THE DEMON CORE & FRIENDS

MATERIAL SCIENCE OF THE A-BOMBS

Dogbone of the Week 10/21/22

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What is it?

- 6.2 kg subcritical sphere of plutonium-gallium alloy, 3.5 inches in diameter
- Developed by the United States as the fissile material core for a 3rd atomic bomb under the Manhattan Project.
- Never used, but planned for a bomb that would have been dropped on Tokyo

  Suspected to have been planned for August 19, 1945. Japanese surrendered on August 15.
- Laboratory accidents post Japanese surrender involving the core resulted in the death of two physicists

https://www.sciencealert.com/the-chilling-story-of-the-demon-core-and-the-scientists-who-became-its-victims-plutonium-bomb-radiation-wwii

Fission

- When a stray neutron bombards an atomic nucleus, the atom becomes heavy and can “split” into two atoms with a release of neutron(s) and gamma radiation

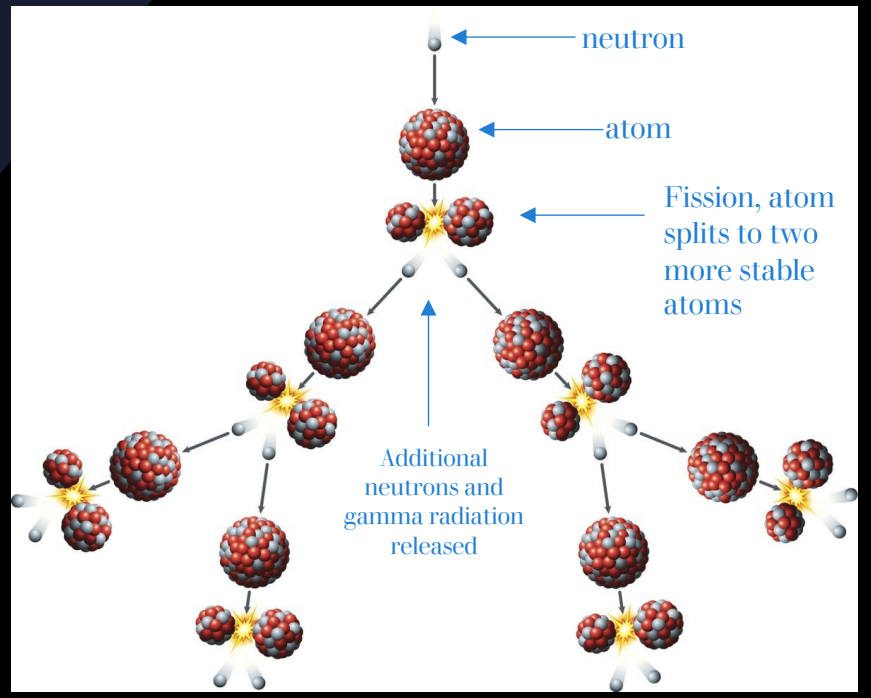


Image: https://www.space.com/what-is-nuclear-fission

Criticality of Nuclear Materials

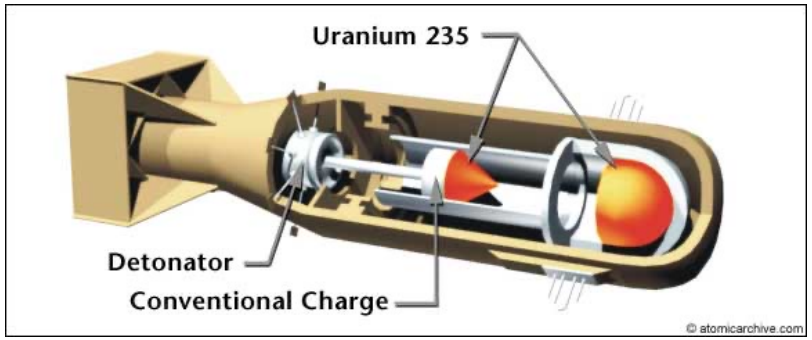
- Cores of nuclear weapons are where fission chain is started when core goes “super critical”
- Critical Mass = the amount of material required to sustain fission reactions by the release of neutrons from previous fission event.

  The higher the density, the smaller the critical mass.

Subcritical = Not enough neutrons released. Reactions will fizzle out or are not occuring.

Critical = fission reactions continues and is self sustaining.

Supercritical = More than enough material to sustain a nuclear reaction and more than 1 neutron produced. Becomes a “runaway” reaction.



- Dropped by the U.S. on the city of Hiroshima on August 6, 1945
- Core made of highly enriched uranium (HEU, more than 20% U-235)
- Core HEU material contained 80% U-235. Called Oralloy.
- HEU target in a gun barrel shot at another target of HEU producing a critical mass in less time than time between spontaneous fissions

Little Boy

Top: https://www.atomicheritage.org/history/little-boy-and-fat-man

Middle: https://www.atomicarchive.com/science/fission/little-boy.html

Bottom: https://en.wikipedia.org/wiki/Enriched_uranium#Highly_enriched_uranium_(HEU)

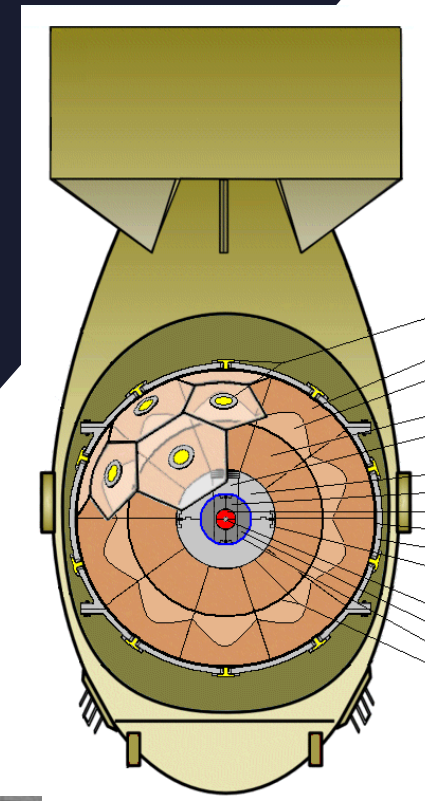
Fat Man

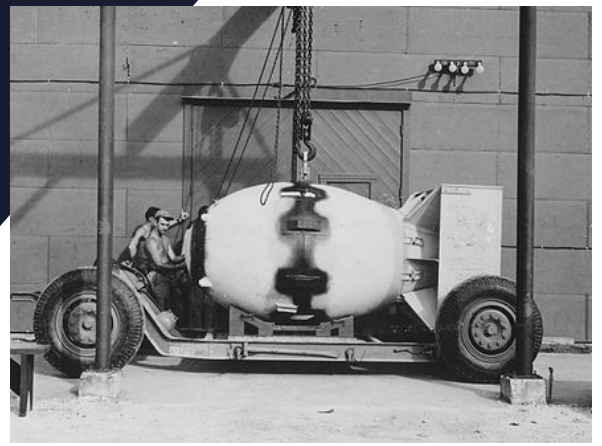
- Dropped by the U.S. on the city of Nagasaki on August 9, 1945
- Core was constructed of Plutonium-Gallium Alloy, the same as the Demon Core.

  Plutonium was more fissile than U-235; more neutrons and less critical mass needed.
- Mechanism had to be changed because of Pu's reactivity

  Significant Pu-240 in core that is prone to spontaneous fission.
- "Implosion style" - explosions on outside of the physics package surrounding the core were detonated, crushing the Pu-Ga core into criticality.

  Surrounded by a U-238 tamper to reflect more neutrons inward.





https://en.wikipedia.org/wiki/Fat_Man#Interior_of_bomb

Construction of the Fat Man and Demon Cores

- Pu-239 was created in Hanford, WA nuclear reactors from U-238. Took a few days of neutron radiation to separate.
- δ phase Pu can be stabilized with the addition of 3-3.5 mol% Ga. The phase is the least dense, most easily machinable.
- Hot pressed into two half sphere and then coated with Ni to avoid corrosion. The alloy was shown to have low thermal expansion and...
- Good castability – liquid phase is denser than the solid phase therefore making the alloy less susceptible to internal defects, bubbles etc.

$$^{238}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \longrightarrow {}^{239}_{92}\mathrm{U} \xrightarrow[23.5\ \mathrm{min}]{\beta^-} {}^{239}_{93}\mathrm{Np} \xrightarrow[2.356\ \mathrm{d}]{\beta^-} {}^{239}_{94}\mathrm{Pu}$$

https://en.wikipedia.org/wiki/Plutonium-239
https://svedic.org/history/demon-core#:~:text=Nothing%20happened%20to%20the%20core%2C%20except%20for%20the,Alamos%20started%20calling%20this%20one%20the%20Demon%20core.

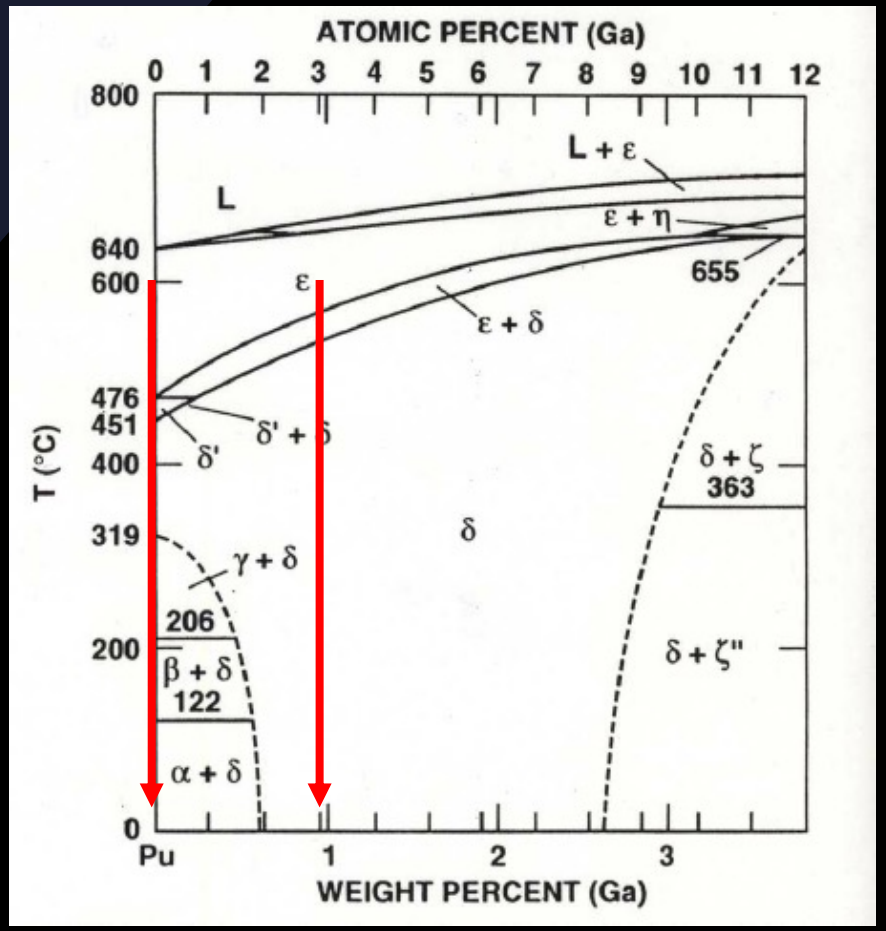
Plutonium-Gallium Alloy

- Found that machining Plutonium alone was difficult due to many phase changes

  Cracking and deformation upon cooling as it passes through 4 phases

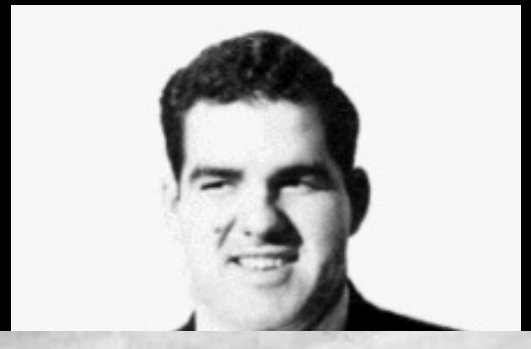
- Alloying with ~1 weight% gallium results in only an epsilon to δ-phase plutonium phase change upon cooling.

  Gallium is trivalent, has a low absorption cross section and protects against corrosion



https://www.researchgate.net/figure/Plutonium-gallium-phase-diagram-for-low-gallium-concentrations-5_fig1_2552269

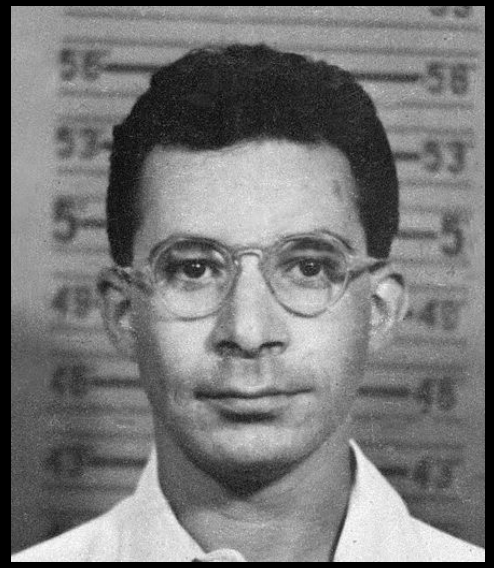
The Accidents with the Demon Core



The First Accident

- August 21, 1945
- Harry Daghlian, a graduate student, was working alone and placing tungsten carbide bricks around the subcritical core to act as neutron reflecting tampers.
- Attempting to see how close to criticality he could get the core to to try and reduce it's critical mass
- Dropped the final brick, caused the core to go supercritical
- Removed bricks to stop reaction.
- **Received 510 rem of radiation. Died at the age of 24, 25 days after the accident of acute radiation poisoning.**
- **Led to additional safety scrutiny and a "two person" rule**

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



The Second Accident

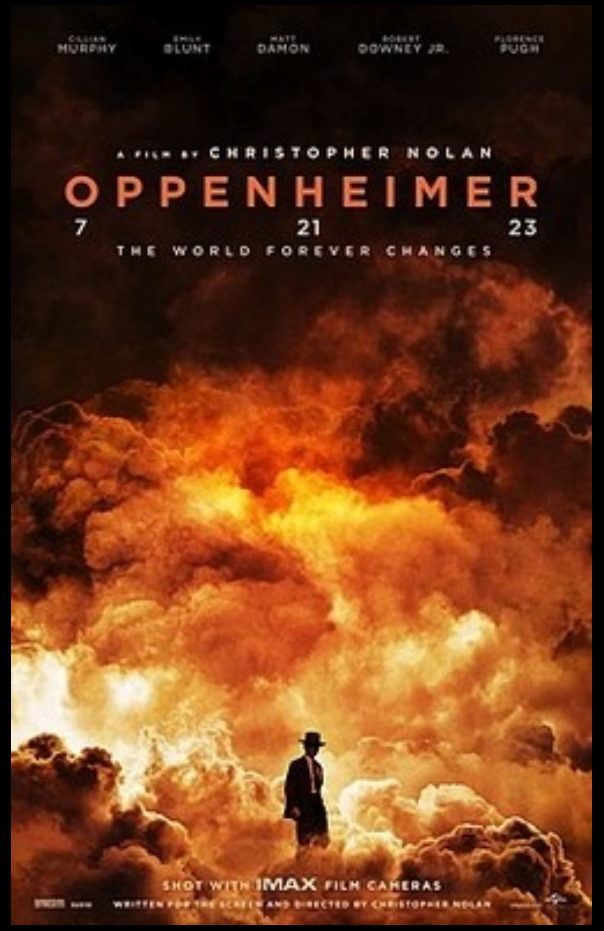
- May 21, 1946
- Louis Stolin, an outgoing physicist, was demonstrating an experimental to his successor Alvin Graves ahead of a test at Bikini Atoll
- Neutron reflecting half spheres of beryllium were being placed around core. When the half sphere tampers met, criticality was achieved but they were separated by shims usually. Stolin used a (unapproved) flathead in the demonstration.
- He performed this experiment in this unsafe manner dozens of times. Fermi and Feynmann expressed concern and disapproval.
- In the accident, the screwdriver slipped. Stolin pushed the top beryllium hemisphere to the ground. No one was wearing dosimetry badges which were placed at the accident location moments later.
- Received 1000 rems of radiation, died 9 days later after complete organ shut down.

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

The Demonic End

- Core was set to be tested but after too many postponed tests eventually melted down in 1946 for use in additional cores or stockpiled.

The Making of the Atomic Bomb, Richard Rhodes



Resources

https://www.sciencealert.com/the-chilling-story-of-the-demon-core-and-the-scientists-who-became-its-victims-plutonium-bomb-radiation-wwii

https://www.space.com/what-is-nuclear-fission

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

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

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

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

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

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

https://physics.stackexchange.com/questions/248504/find-the-energy-release-in-this-nuclear-reaction-fission

https://chem.libretexts.org/Bookshelves/Introductory_Chemistry/Map%3A_Introductory_Chemistry_(Tro)/17%3A_Radioactivity_and_Nuclear_Chemistry/17.03%3A_Types_of_Radioactivity-_Alpha_Beta_and_Gamma_Decay

http://wordpress.mrreid.org/2010/07/

https://www.atomicheritage.org/history/little-boy-and-fat-man

https://www.atomicarchive.com/science/fission/little-boy.html

https://en.wikipedia.org/wiki/Enriched_uranium#Highly_enriched_uranium_(HEU)

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https://www.researchgate.net/figure/Plutonium-gallium-phase-diagram-for-low-gallium-concentrations-3_fig1_2352269

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

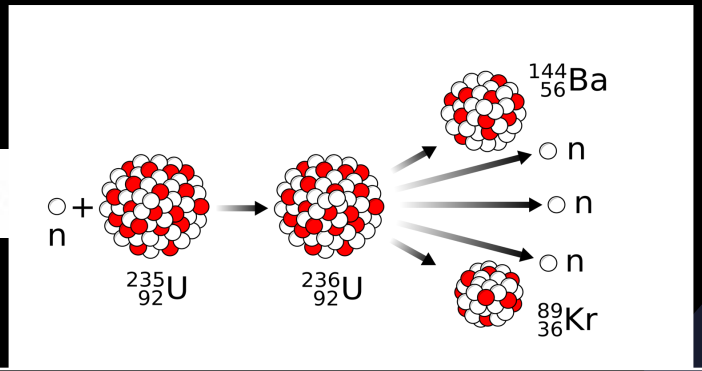
https://en.wikipedia.org/wiki/Louis_Slotin

Back up

Uranium vs Plutonium

- U-238 is naturally occurring. It is more likely that a stray neutron encounter will result in U-239 and beta decay, rather than cause fission.
- U-235 is fissile but barely naturally occurring, has to be separated from U-238.
- Pu-239 has a higher spontaneous fission rate than that of U-235, meaning it can naturally split without bombardment. It will fission with bombardment and is denser than Uranium.

$$^{239}_{94}\mathrm{Pu} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{91}_{38}\mathrm{Sr} + {}^{146}_{56}\mathrm{Ba} + x\,{}^{1}_{0}\mathrm{n}$$



https://physics.stackexchange.com/questions/248504/find-the-energy-release-in-this-nuclear-reaction-fission
https://chem.libretexts.org/Bookshelves/Introductory_Chemistry/Map%3A_Introductory_Chemistry_(Tro)/17%3A_Radioactivity_and_Nuclear_Chemistry/17.03%3A_Types_of_Radioactivity-_Alpha_Beta_and_Gamma_Decay
http://wordpress.mrreid.org/2010/07/

What was Involved in the Experiments

- Physicists were attempting to have core reach close to criticality and lower the critical mass with the use of tampers

  Tampers were materials that were neutron reflectors (dense metals with low z numbers had high scattering cross sections)

- Wanted to understand how many neutrons were needed to push the core over criticality and into supercriticality without taking core to that point
- Accidents caused the core to go supercritical momentarily and resulted in death and injury to those in the lab