

Nuclear Energy

- Nuclear energy levels are a few MeV compared to atomic energy levels of a few eV; so fuel energy density is 10^6 times larger for nuclear fuel
- Both fission and fusion processes can release energy
- Most promising fission reactions are uranium and plutonium because these reactions are neutron-induced and release neutrons making a chain reaction possible
- Most promising fusion reactions involve hydrogen, deuterium, tritium- \rightarrow helium

Nuclear Energy

- Energy release can either be controlled or explosive
- Both controlled and explosive fission reactions have been achieved
- Only explosive fusion reactions have been achieved on a large scale

Fission Bombs

- Hahn, Strassman and Meitner discovered in 1938 that uranium could be fissioned by neutrons and that fission produced neutrons
- Questions: Which isotope? How much do you need (fission cross-section)? Where do you get the uranium? How do you detonate the bomb and avoid early or late detonation?

Uranium Isotopes

- First ^{235}U isolated electromagnetically in basement on Feb. 29, 1940. About 1% of natural uranium. Shown to be fissionable isotope.
- Need more uranium from Belgian Congo. Need to develop separation strategy based solely on mass.
- Surround bomb with a “tamper” to reflect neutrons and contain initial explosion

Isotope Separation

- Electromagnetic: one atom at a time
- Diffusion: gas diffusion or thermal diffusion proportional to square root of mass=1.006. Gas diffusion uses UF_6 that is highly corrosive; requires thousands of cascading stages
- Centrifuge
- Laser excitation

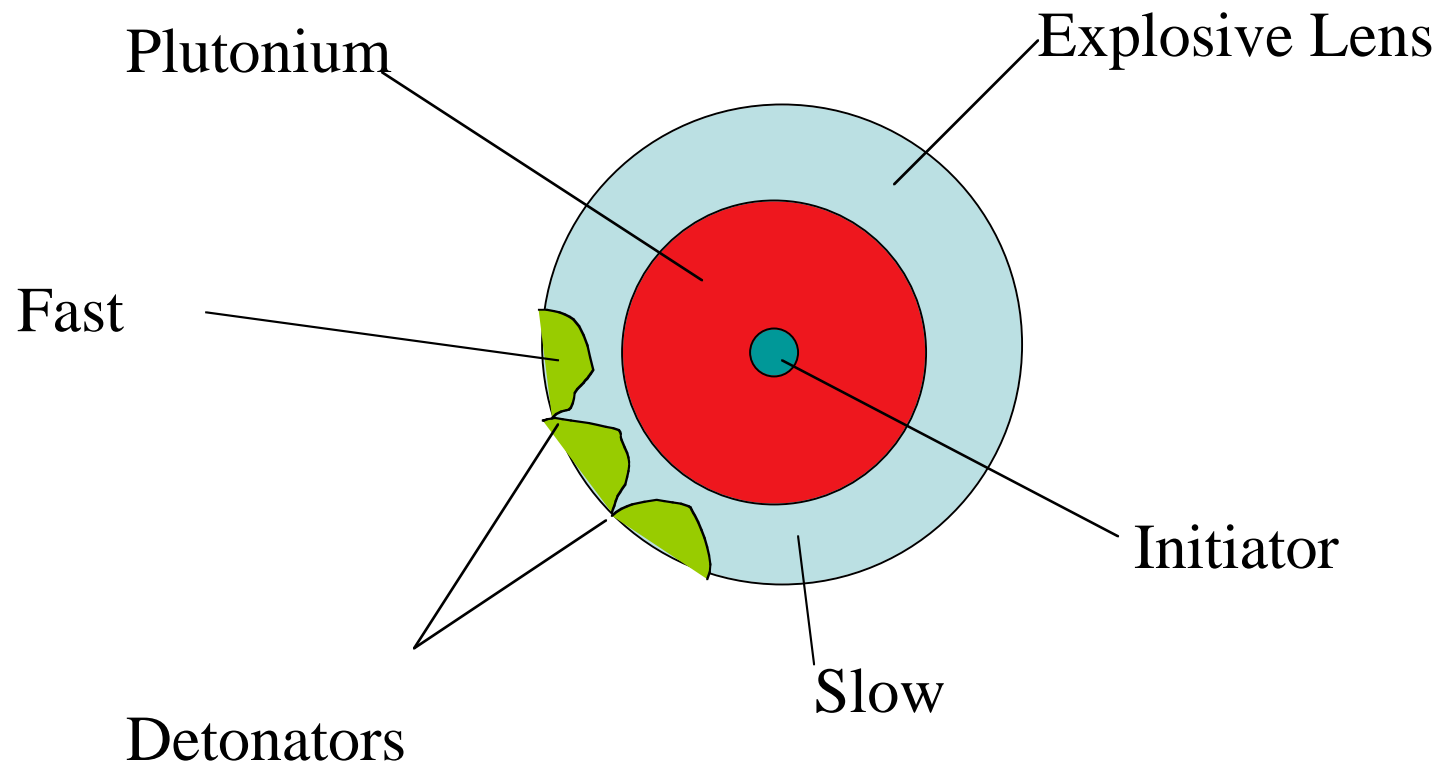
Plutonium

- ^{240}P is made from ^{238}U by absorption of two neutrons plus two beta decays
- If ^{240}P is left in a reactor for a period of time, it transmutes into ^{241}P , which is difficult to make into a bomb because of its high spontaneous fission rate
- Plutonium can be separated chemically
- Neutrons must be slowed by a moderator to enhance capture cross-section. Possible moderators include carbon and deuterium; reactors are poisoned by boron and cadmium

Detonation

- Quickly assemble a critical mass and ensure a supply of initial neutrons
- How quickly: depends on spontaneous fission rate. Plutonium is much more difficult than uranium
- Bomb dropped on Hiroshima was uranium bomb with a naval gun as detonator
- Plutonium bomb tested at Alamogordo and dropped on Nagasaki; used implosion

Implosion



Fission Reactors

- Biggest technological problem is neutron damage to reactor components
- Embrittlement of metals threatens reactor structural integrity
- Swelling of fuel rods makes rod removal problematic
- Political climate means no new reactors in U.S. and several other countries

Thermonuclear Fusion

- Require high temperatures and pressures to overcome Coulomb repulsion because strong force is short-range
- Hydrogen bombs use fission bombs as detonators
- Controlled fusion strategies include: electromagnetic containment (plasmas), laser implosion and small bombs
- Progress likely to be slow unless (a) technical breakthrough or (b) exhaustion of fossil fuels