomb bay without difficulty.
- Design specifications were completed in February 1945, with components manufactured at different plants.
- The bomb (except uranium payload) was ready by early May 1945.
- The enriched uranium projectile and target were completed in June and July 1945, respectively.
- No full test of the gun-type bomb was conducted before the Hiroshima bombing.

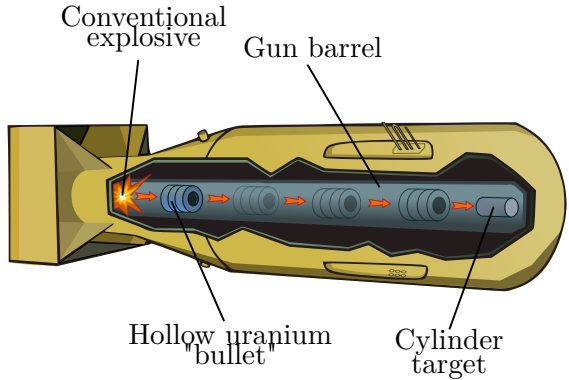

Figure 4: The "gun" assembly method. When the hollow uranium projectile was driven onto the target cylinder, a nuclear explosion resulted.

- Little Boy had an estimated yield of 15 kilotons based on data from instruments dropped by parachute.
- A rule of thumb was developed: the "5 psi lethal area" where overpressure $\geq$ 34 kPa would be fatal.
- At Hiroshima, this lethal area had a diameter of 3.5 km.
- Three main effects: blast, fire, and radiation.

Blast

- Everything within 1 km was destroyed except reinforced concrete buildings.
- Severe blast damage followed the 34 kPa overpressure contour at 1.8 km radius.
- Fuel for fires was created by blast damage to structures.

Fire

- Fireball surface temperature was $6,000°C$, igniting fires across the destruction zone.
- Fires merged into a 3.2 km diameter firestorm within 20 minutes.
- An estimated 60% of immediate deaths were from fires.

Radiation

- No local fallout since it was an air burst.
- Lethal radius of 1.3 km from initial radiation.
- 30% of immediate deaths from direct radiation exposure.
- 30% of survivors had radiation injuries, increasing cancer risk.

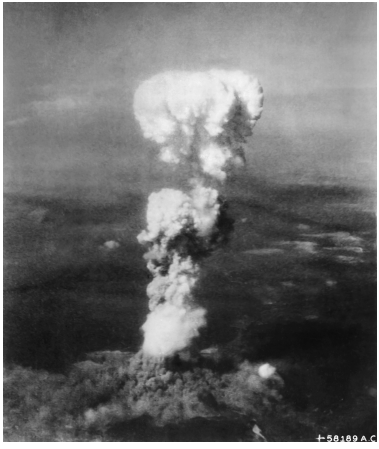

Figure 5: The mushroom cloud over Hiroshima after the detonation of Little Boy on 6 August 1945.

- After falling for 44.4 seconds. Detonation occurred at an altitude of 600 ± 15 m.
- It was less powerful than the Fat Man bomb dropped on Nagasaki.
- However, damage and casualties in Hiroshima were higher due to its flat terrain.
- Published figures in 1945 stated 66,000 people killed and 69,000 injured.
- Later estimates put the death toll as high as 140,000.

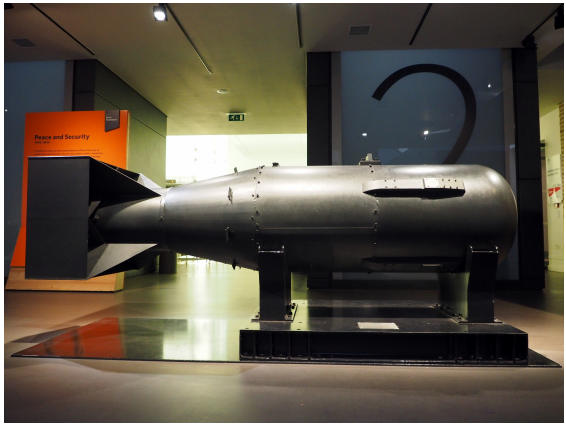

Figure 6: One of five casings built for the Little Boy bomb used on Hiroshima on display at the Imperial War Museum in London during 2015

Fat Man

- The idea of using shaped charges as 3D explosive lenses came from James L. Tuck and was developed by John von Neumann.
- Precision in the inward motion of the explosive plates was crucial, achieved using exploding-bridgewire detonators invented by Luis Alvarez and Lawrence Johnston.
- Robert Christy's calculations showed that a solid plutonium sphere could be compressed to a critical state, simplifying the task.
- The bomb size was constrained by the available aircraft; (maximum length: 3.4 m, width: 1.5 m, weight: 9,100 kg).
- Drop tests led to modifications, including the addition of a "California Parachute" stabilizer for a stable descent.
- The final wartime Y-1561 design was assembled with 90 bolts and yielded approximately 100 TJ (25 kilotonnes) in the Trinity test on July 16, 1945.

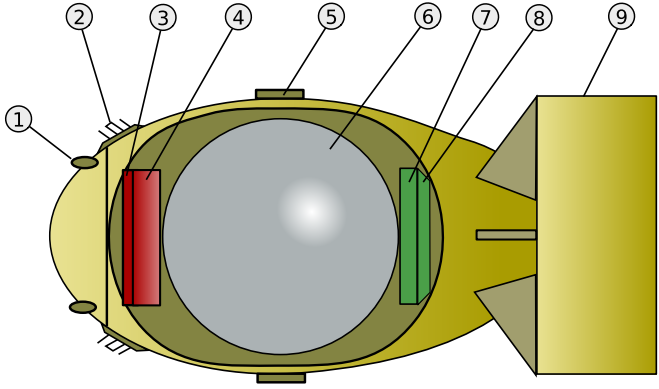

Figure 7: Fat Man external schematic.

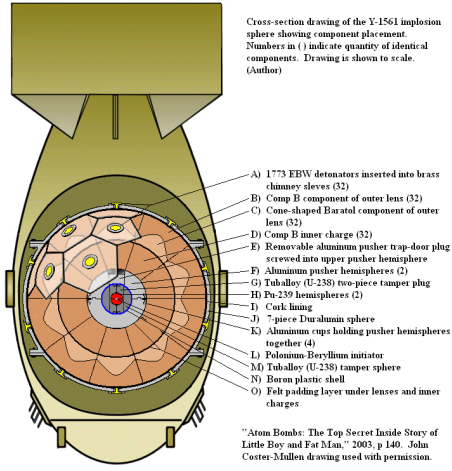

Figure 8: Fat Man internal schematic

The Implosion

https://upload.wikimedia.org/wikipedia/commons/0/05/ImplosionShapedCharge.gif

The Urchin

- The neutron initiator design typically combines beryllium-9 and polonium-210, separated until activation.
- The alpha source isotope must have strong alpha emissions and weak gamma emissions.
- It consisted of a beryllium pellet (0.8 cm diameter), beryllium shell (2 cm outer diameter, 0.6 cm wall thickness) with grooves, and polonium-210 (50 curies, 11 mg) deposited between them.

- Gold and nickel coatings shielded the beryllium from polonium's alpha particles.
- Upon implosion, the shock wave mixed the beryllium and polonium, allowing alpha particles to bombard beryllium and emit neutrons (1 neutron every 5-10 ns).
- The neutrons triggered the chain reaction in the compressed plutonium core.

https://youtube.com/clip/UgkxPCbwqQO4_6HBbKd4qxSKm2mrt0CYYnDy?si=m5m0Mrrw2ZoW0jmk

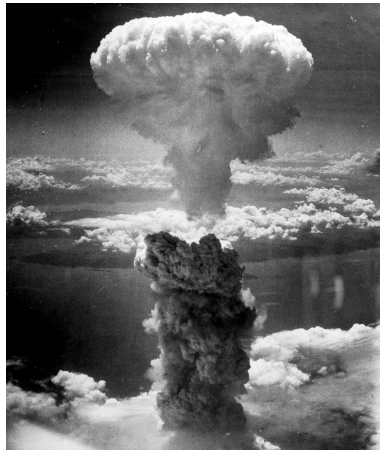

Figure 9: Mushroom cloud after Fat Man exploded over Nagasaki on 9 August 1945

References & Conclusion

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Thank you for listening.