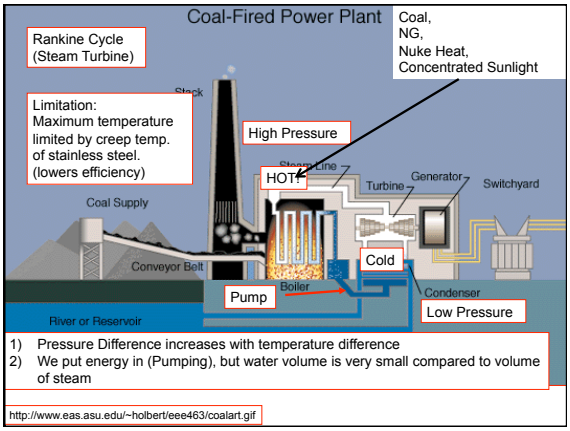
Lecture 11a: Nuclear Energy, the Technology

Pete Schwartz *Cal Poly Physics*

- How is it that we can extract nuclear power (mass deficit)
- What is Fission vs. Fusion?
- How do we control the nuclear reaction?



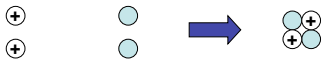
$E = mc^2$

Energy Released

Speed of Light = $3x10^8$ m/s

"mass defect", "mass deficit"
The mass that is lost

Fusion process:



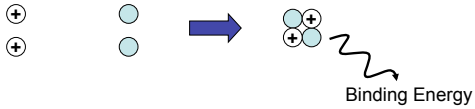
2 protons + 2 neutrons => 1 helium nucleus (α)

The alpha particle has a mass of only 99.25% the original mass

We "lost" 0.75% of the original mass… turned it to energy

If we started with 1 kg of protons and neutrons, 7.5 g to energy:

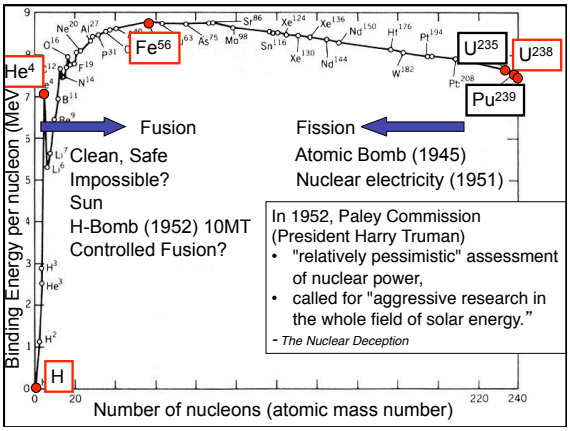
$E = mc^2 = 0.075\ kg * 9x10^{16} m^2/s^2 = 6.8x10^{14}\ J = 15{,}000\ TOE$

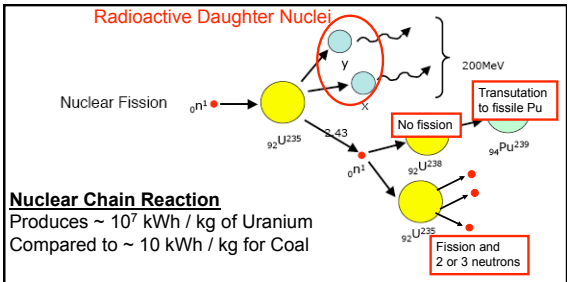


2 protons + 2 neutrons => 1 helium nucleus (α)

$E = mc^2$ is given off in the fusion process, **Binding Energy**
Energy must be supplied to make the reaction go backwards

- So protons and neutrons are more stable as an alpha particle
- Binding Energy per nucleon is a measure of stability
- Further fusion to larger nuclei releases more binding energy





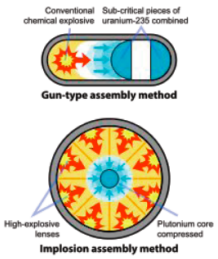
Nuclear Chain Reaction
Produces ~ 10^7 kWh / kg of Uranium
Compared to ~ 10 kWh / kg for Coal

At critical mass, the chain reaction becomes self sustaining, and increases exponentially.

Only need to attain critical mass:
1) Increase mass of fissile material
2) Increase density,
3) or reaction cross section (moderators: graphite, water)

Little boom (conventional explosives) => **BOOM!!**

Little Boy, U235 (Hiroshima)



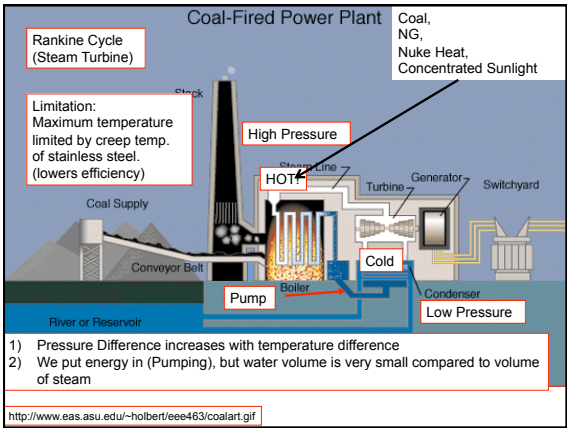
Fat Man Pu (Nagasaki)

Controlling the Chain Reaction in a nuclear reactor! so it stays going, but doesn't get out of control

Critical Mass: Increase the "nuclear cross section" of the reaction.
Slow the neutrons with a neutron moderator like carbon, or water!

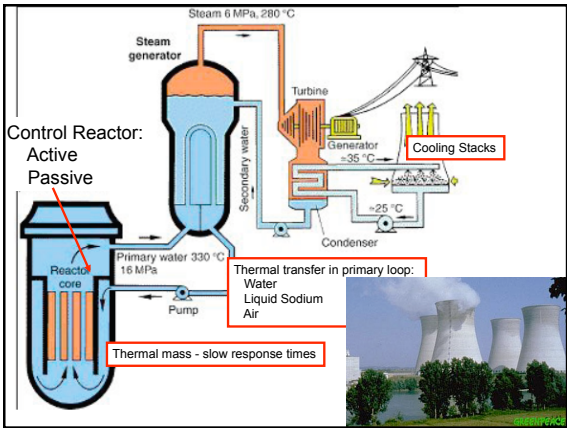
STOP a chain reaction by absorbing the neutrons
Control rods can be lowered into the reaction chamber.

Delayed Neutrons: After the reaction goes "sub critical" it is dying away. However, there are many radioactive "daughter nuclei" that are decaying, producing neutrons.

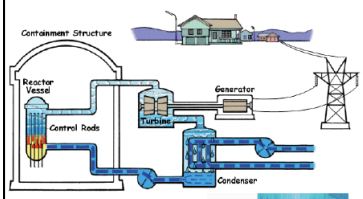


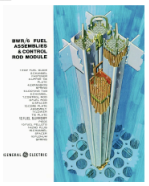
1) Pressure Difference increases with temperature difference
2) We put energy in (Pumping), but water volume is very small compared to volume of steam

http://www.eas.asu.edu/~holbert/eee463/coalart.gif



*Boiling water reactor (BWR)**

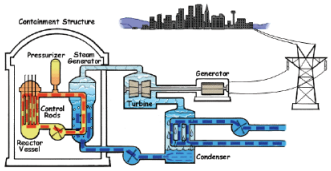


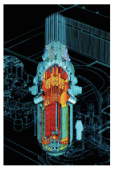


- **BWR RPV is ~36 feet high, 18 feet in diameter and ~6 inches thick. The core consists of about *700 fuel assemblies*, each containing about 63 *fuel rods* encased in a square channel. The core is ~15 feet diameter and 12 feet high.**
- **Water is boiled in the core at a pressure of about 1000 psi and about 280°C (545 °F)**
- **Low-pressure reject steam is converted to liquid in the condenser**
- **Water is returned to the core via a feedwater pump with intermediate purification**
- **The chemical composition of the water is controlled by addition of selected chemicals - no reactivity control, generally H_2 added to reduce corrosion due to radiolysis**

* http://www.nucleartourist.com/type/bwr.htm

*Components of a nuclear power plant**





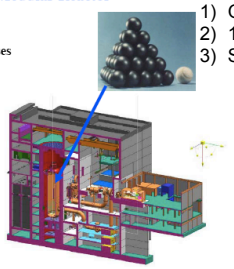
Pressurized Water Reactor

- **Core contained in *reactor pressure vessel* at a pressure of about 2200 psi. RPV is ~60 feet high, 12 feet in diameter and ~8-10 inches thick.**
- **Core consists of about *190 fuel assemblies*, each about 12 feet tall and containing about 250 - 300 *fuel rods*.**
- **The *primary* circuit circulates water from the core to the *steam generator*, used to boil the water in the *secondary* circuit at 1100 psi and 280°C., and then spin a turbine to generate electricity.**
- **The critical components of a nuclear power plant are:**
  - **Coolant & moderator**
  - **Control (neutron absorbing) materials**
  - **Safety systems**

* http://www.nucleartourist.com/type/pwr.htm

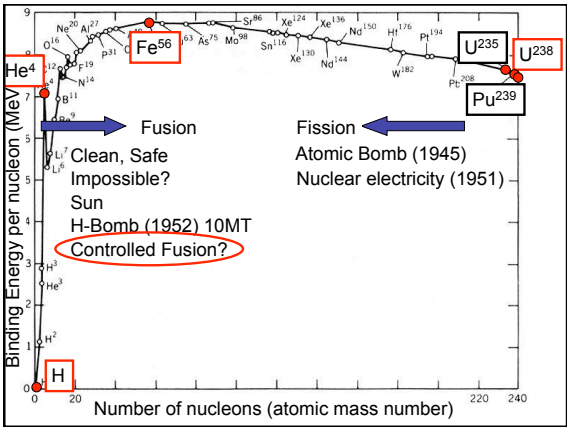
The Pebble Bed Modular Reactor

- Being constructed in South Africa
- Helium-cooled modular reactor uses "pebble fuel"
- Power output options:
  - 200 MWe gas Brayton cycle
  - 136 MWe gas Brayton and 286 MWt process steam production
  - 500 MWt high-temperature process heat
  - 250 MWe hydrogen
- Can be used to produce low-carbon transportation fuels

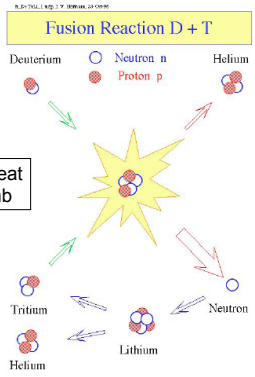


1) Gas Cooled!
2) 1600 °C
3) Self Limiting!

UC Berkeley



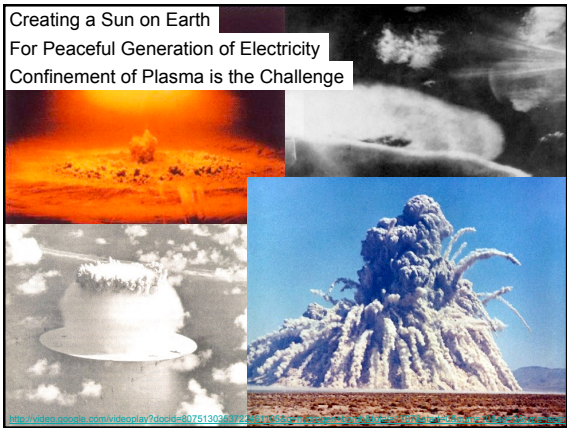
Fusion Reaction D + T



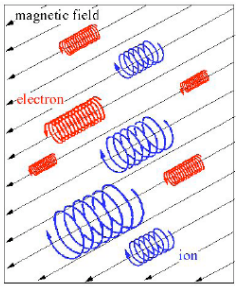
Must be Hot
Must be Dense
Compress and Heat With Fission Bomb

http://www.ipp.mpg.de/BB/Kernfusion/fig2.gif

Creating a Sun on Earth
For Peaceful Generation of Electricity
Confinement of Plasma is the Challenge



Charged Particles in a Magn. Field

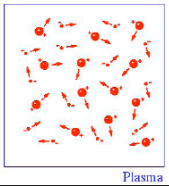


⇒ no confinement along magnetic fieldlines!

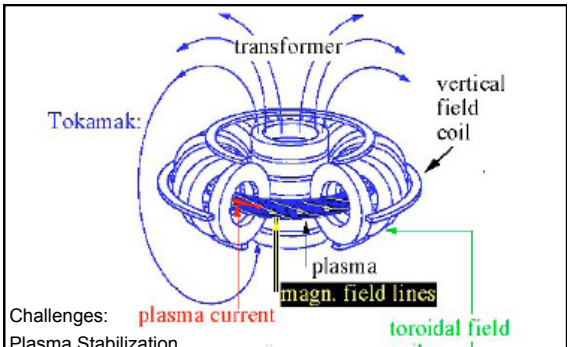
http://www.ipp.mpg.de/BB/Kernfusion/fig2.gif

Gas and Plasma

Gas

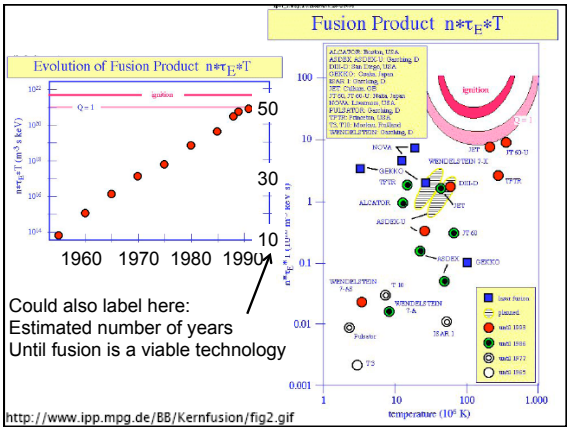


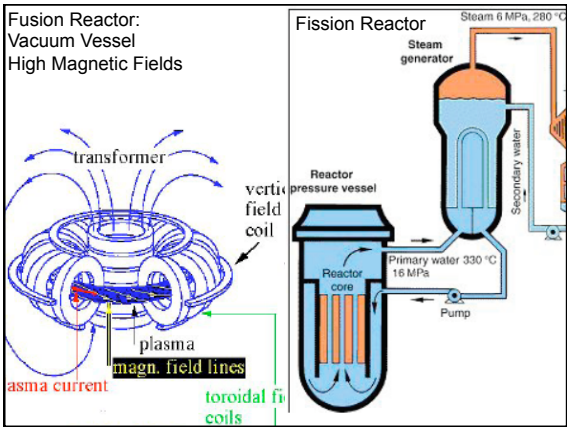
Plasma



Challenges:
Plasma Stabilization
First Wall Interactions
Vacuum Contamination with "high Z impurities"

http://www.ipp.mpg.de/BB/Kernfusion/fig2.gif





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