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

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.
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 occurring.
  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
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.*
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.
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 $\delta$-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-3_fig1_2352269
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 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.
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.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/Fissile_material
https://en.wikipedia.org/wiki/Plutonium
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/17.05%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)
https://en.wikipedia.org/wiki/Fat_Man#Interior_of_bomb
https://svedic.org/history/demon-core#:~:text=Nothing%20happened%20to%20the%20core%20except%20for%20the%20bomb,Alamos%20started%20calling%20this%20the%20Demon%20core.
https://www.researchgate.net/figure/Plutonium-gallium-phase-diagram-for-low-gallium-concentrations-5_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.

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_(Trot)/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