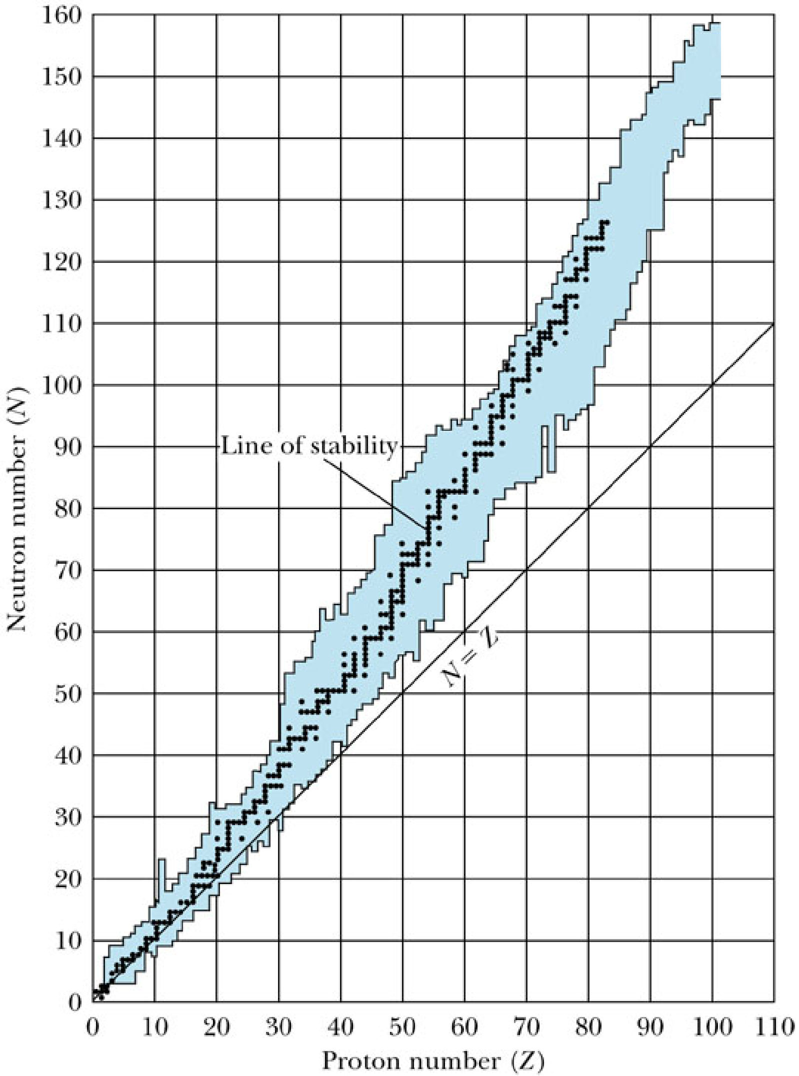
# The Nucleus

- Z, N, A, isotopes
- Nucleons, mass
- Radius $R = r_o A^{1/3}$
- Nuclear density
- Nuclear magnetic moments

# Nuclear Stability



Up to A~40, N ~ Z

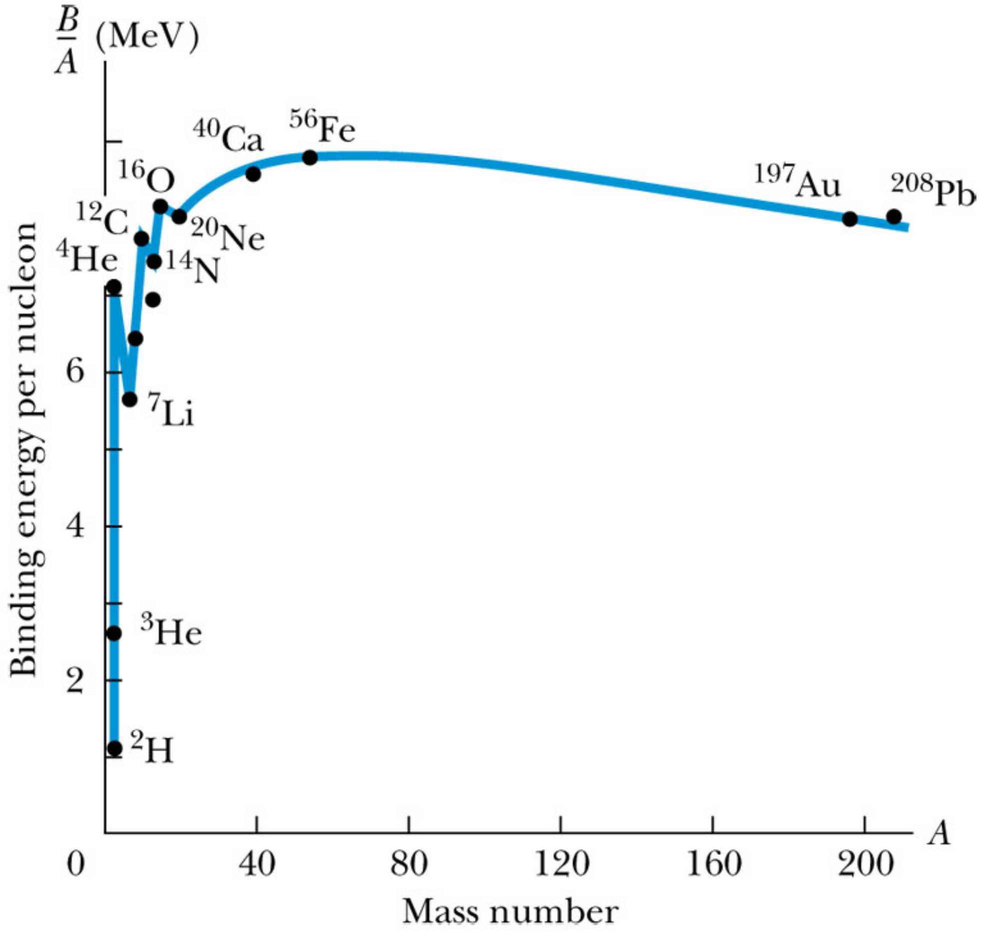
Beyond that N>Z shielding Coulomb repulsion

$^{238}$U is largest naturally occurring nuclide

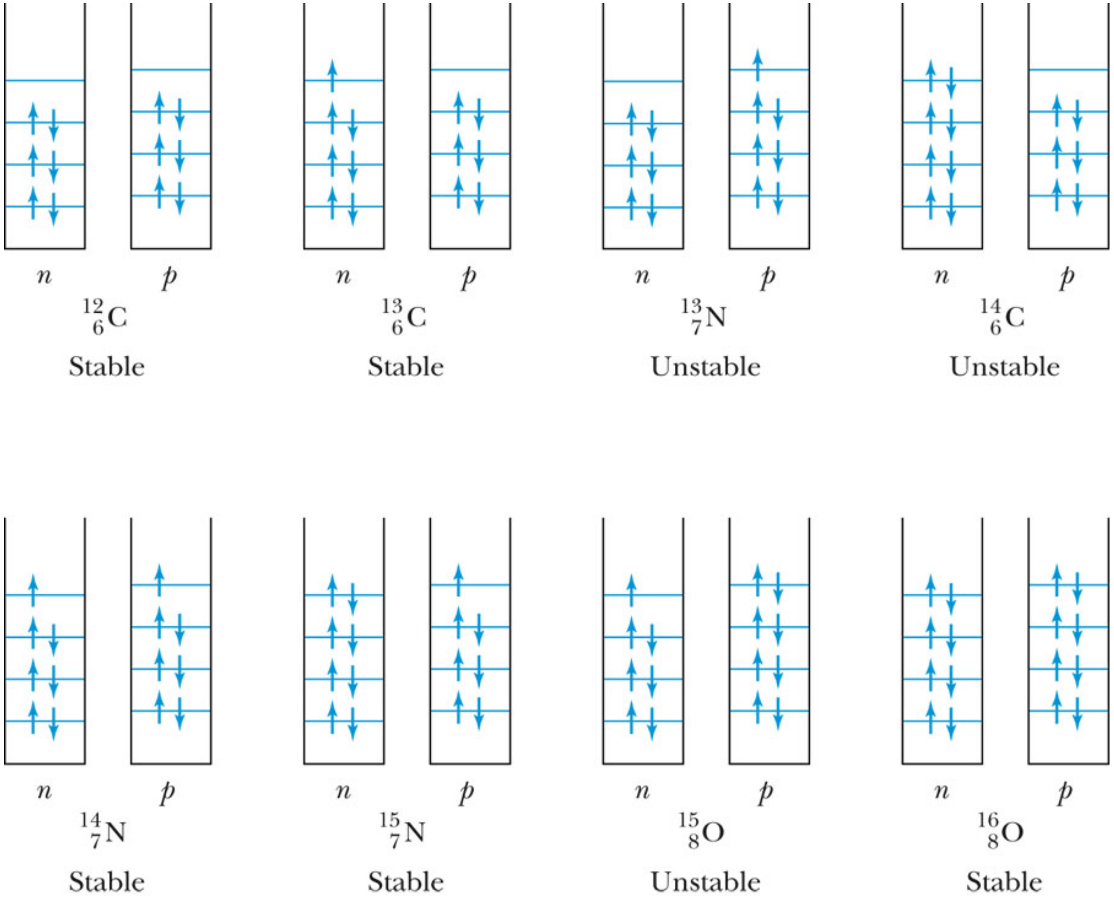
# Binding Energy per Nucleon

- For X splitting to R + S:

$$B = [m(R) + m(S) - m(X)]c^2$$



# Proton & Neutron E levels



# Activity & Half Life

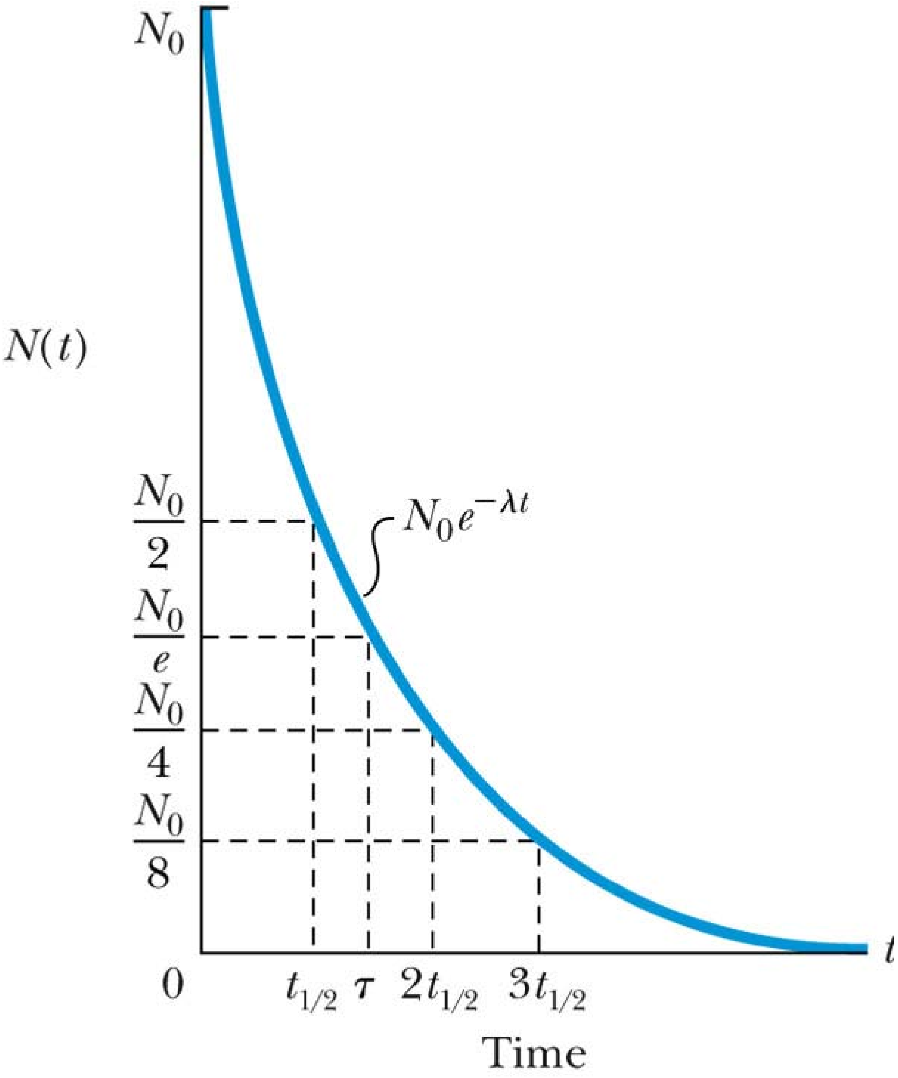
- Activity = R = $-dN/dt$
- Unit = 1 decay/s = 1 becquerel (Bq)

  also 1 Curie (Ci) = $3.7 \times 10^{10}$ Bq
- $R = \lambda N(t) = -dN/dt$, so $dN/N = -\lambda dt$

  or $N(t) = N_o e^{-\lambda t} = N_o e^{-t/\tau}$ , where $\tau = 1/\lambda$ --
  also $R(t) = R_o e^{-\lambda t}$, where $R_o = \lambda N_o$
- $N(t = t_{1/2}) = N_o/2 = N_o e^{-\lambda t_{1/2}}$

  so $t_{1/2} = \ln(2)/\lambda = 0.693/\lambda = 0.693\tau$

# Half Life and Radioactive Decay



# Alpher, Bethe, Gamow

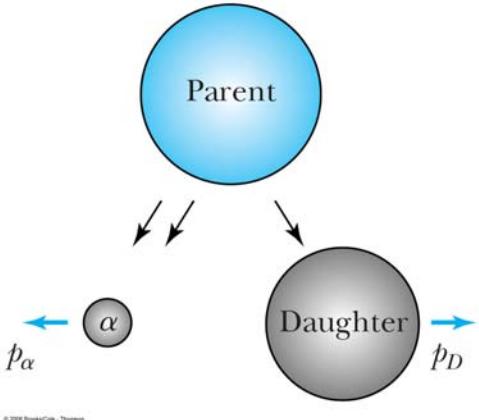
- Radioactivity reactions must satisfy all conservation laws (E, p, L, etc., plus, all lower E (<100MeV) conservation of nucleons (A)
- Parent nuclide $\longrightarrow$ Daughter + small fragment

  Cons of E: $M(X) = M(D) + M_y + Q/c^2$

  where Q = disintegration energy; Q = -B;

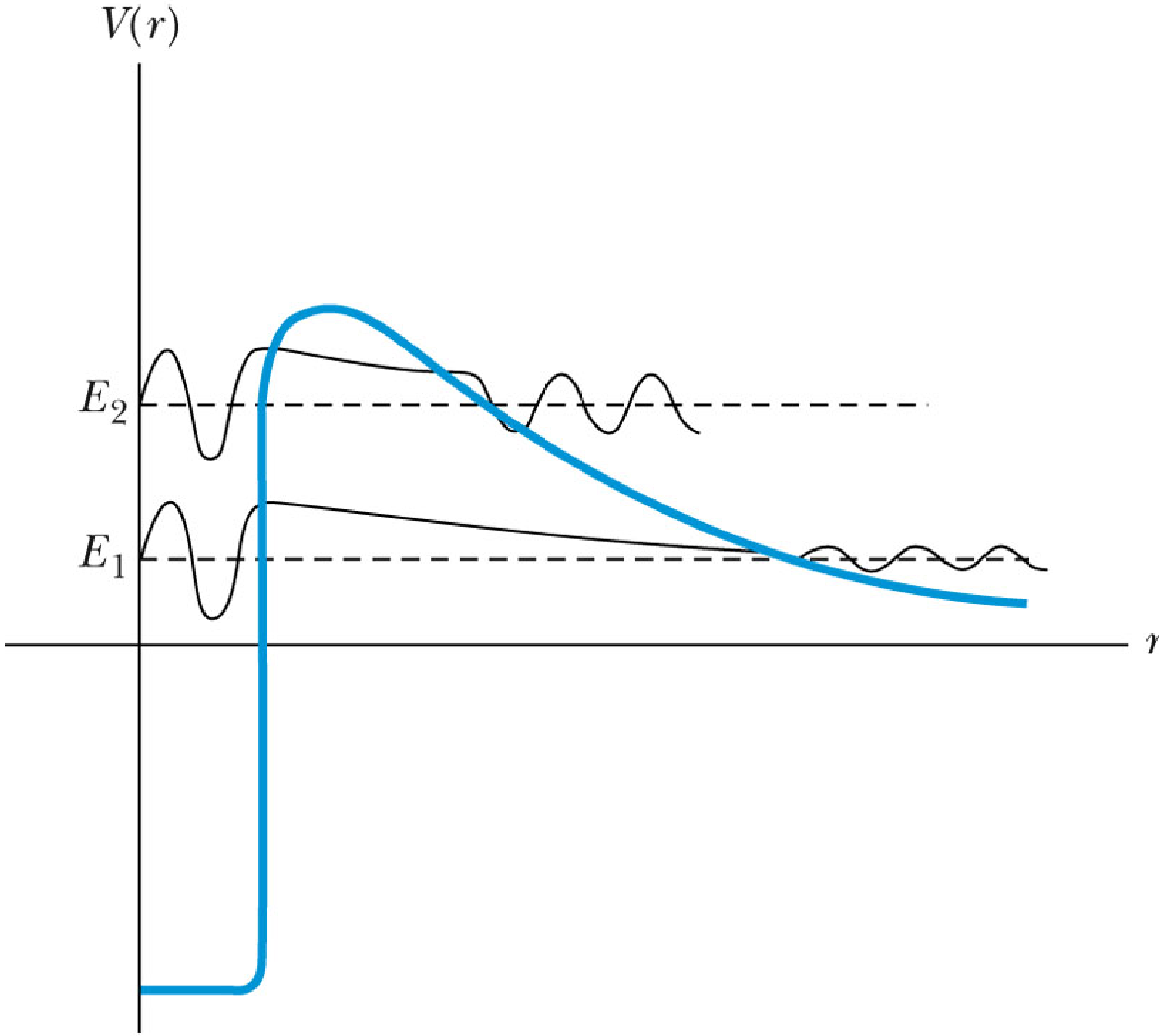
  $Q > 0$ unstable
- Three types of radiation: $\alpha, \beta, \gamma$
- Alpha decay: ${}^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}D + \alpha$ where

  $\alpha = {}^{4}_{2}He$



$\alpha$ gets most of the KE since it is so much lighter

# Tunneling



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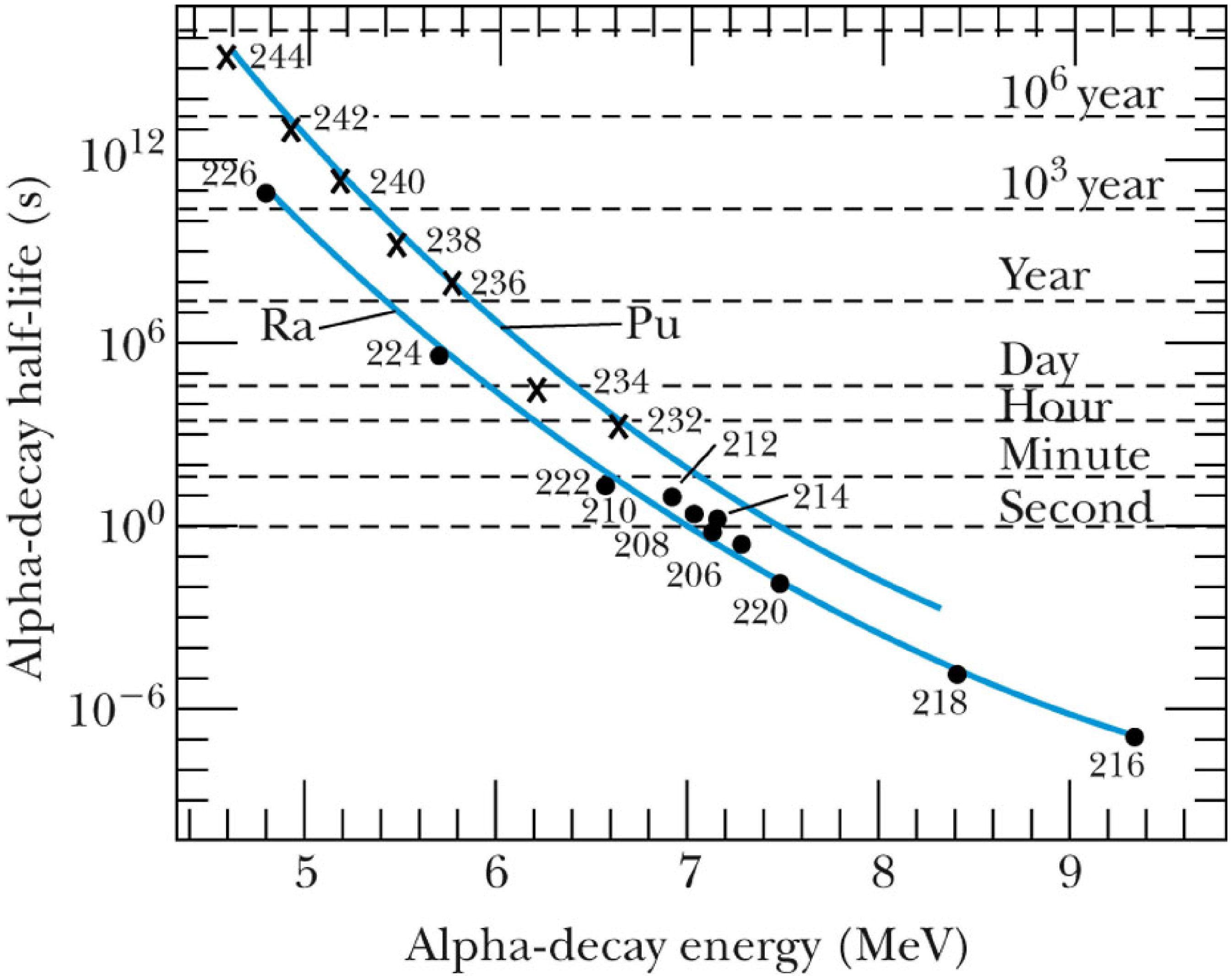
- Higher E means shorter lifetime

# Half-lives for alpha decay

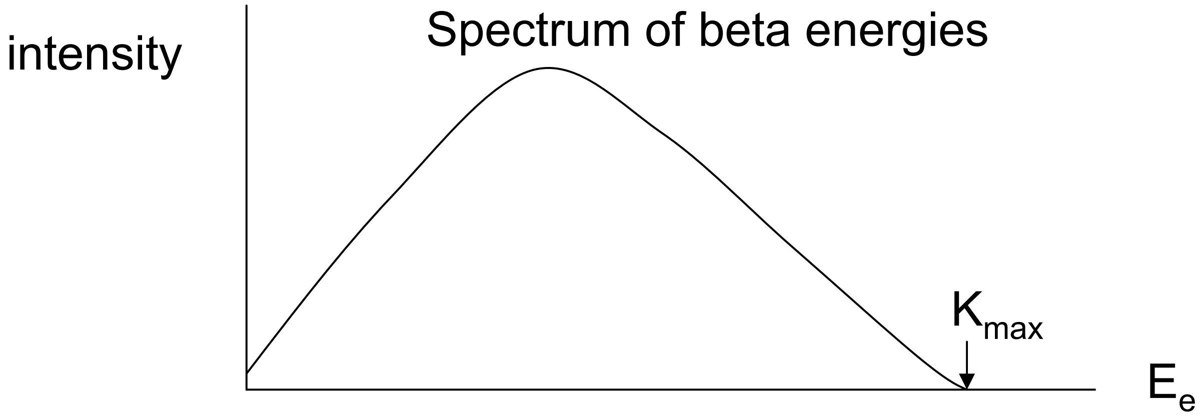


# Beta Decay

Beta decay: n $\longrightarrow$ p + $\beta^-$ + neutrino

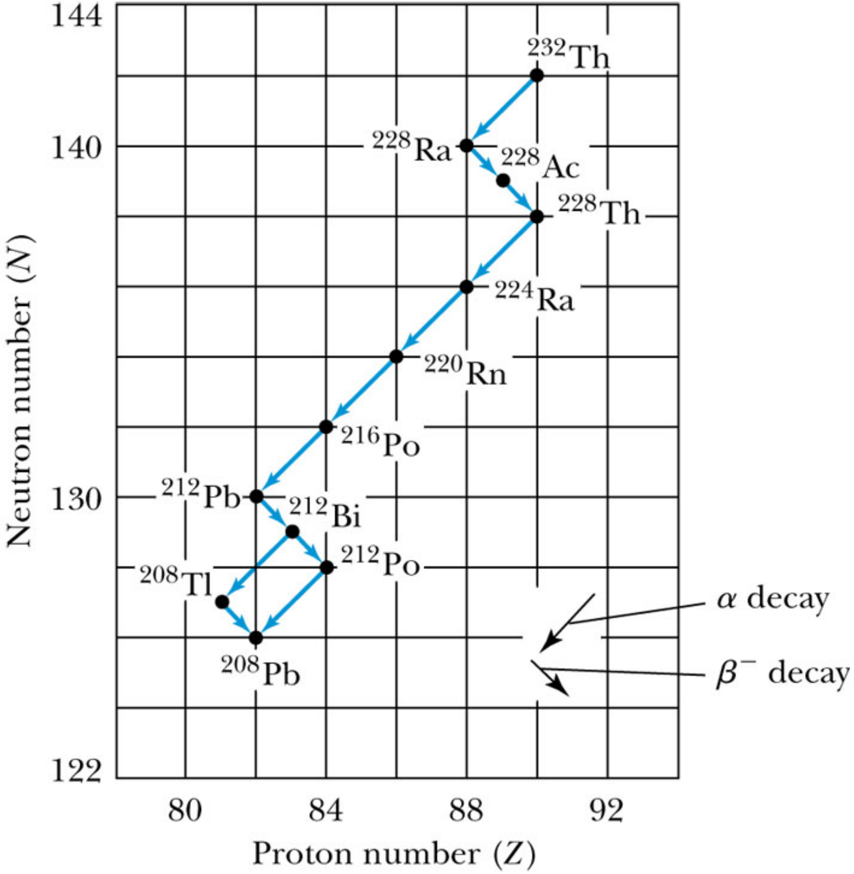
e.g. $^{14}C \longrightarrow {}^{14}N + \beta^- +$ neutrino

- Neutrino not detected, but conservation laws demanded it – first predicted by Pauli in 1930, but not detected till 1956
- Also positron decay: ${}^{A}_{Z}X \longrightarrow {}^{A}_{Z-1}D + \beta^+ + \nu$



# Example decay scheme

- Alpha decay shifts N,Z and often ends up further off line of stability – resulting in beta decay



# Radioactive Series

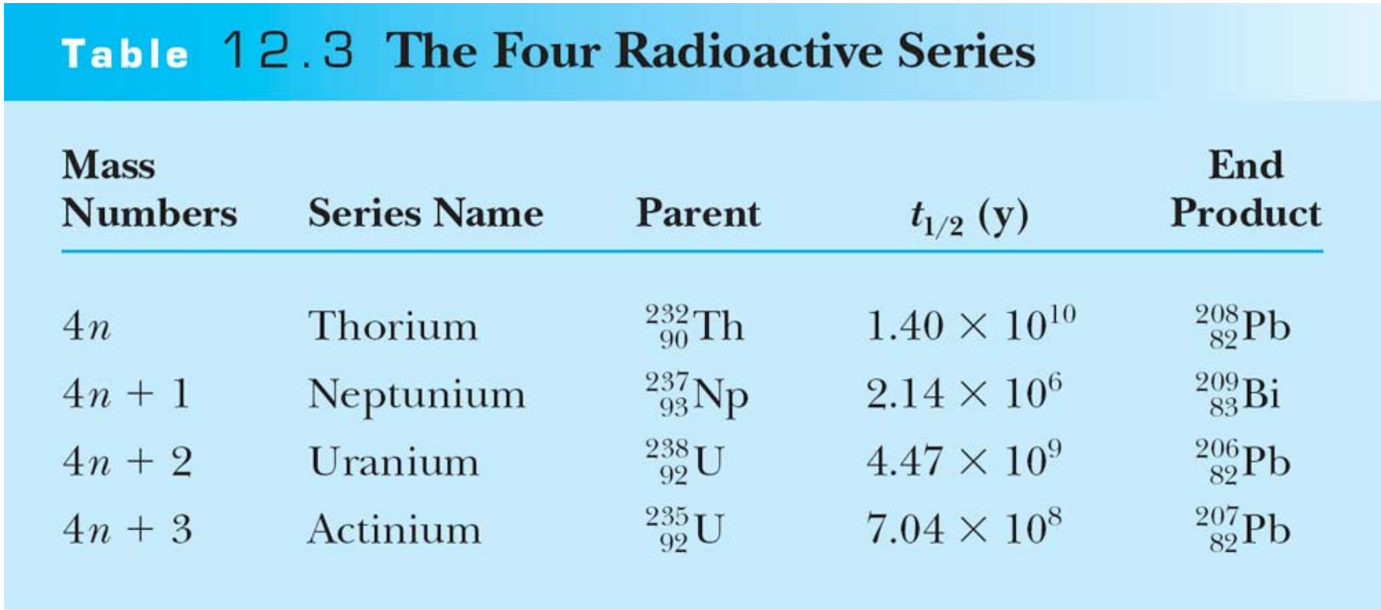
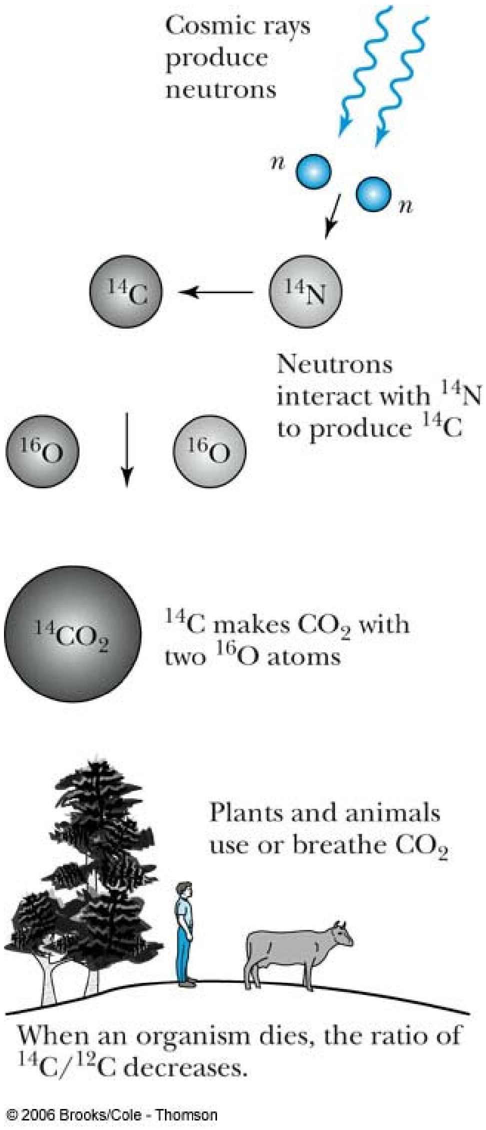


**Table 12.3 The Four Radioactive Series**

| Mass Numbers | Series Name | Parent | $t_{1/2}$ (y) | End Product |
|---|---|---|---|---|
| $4n$ | Thorium | ${}^{232}_{90}\mathrm{Th}$ | $1.40 \times 10^{10}$ | ${}^{208}_{82}\mathrm{Pb}$ |
| $4n + 1$ | Neptunium | ${}^{237}_{93}\mathrm{Np}$ | $2.14 \times 10^{6}$ | ${}^{209}_{83}\mathrm{Bi}$ |
| $4n + 2$ | Uranium | ${}^{238}_{92}\mathrm{U}$ | $4.47 \times 10^{9}$ | ${}^{206}_{82}\mathrm{Pb}$ |
| $4n + 3$ | Actinium | ${}^{235}_{92}\mathrm{U}$ | $7.04 \times 10^{8}$ | ${}^{207}_{82}\mathrm{Pb}$ |

# $^{14}C$ decay & Radioactive Dating



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- $n + {}^{14}N \rightarrow {}^{14}C + p$

# Fuels & Power Plants

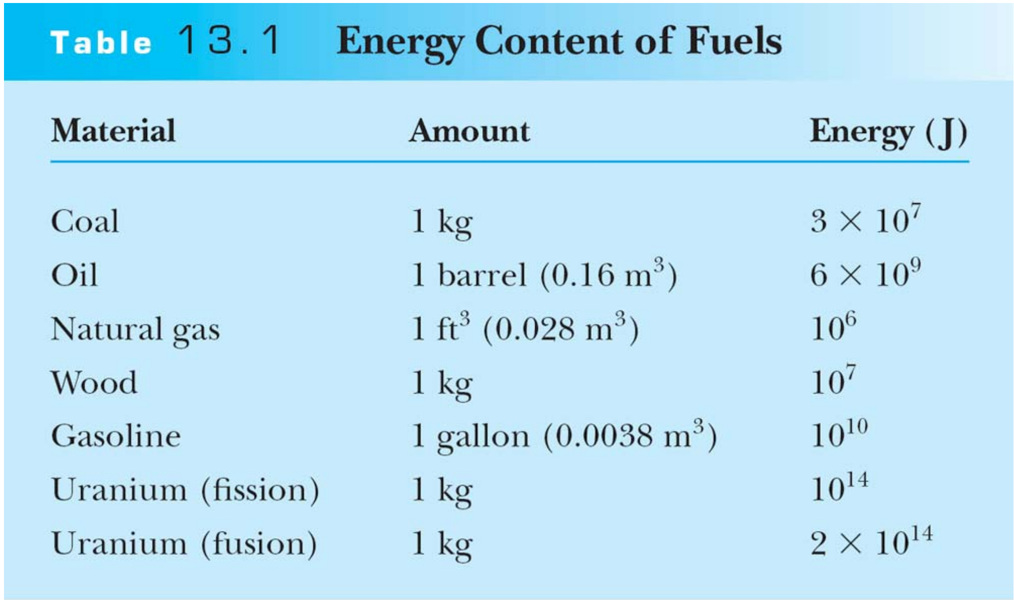


**Table 13.1 Energy Content of Fuels**

| Material | Amount | Energy (J) |
|---|---|---|
| Coal | 1 kg | $3 \times 10^7$ |
| Oil | 1 barrel (0.16 $m^3$) | $6 \times 10^9$ |
| Natural gas | 1 $ft^3$ (0.028 $m^3$) | $10^6$ |
| Wood | 1 kg | $10^7$ |
| Gasoline | 1 gallon (0.0038 $m^3$) | $10^{10}$ |
| Uranium (fission) | 1 kg | $10^{14}$ |
| Uranium (fusion) | 1 kg | $2 \times 10^{14}$ |

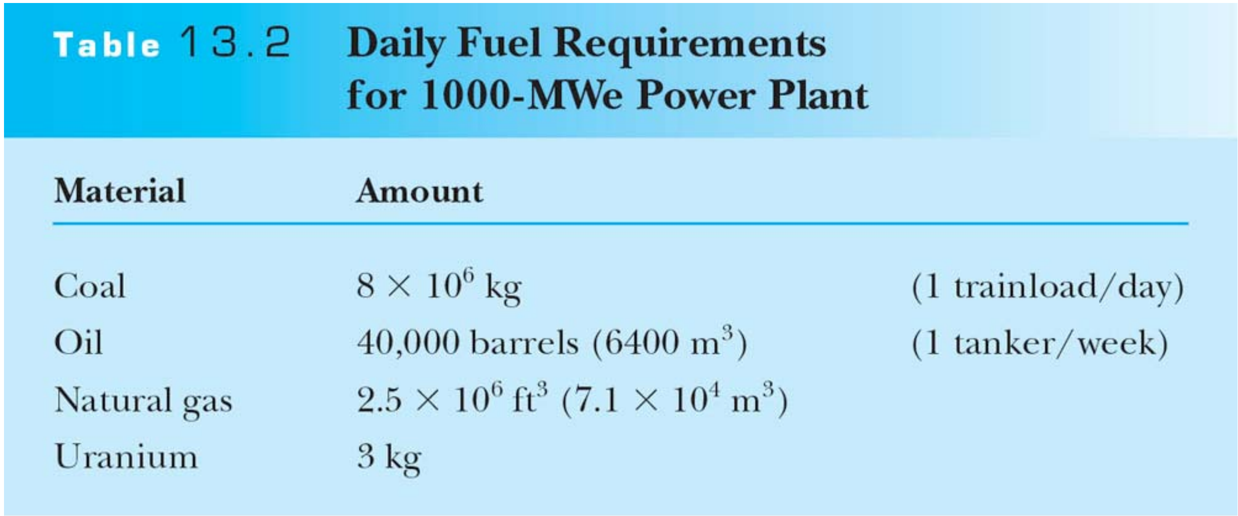
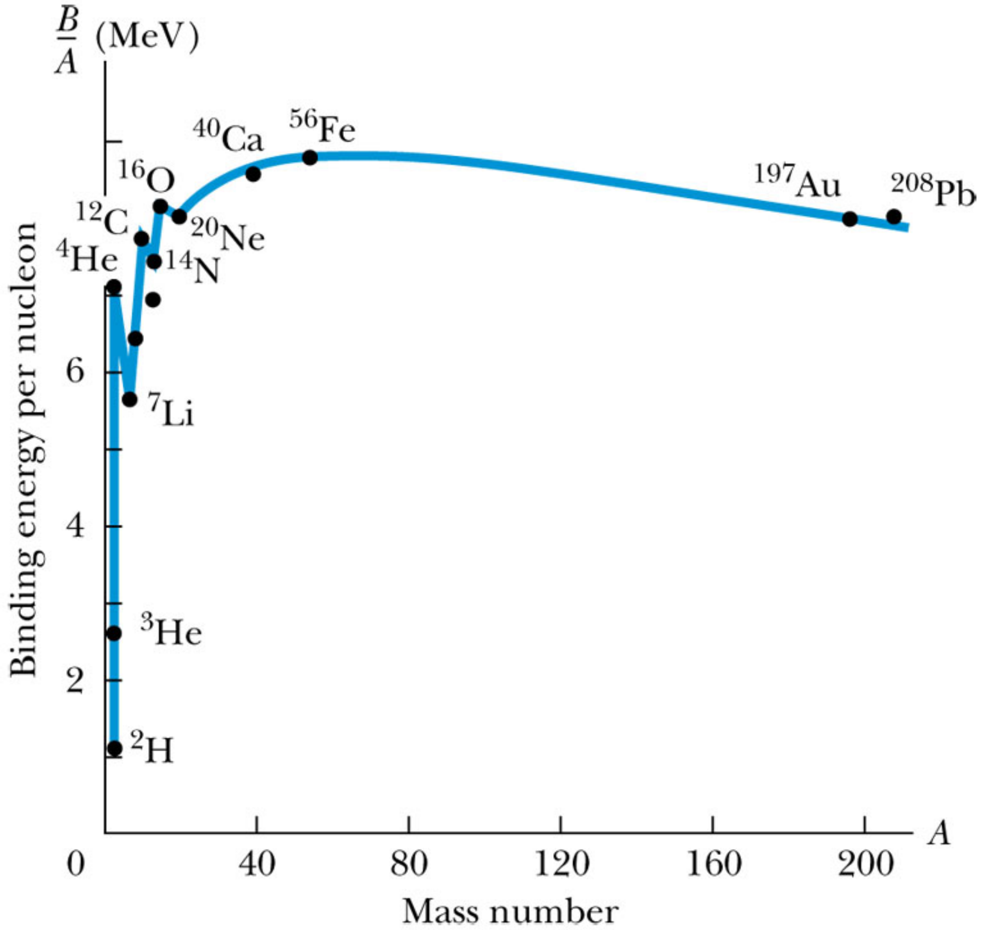


**Table 13.2 Daily Fuel Requirements for 1000-MWe Power Plant**

| Material | Amount | |
|---|---|---|
| Coal | $8 \times 10^6$ kg | (1 trainload/day) |
| Oil | 40,000 barrels (6400 $m^3$) | (1 tanker/week) |
| Natural gas | $2.5 \times 10^6$ $ft^3$ ($7.1 \times 10^4$ $m^3$) | |
| Uranium | 3 kg | |

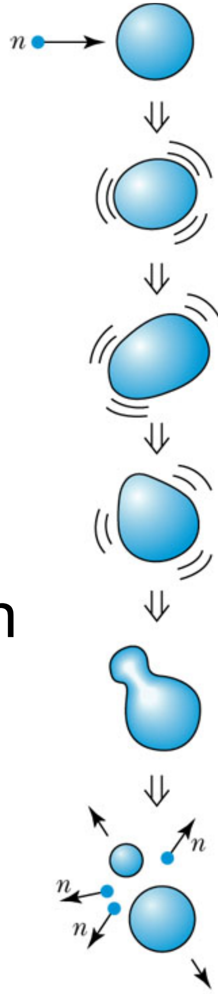
# Binding Energy per Nucleon

- Review



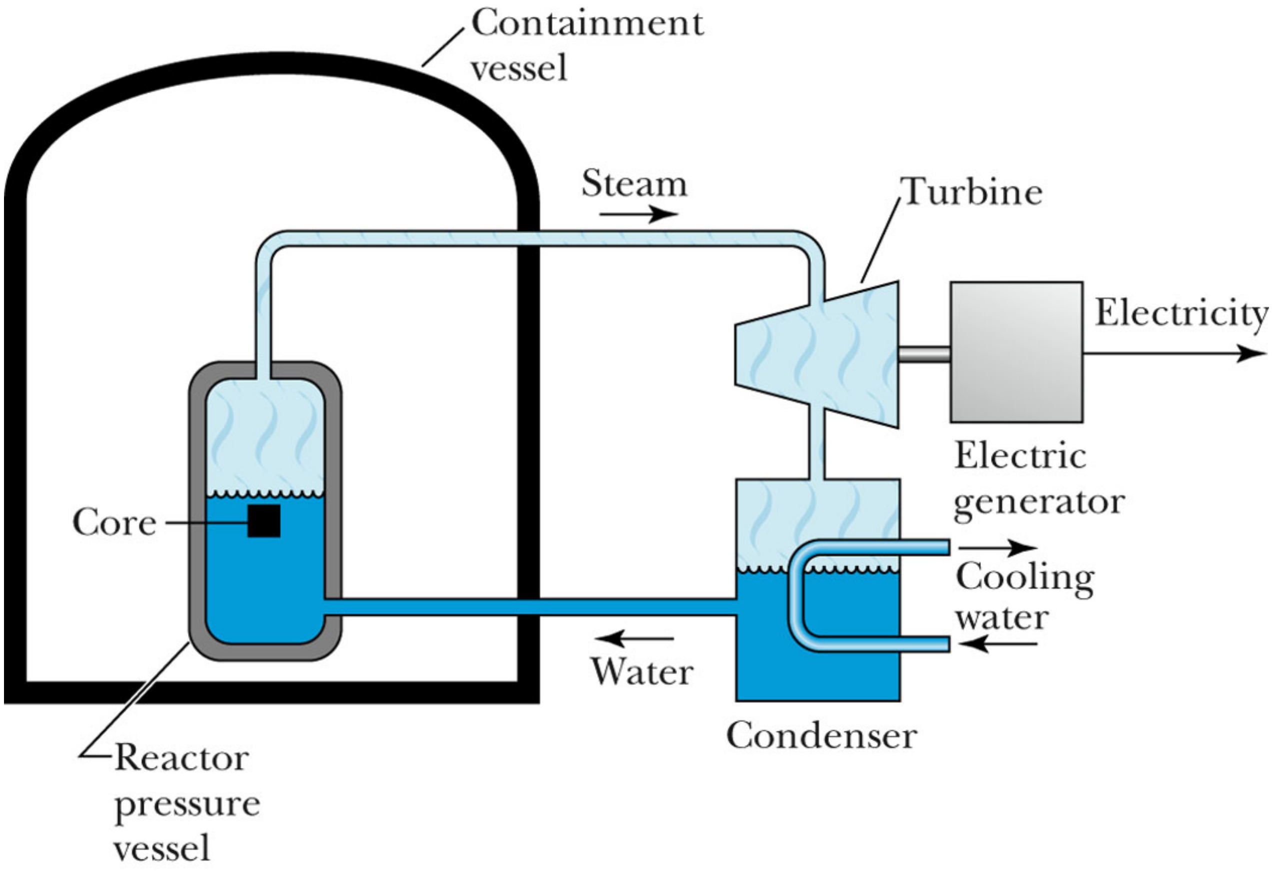
# Fission

- Liquid drop model of nucleus – as sphere distorts, larger surface energy – less well shielded Coulomb repulsion – overcomes fission barrier – spontaneous fission if $Z^2/A \geq 49$
- To be useful, fission must be induced – usually by slow neutron absorption (use moderator [water, graphite or beryllium] to slow n) to a highly excited compound nucleus – products have a N/Z ratio that is too high and 2 – 3 neutrons are emitted during fission
- These an be used to produce a self-sustaining chain reaction – if just 1 n on average then critical (vs. sub-critical or super-critical = bomb)
- Neutron control via control rods [cadmium] that absorb n
- $^{235}$U absorbs thermal n better – need to enrich it (0.7% natural)



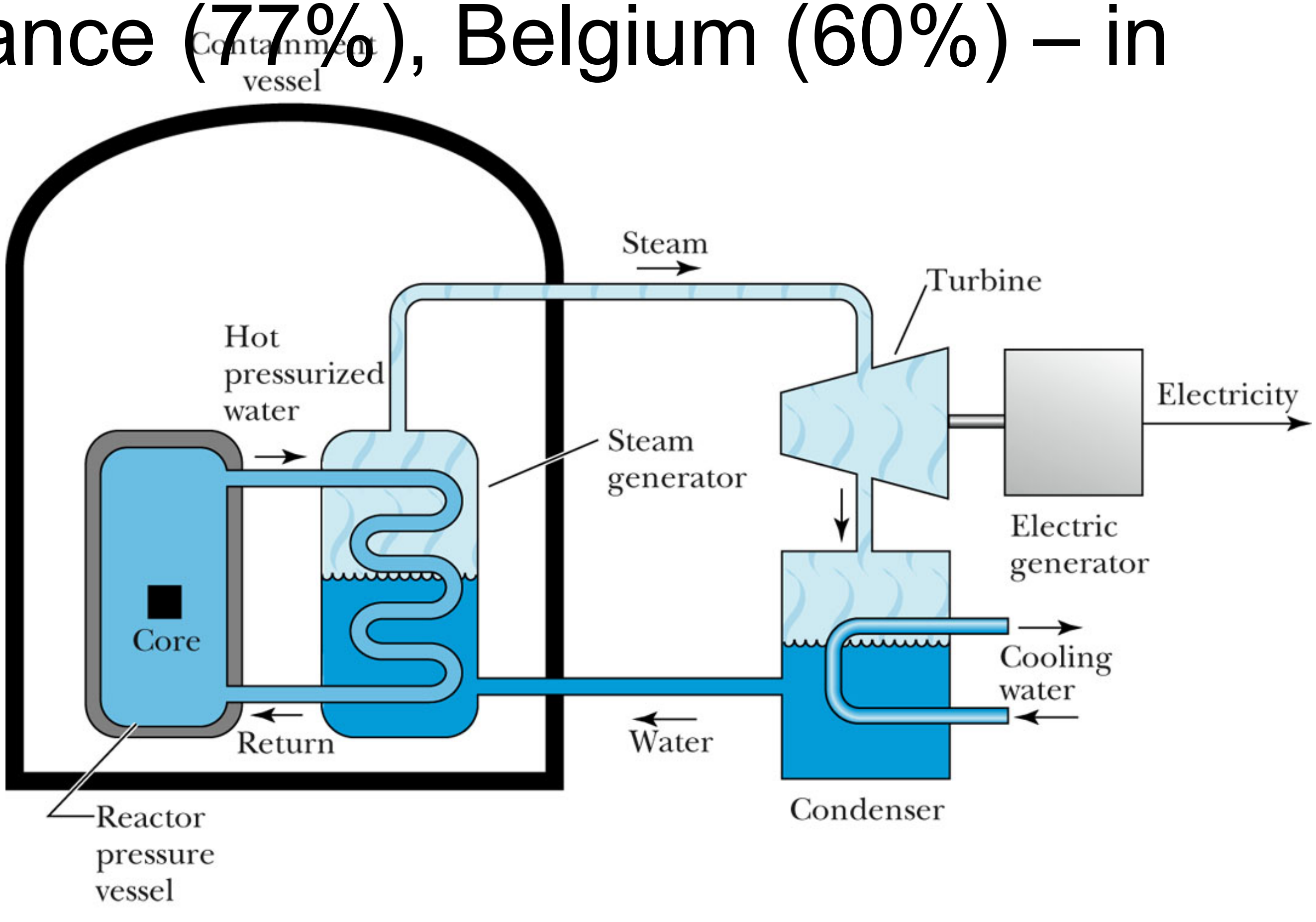
# BW Reactor Block Diagram

- BWR (Boiling Water Reactor) – danger that water can become contaminated



# Alternate PWR

- Pressurized Water Reactor –
- Highest use of nuclear power: Lithuania (82%), France (77%), Belgium (60%) – in US (20%)



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# Progress on Fusion

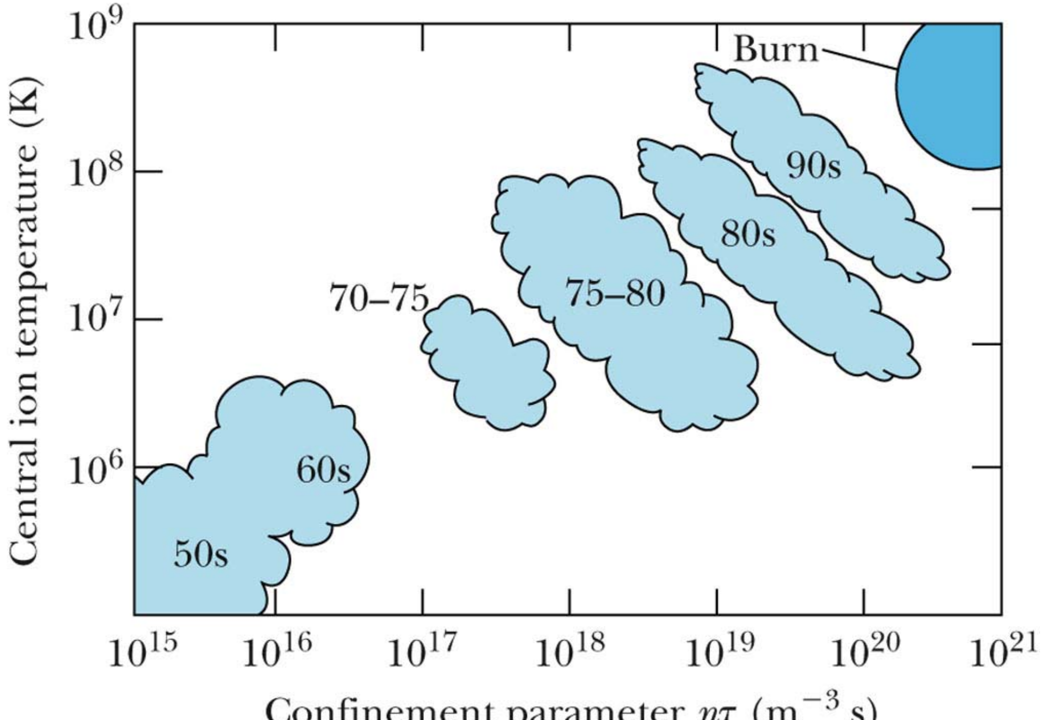
- Stellar process
- Best reaction is $^{2}H + {}^{3}H \longrightarrow n + {}^{4}He$ Q=17.6MeV
- Enough $^{2}$H for billions of years in sea water

**3 Requirements for Fusion:**

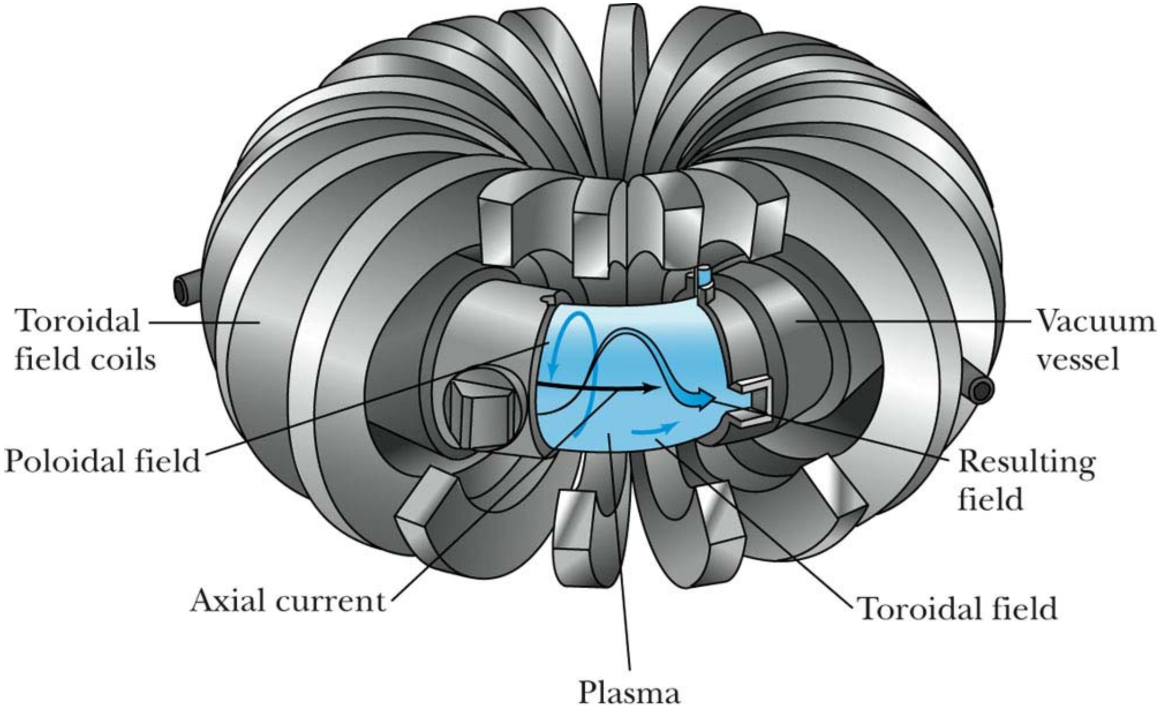
1. **High T – 1-200 million K**
2. **High Density – 2-3x$10^{20}$ ions/$m^3$**
3. **Sufficient confinement time – 1-2 s**

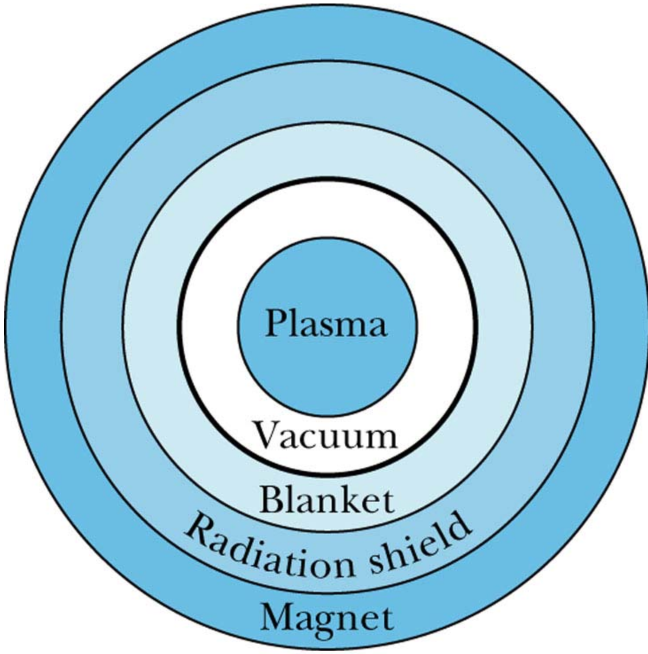
**Lawson criterion:**
**$n t \geq 3 \times 10^{20}$ s/$m^3$**

**Two schemes: MCF & ICF**

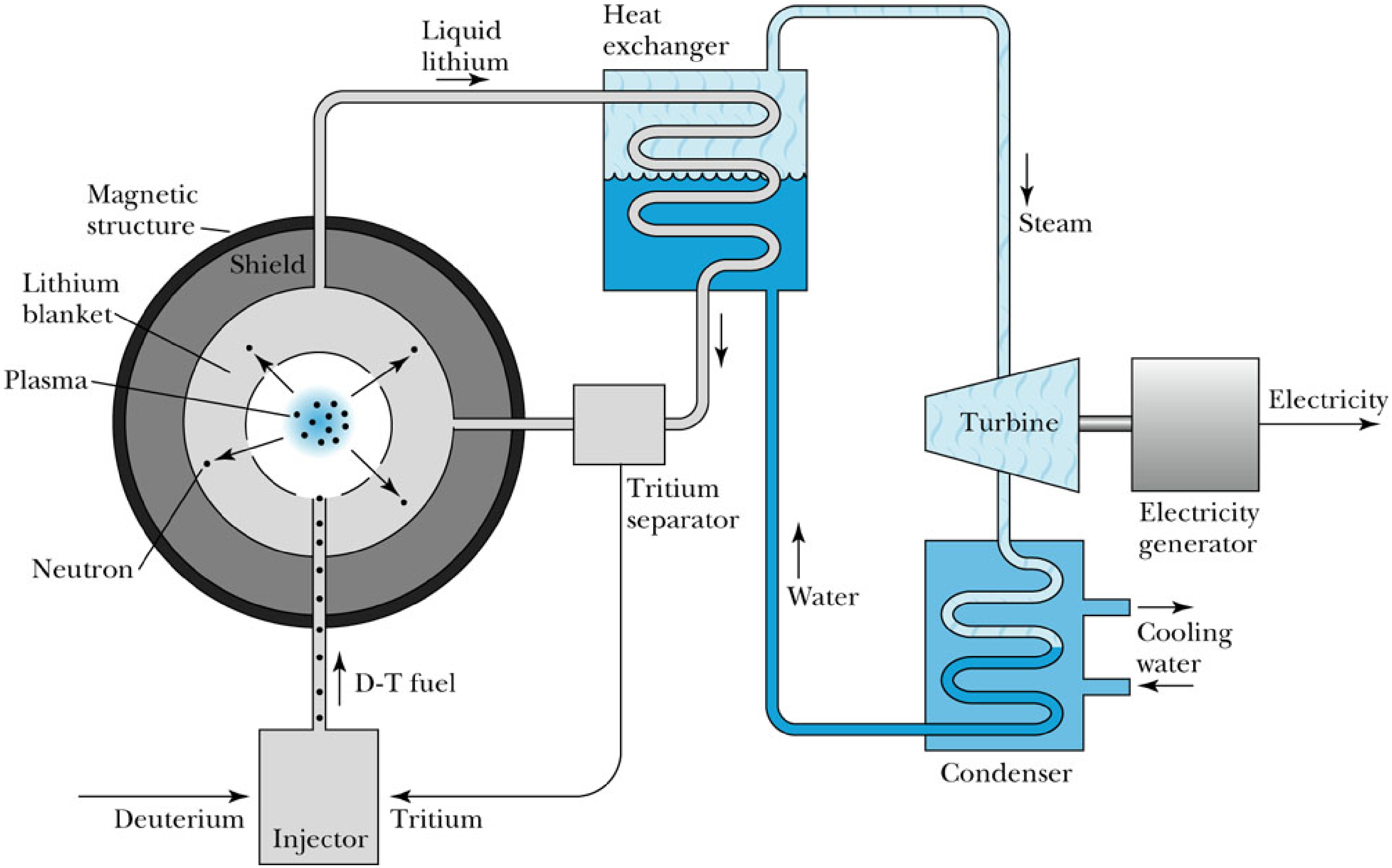


# MCF - Tokamaks



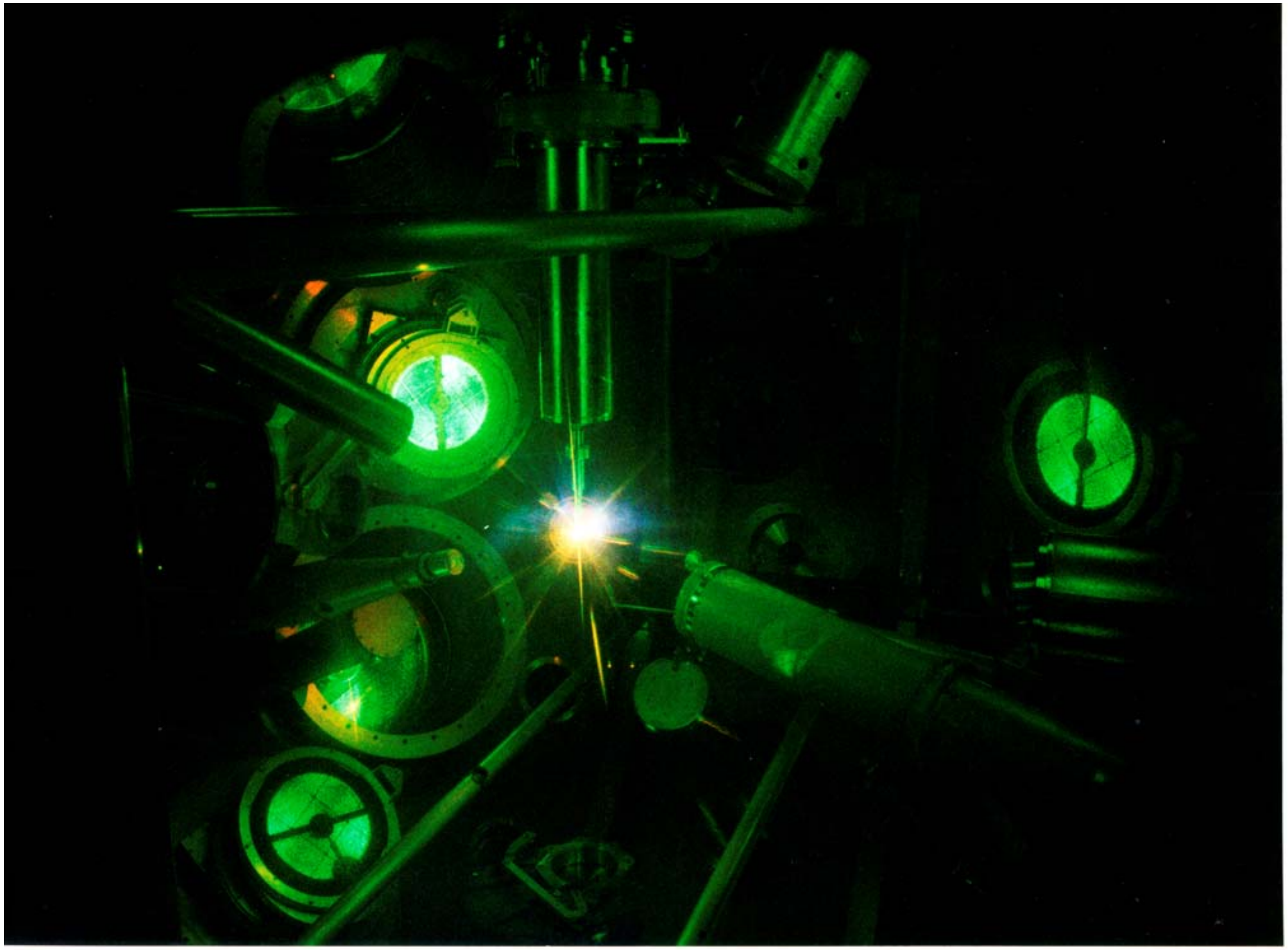


# MC Fusion Power Plant of the Future?



# Laser Fusion

- NIF (National Ignition Facility – Livermore)



# Advertisement

- April 23 – 24 (Friday/Saturday) at Union – meeting of the NY State and New England Sections of the American Physical Society

  Modern Nuclear Applications: Medicine, Power and non-Proliferation

  Help out at meeting and hear about the latest