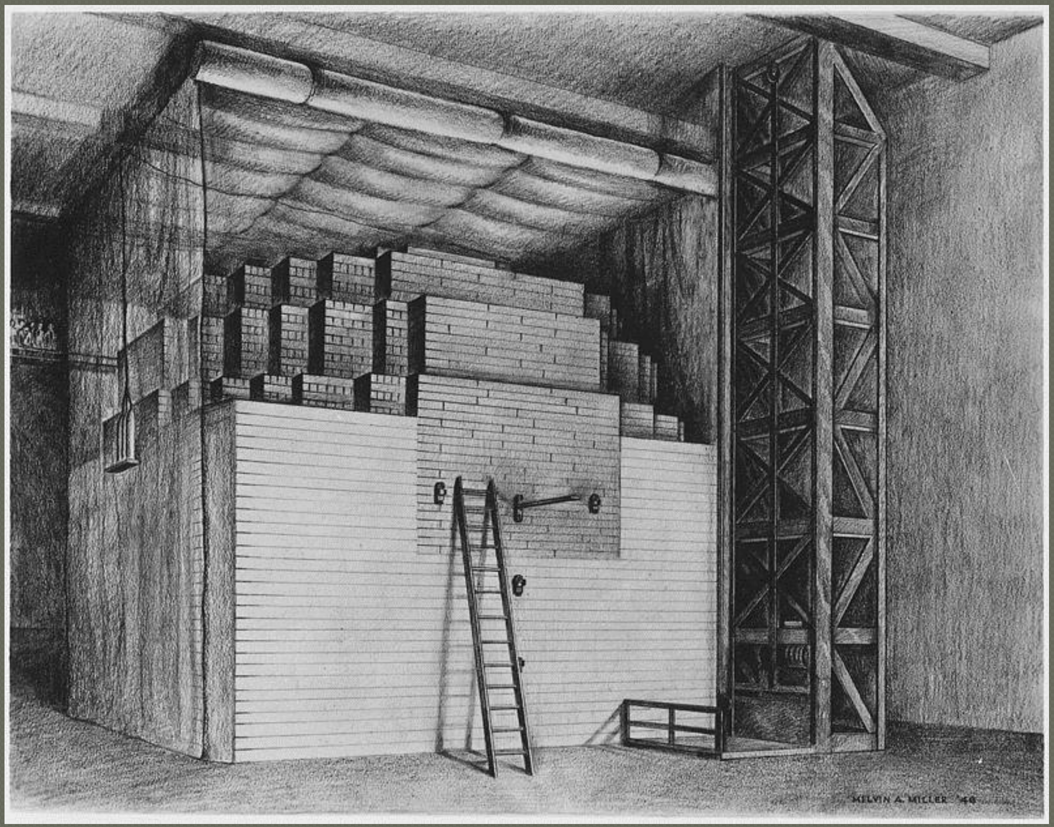
Nuclear Reactors

Neutrons

- 1932, neutrons discovered
- 1935, used to transmute elements.
- 1939, used to cause fission in Uranium
- 1939: beginning of WWII
- 1940: Plutonium made from Uranium

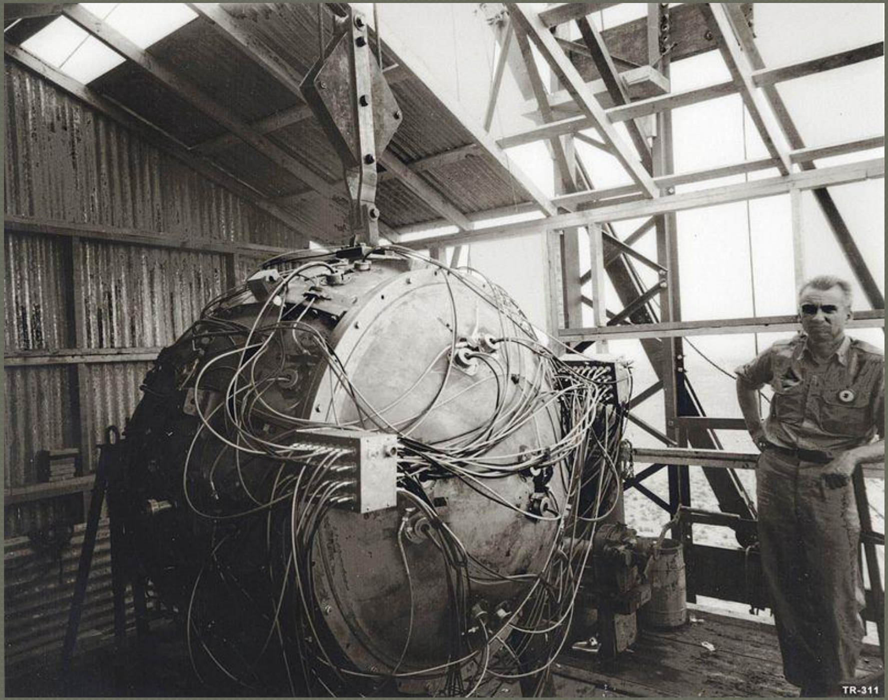
Fission Energy

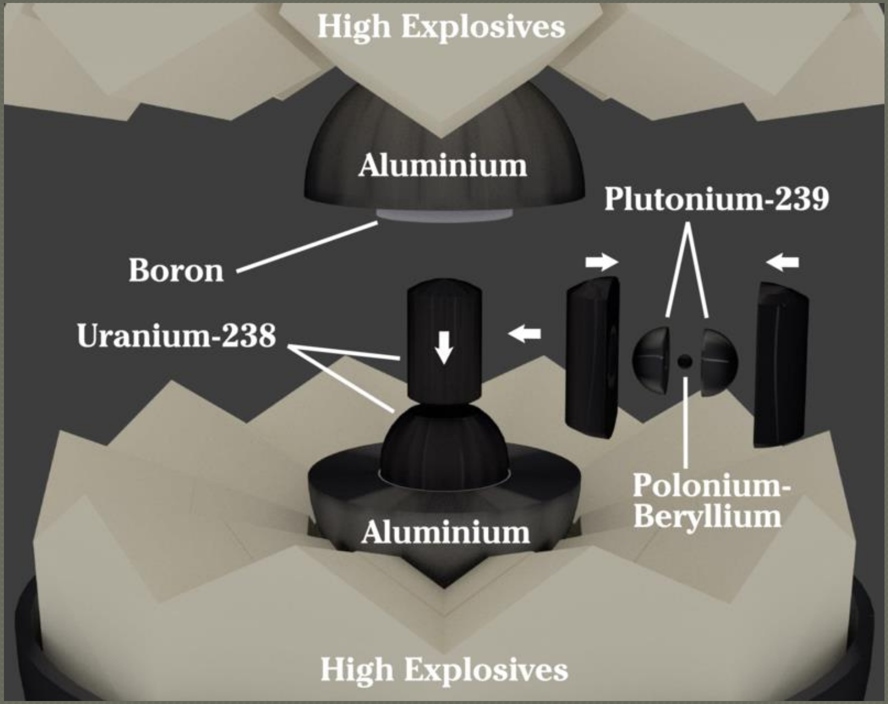
- 1942, first sustained chain reaction (CP-1)



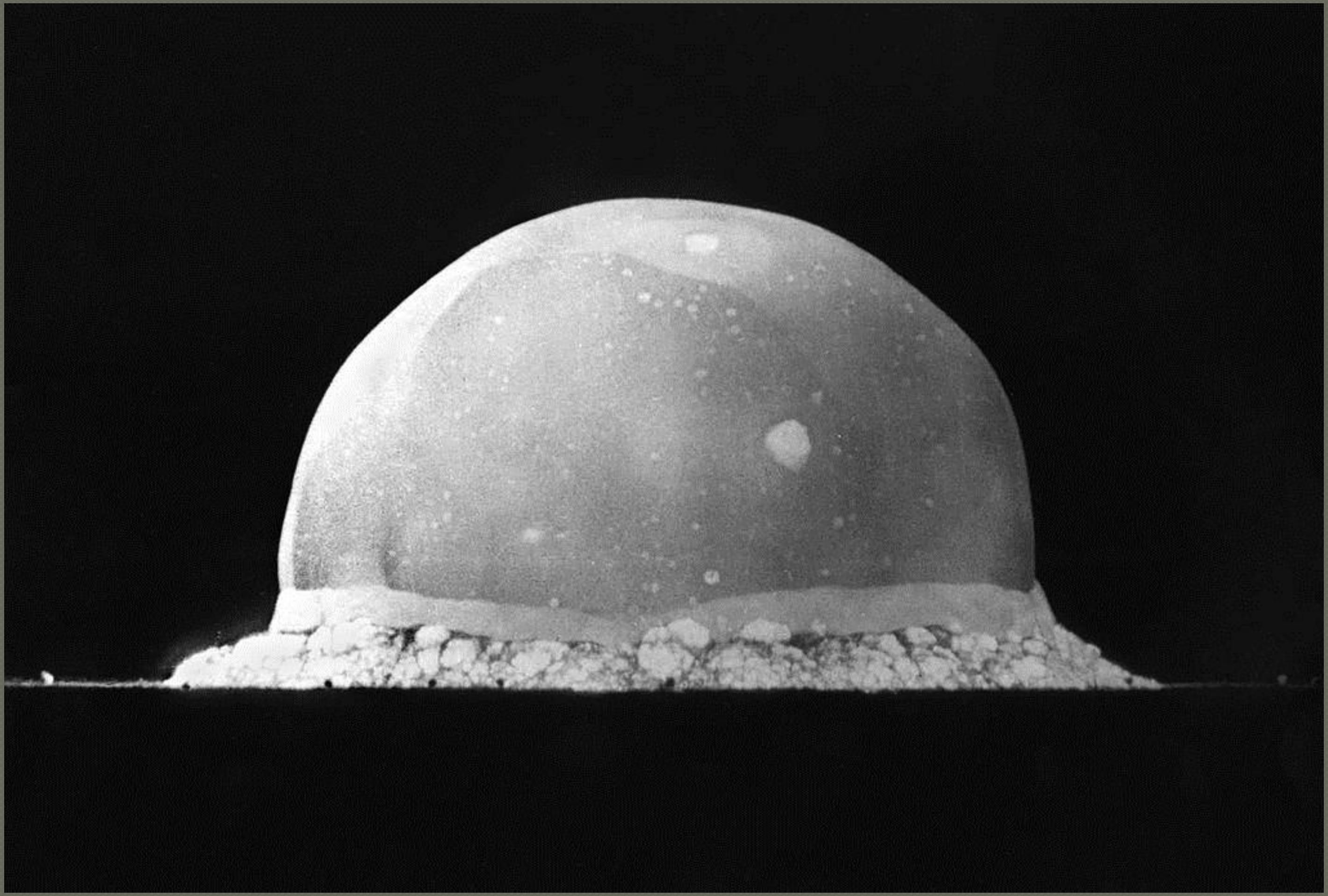
Fission Energy

- 1945, First nuclear bomb detonation



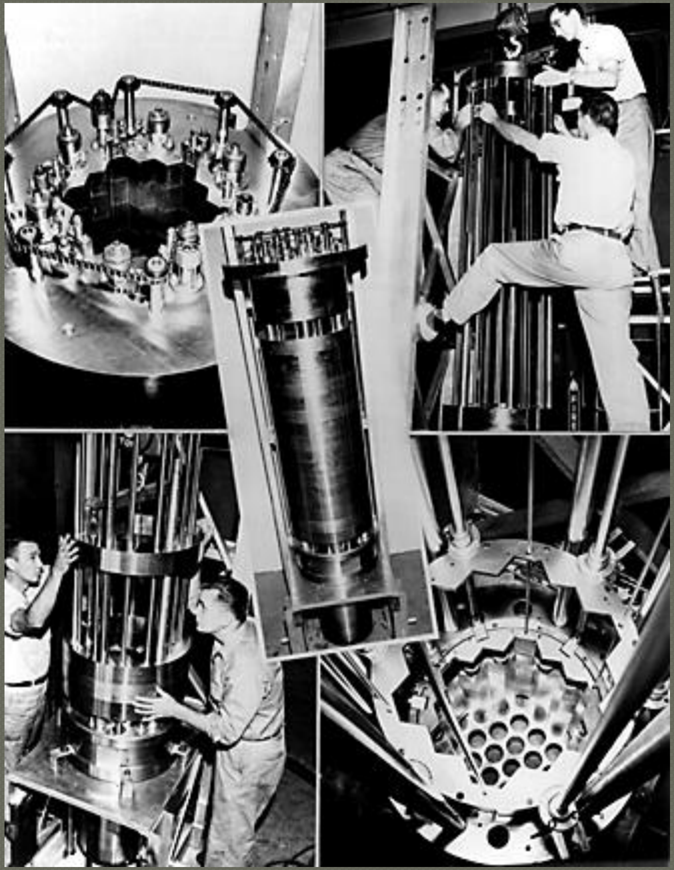


Fission Energy



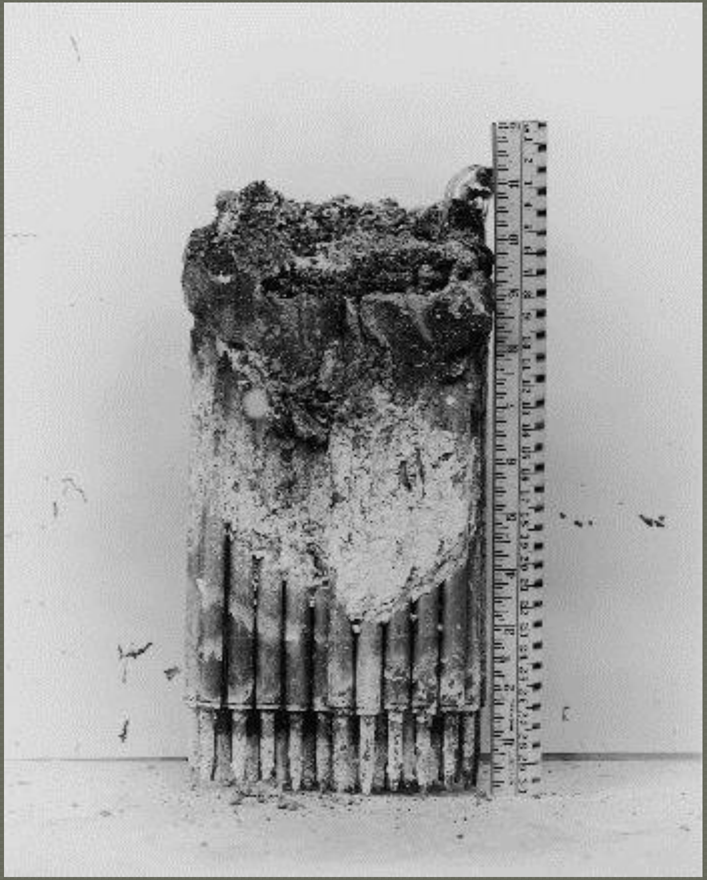
Fission Energy

- 1951, first power reactor (EBR-1)



Fission Energy

- 1952, First meltdown



Energy/Mass

- $E = mc^2$
  - $m =$ mass of particle
  - $c =$ speed of light
- Electron-Volt (eV)
  - Unit of energy
  - Energy gained by an electron accelerated through $1\ Volt$ of electric potential.
  - Electrical appliances operate around $120\ Volts$

Scientific Notation

- $\#.\# \times 10^{\#}$
  - $10^1 = 10$
  - $10^2 = 100$
  - $10^3 = 1{,}000$
- $1.5 \times 10^1 = 15$
- $1.5 \times 10^2 = 150$

- $1 \times 10^6\ eV = 1\ MeV$

Mass of Particles

- Proton
  - $938.272\ MeV$
- Neutron
  - $939.566\ MeV$
  - Alone, decays to proton after $\sim 15\ min$
- Electron
  - $0.511\ MeV$

Nucleus

- Made up of protons and neutrons
  - Called Nucleons
- $Z =$ # of protons (element number)
- $A =$ # of nucleons (protons + neutrons)
- $A - Z =$ # of neutrons

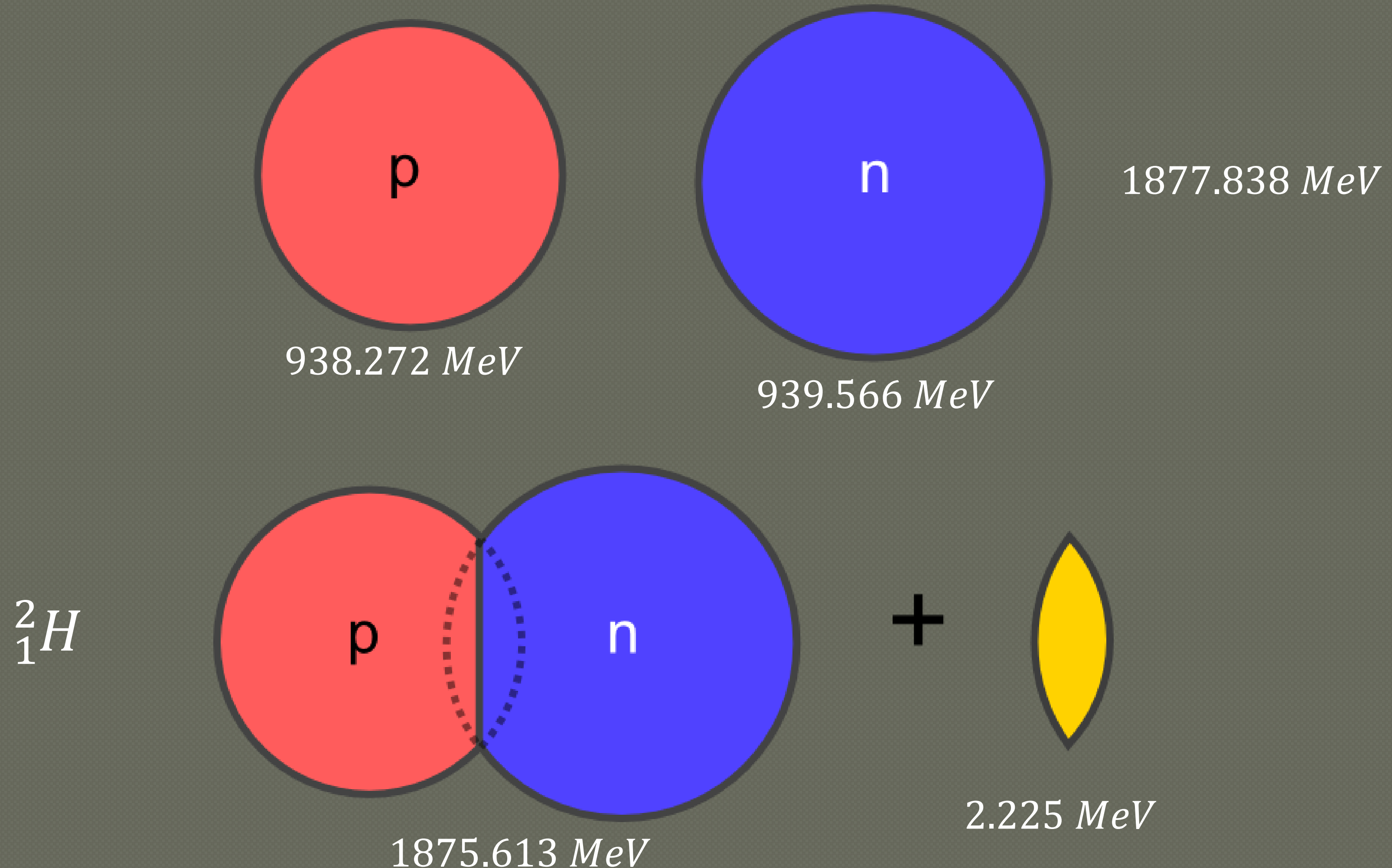
- Isotope Notation: ${}_{Z}^{A}E$
  - $E =$ symbol for element

- Hydrogen: ${}_{1}^{1}H$

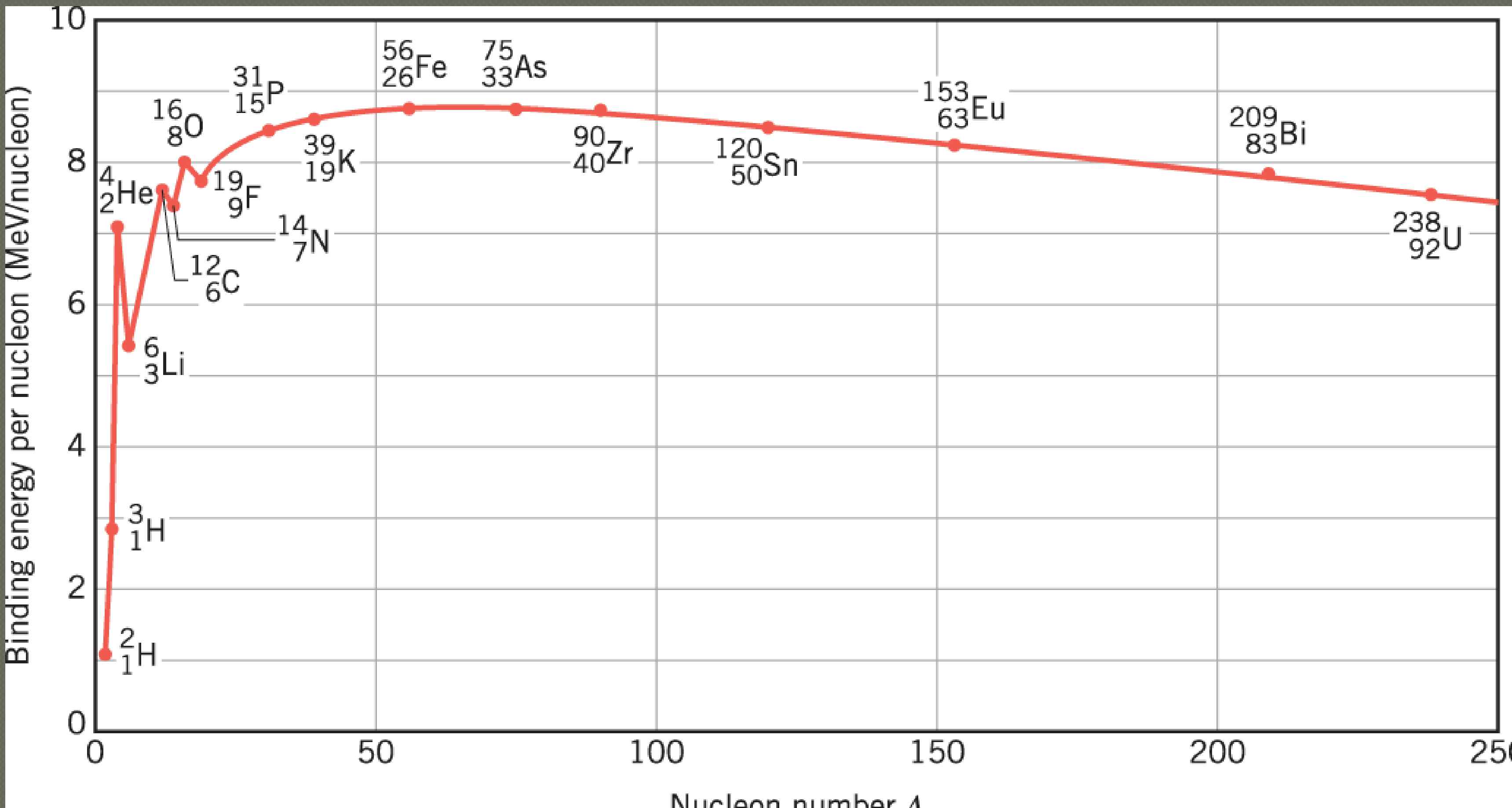
Isotopes

- Hydrogen: $^{1}_{1}H$
  - Deuterium: $^{2}_{1}H$
  - Tritium: $^{3}_{1}H$
- Uranium
  - $^{233}_{92}U$
  - $^{235}_{92}U$
  - $^{238}_{92}U$

Binding Energy



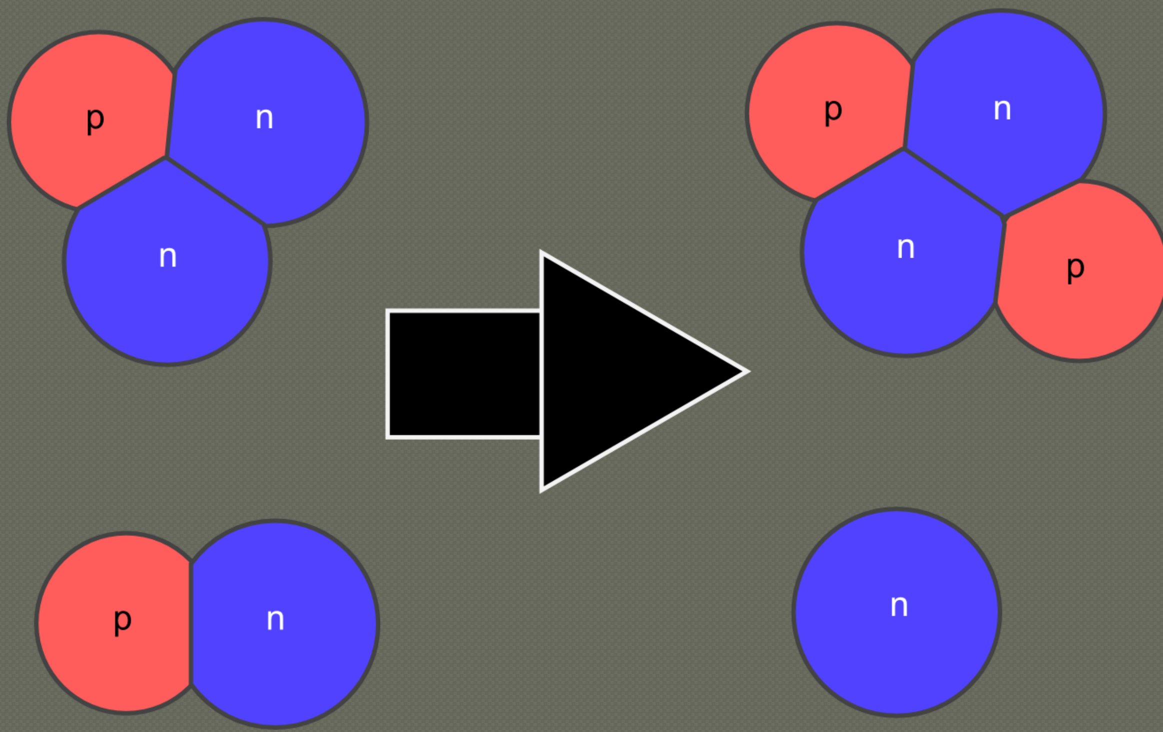
Binding Energy



http://staff.orecity.k12.or.us/les.sitton/Nuclear/313.htm

Nuclear Fusion

- D-T Fusion
  - Fusion of a Deuterium + Tritium nucleus
  - ${}^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{4}_{2}He + n + energy$



Fusion Energy

- ${}^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{4}_{2}He + n + energy$

- How much energy do we get?
  - ${}^{2}_{1}H$: $1875.613\ MeV$
  - ${}^{3}_{1}H$: $2808.920\ MeV$
  - ${}^{4}_{2}He$: $3727.378\ MeV$
  - n : $939.566\ MeV$

Fusion Energy

- ${}_{1}^{2}H + {}_{1}^{3}H$
  - $1875.613\ MeV + 2808.920\ MeV =$

Fusion Energy

- ${}^{2}_{1}H + {}^{3}_{1}H$
  - $1875.613\ MeV + 2808.920\ MeV = 4684.533\ MeV$

- ${}^{4}_{2}He + n$
  - $3727.378\ MeV + 939.566\ MeV =$

Fusion Energy

- ${}^{2}_{1}H + {}^{3}_{1}H$
  - $1875.613\ MeV + 2808.920\ MeV = 4684.533\ MeV$
- ${}^{4}_{2}He + n$
  - $3727.378\ MeV + 939.566\ MeV = 4666.944\ MeV$
- Energy
  - $4684.533\ MeV - 4666.944\ MeV =$

Fusion Energy

- ${}_{1}^{2}H + {}_{1}^{3}H$
  - $1875.613\ MeV + 2808.920\ MeV = 4684.533\ MeV$

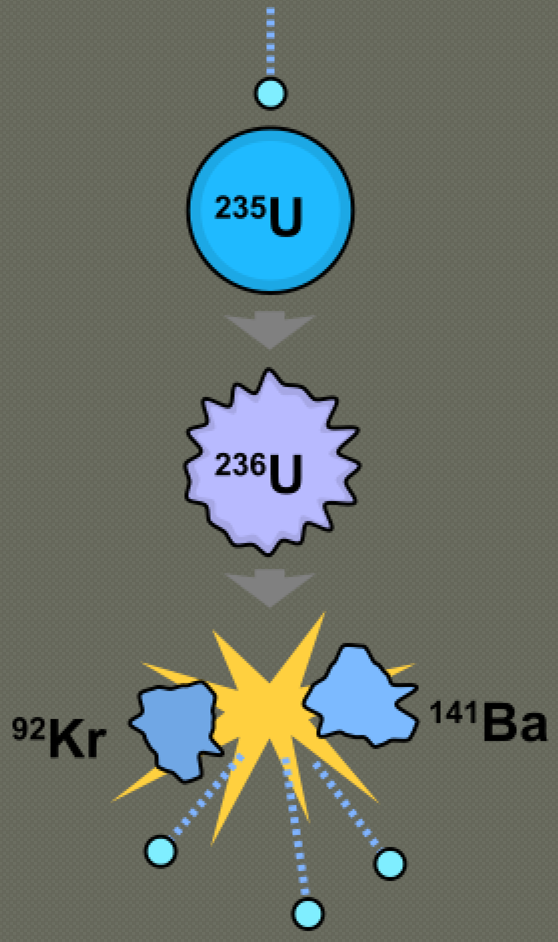
- ${}_{2}^{4}He + n$
  - $3727.378\ MeV + 939.566\ MeV = 4666.944\ MeV$

- Energy
  - $4684.533\ MeV - 4666.944\ MeV = 17.6\ MeV$

Fission Energy

- U-235
  - ${}^{235}_{92}U + n \rightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3n$

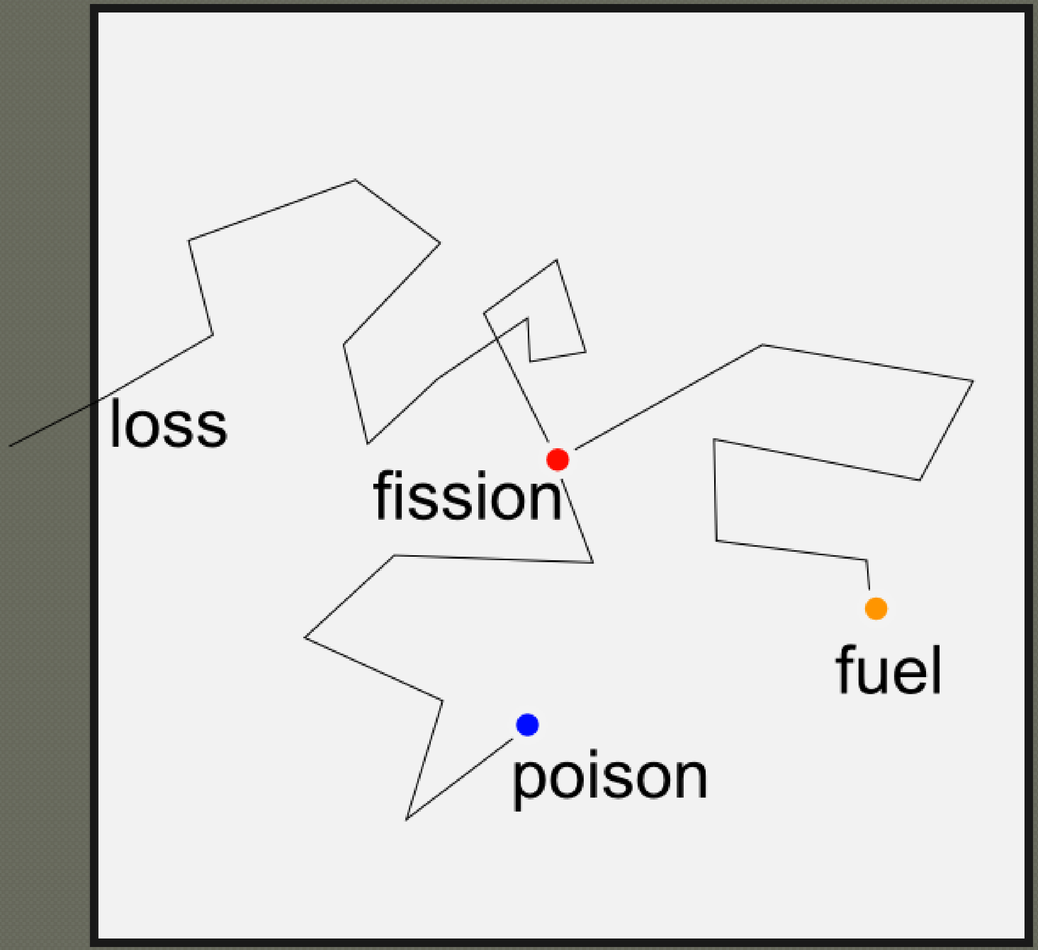
- ${}^{235}_{92}U$: $218{,}941.983\ MeV$
- ${}^{141}_{56}Ba$: $131{,}260.924\ MeV$
- ${}^{92}_{36}Kr$: $85{,}628.657\ MeV$
- n : $939.566\ MeV$



Nuclear Reactor

- The story of a neutron
  - Born from a fission reaction
  - It bounces around the reactor slowing down.
  - Once it is slow enough, it causes another fission.
- But things can go wrong in the story
  - It leaves the reactor.
  - It gets absorbed by something other than fuel.

Nuclear Reactor



Criticality

- To keep this going…
  - On average, make one new fission for every fission that happens.
  - Out of all the neutrons born from a fission, we need one to cause a new fission.
  - Minimize the loss of neutrons.

Criticality

- $k = nP_aP_c$
  - $n =$ avg. number of neutrons born per neutron absorbed by fuel (from fission).
  - $P_a =$ probability neutron is absorbed by fuel
  - $P_l =$ probability a neutron stays in reactor.

- $k = 1$: critical
- $k < 1$: sub-critical
- $k > 1$: super-critical

Criticality

- $n \approx 1.65$
  - Number of neutrons made per neutron absorbed by fuel
- $P_a \approx 0.62$
  - 62% of neutrons that stay in reactor are absorbed by fuel
  - $nP_a \approx 1.023$
- $k = 1 : P_c = \frac{1}{nP_a} \approx 0.98$
  - We need 98% of neutrons to stay in reactor.

Transmutation

- What happens to the neutrons that are absorbed by non-fuel?
- One thing that can happen is Plutonium
  - ${}^{238}_{92}U + n \rightarrow {}^{239}_{92}U \rightarrow {}^{239}_{94}Pu + 2e$
- Another thing is Deuterium
  - ${}^{1}_{1}H + n \rightarrow {}^{2}_{1}H$
  - If there is water (H_2O) in there.
  - Using heavy water prevents that (D_2O)