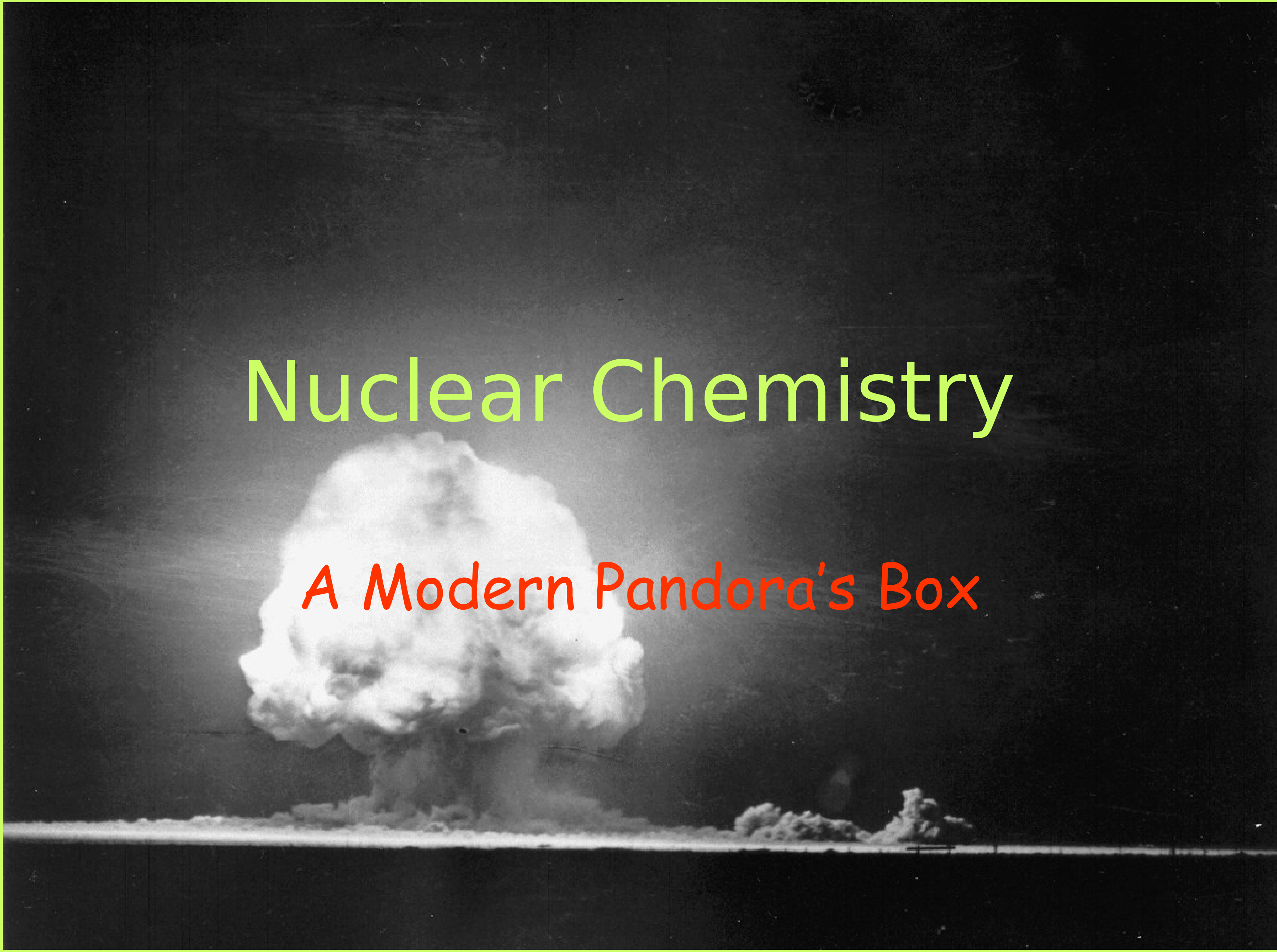
Nuclear Chemistry

A Modern Pandora's Box

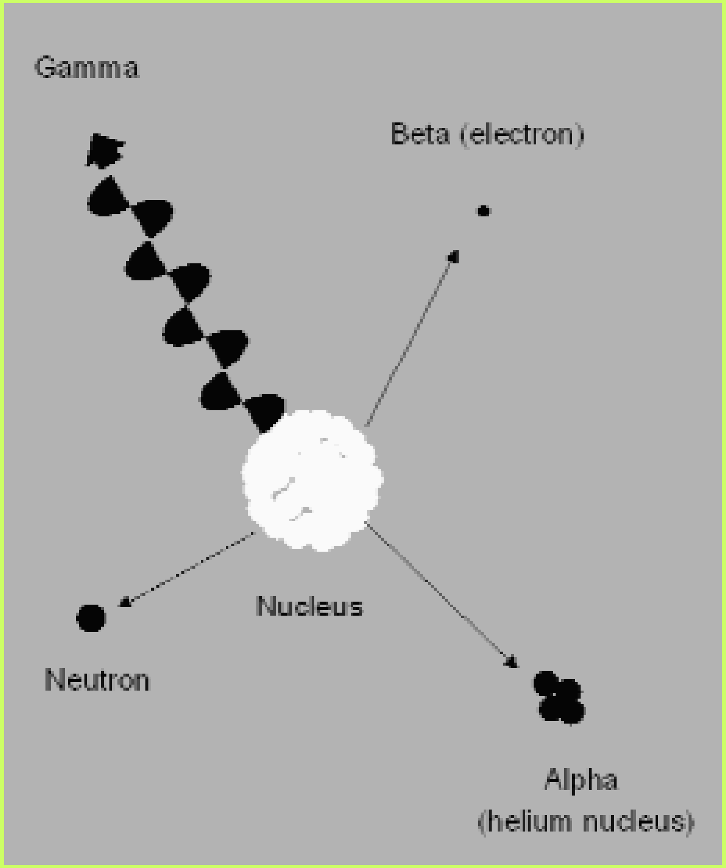


At the heart of it all

- Nucleus
- Isotope
- Nuclide

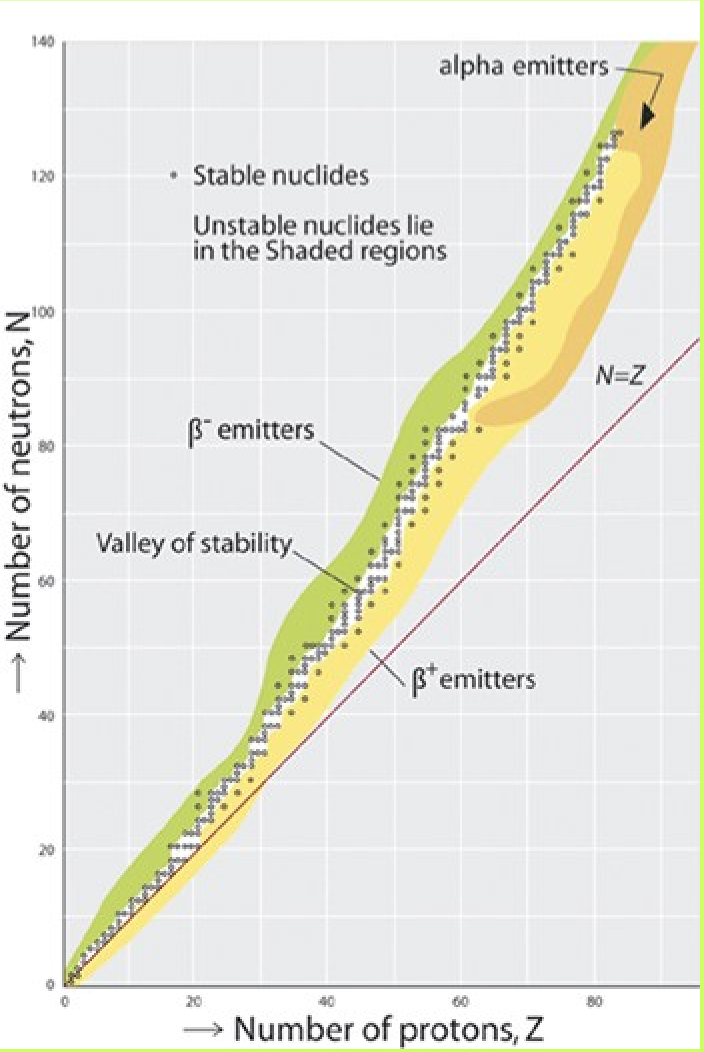
Gaining stability

- The release of energy and particles by the nucleus of an unstable isotope is called radioactivity.

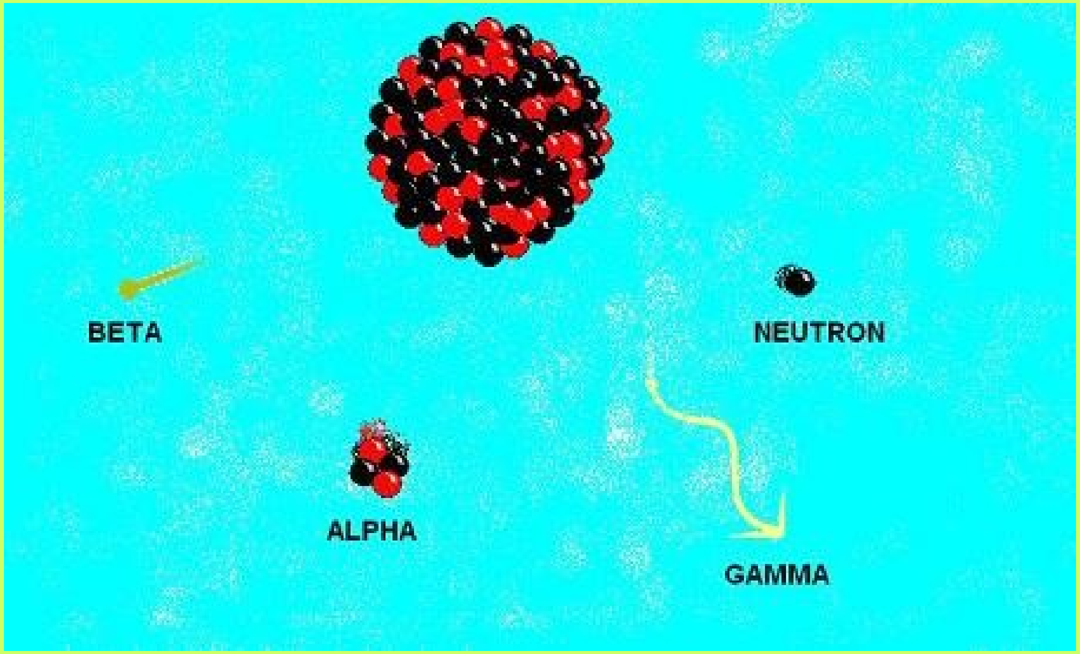


Not all isotopes are unstable

- Neutron/proton number increases to help keep nucleus stable.
- Approximately 2000 isotopes, 279 non-radioactive.



Decay? Or Change?



- Law of Conservation of Mass
- Law of Conservation of Charge
- Must be obeyed

Important types

- Alpha (α) : ${}^{4}_{2}He$
- Beta (β-) : ${}^{0}_{1}e-$
- Positron (β+) ${}^{0}_{1}e+$
- Neutron ${}^{1}_{0}n$
- electron capture ${}^{0}_{1}e-$ is added to nucleus
- Gamma (γ) : high, high energy photon, no mass, no charge, just pure energy

Writing decay reactions

- Do charge and mass balance first, then fill in blanks.
- Recall Z the atomic number is the number of protons. It must always match the chemical symbol
- $^{238}_{92}U$ $^{235}_{92}U$

92 = U,
U=92

Sample Decay reactions

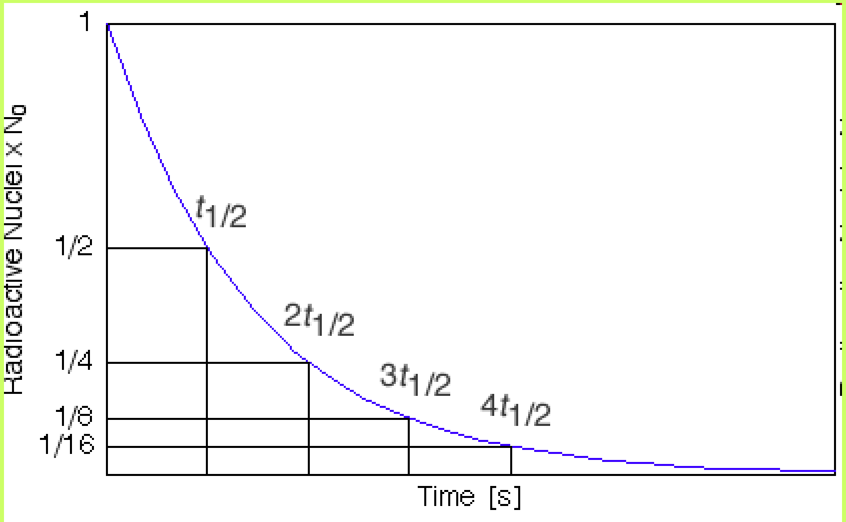
- $^{227}_{89}Ac$ --> $^{227}_{90}Th$ + ______
- $^{13}_{7}N$ --> $^{13}_{6}C$ + _____
- $^{73}_{33}As$ + ______ --> $^{73}_{32}Ge$
- $^{210}_{84}Po$ --> $^{206}_{82}Pb$ + ______

Not So Elementary my dear Watson

- Through the addition and subtraction of particles, elements transmute from one to another.
- Stars build elements by a variety of nuclear processes

Get a life well half-life anyway

- Half-life: amount of time required for 1/2 of the original nuclei to decay into another element.



Rate Laws

- Radioactive decay (all types) follows 1st order kinetics.
- Half-life is constant: independent of concentration
- The rate constant (decay constant) $\ln(N/N_o) = -kt$
- $k = 0.693/t_{1/2}$ $t_{1/2} = 0.693/k$

Age Dating example

- A piece of charred sinew from a mummy has 3.1 beta counts/ minute for each gram of carbon. Living organic material gives off 13.6 counts per minute per gram of carbon. The half-life of $^{14}_{6}C$ is 5,730 years. How many years before present was the mummy killed.

Dating example

- N/No = $\frac{3.1 \text{ cts/min g}}{13.6 \text{ cts/min g}}$
- N/No = 0.23
- ln(N/No) = -kt
- ln(0.23) = -(0.693/5730yrs)t
- t= 12152 yrs before present.
- t= 12,000 yrs before present

Mass Defect not a gene for weight gain

- The difference between the mass of an element, and the mass of the parts needed to make the element.
- Lets make helium 4! To make a mole we need 2 moles protons, 2 moles neutons.

Mass Defect not a gene for weight gain

- $\frac{2 \text{ moles p}}{} \left| \frac{6.022 \times 10^{23} \text{ p}}{1 \text{ mol}} \right| \frac{1.673 \times 10^{-24} \text{ g}}{1 \text{ p}}$
- 2.015 g
- $\frac{2 \text{ moles n}}{} \left| \frac{6.022 \times 10^{23} \text{ n}}{1 \text{ mol}} \right| \frac{1.675 \times 10^{-24} \text{ g}}{1 \text{ n}}$
- 2.017 g
- 4.032 g is what 1 mole ought to weigh.
- 4.026 is actual mass.
- 0.006 is mass defect.

Mass Defect not a gene for weight gain

- 0.006 is mass defect.
- So for every 4 grams of He produced the energy released in a star is given by $E=mc^2$ (mass in kg c in m/s)
- 6.00×10^{-6} kg x $(3.00 \times 10^{8}$ m/s$)^2$
- 5.4×10^{5} kJ/mol !!!!
- Compare this to combustion!!!

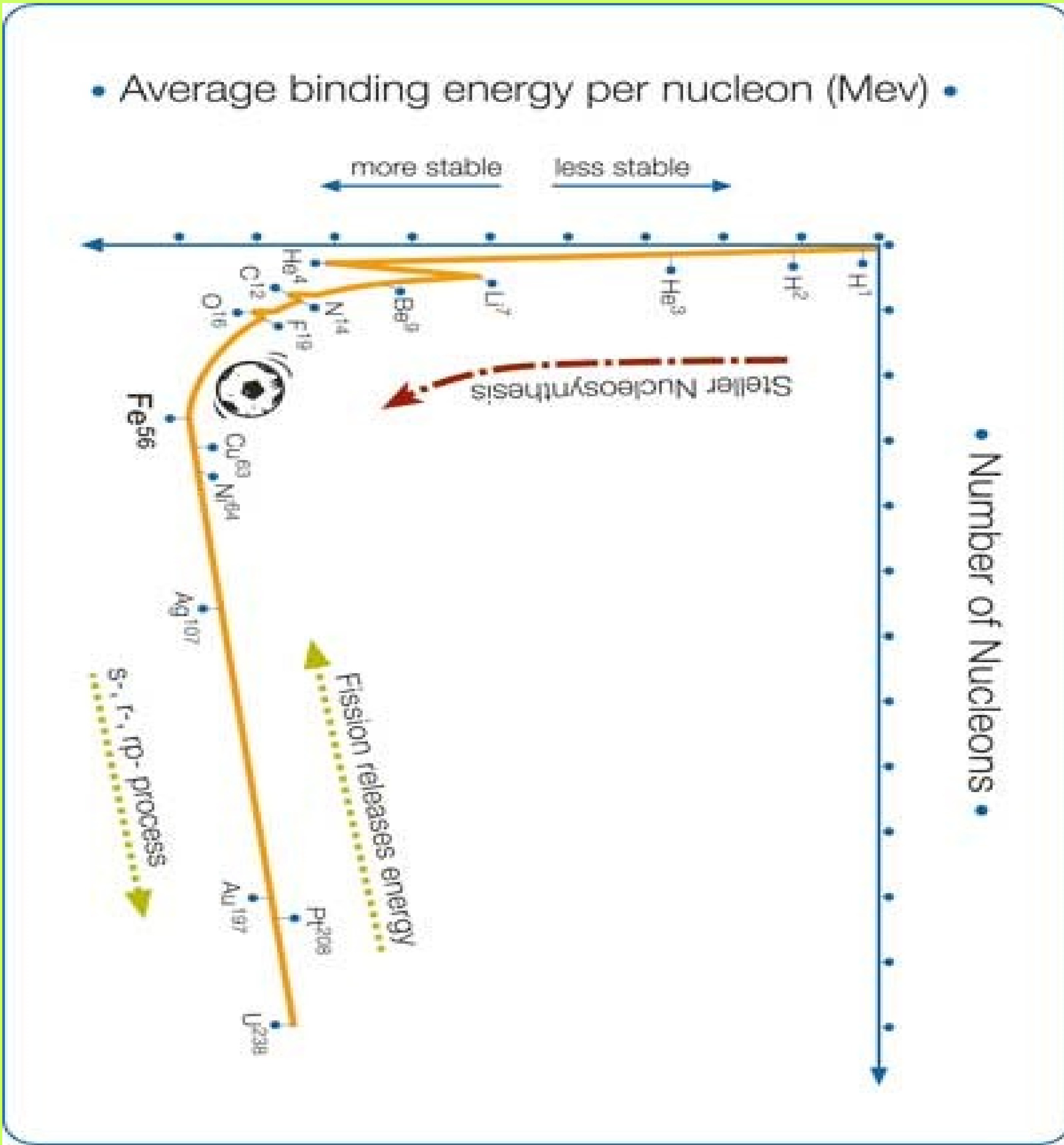
Thermodynamic stability

- Since so much energy has been given up to make He it is implied that He is in a thermodynamic well, or dip.
- That means it is relatively more stable that the collection of its parts.

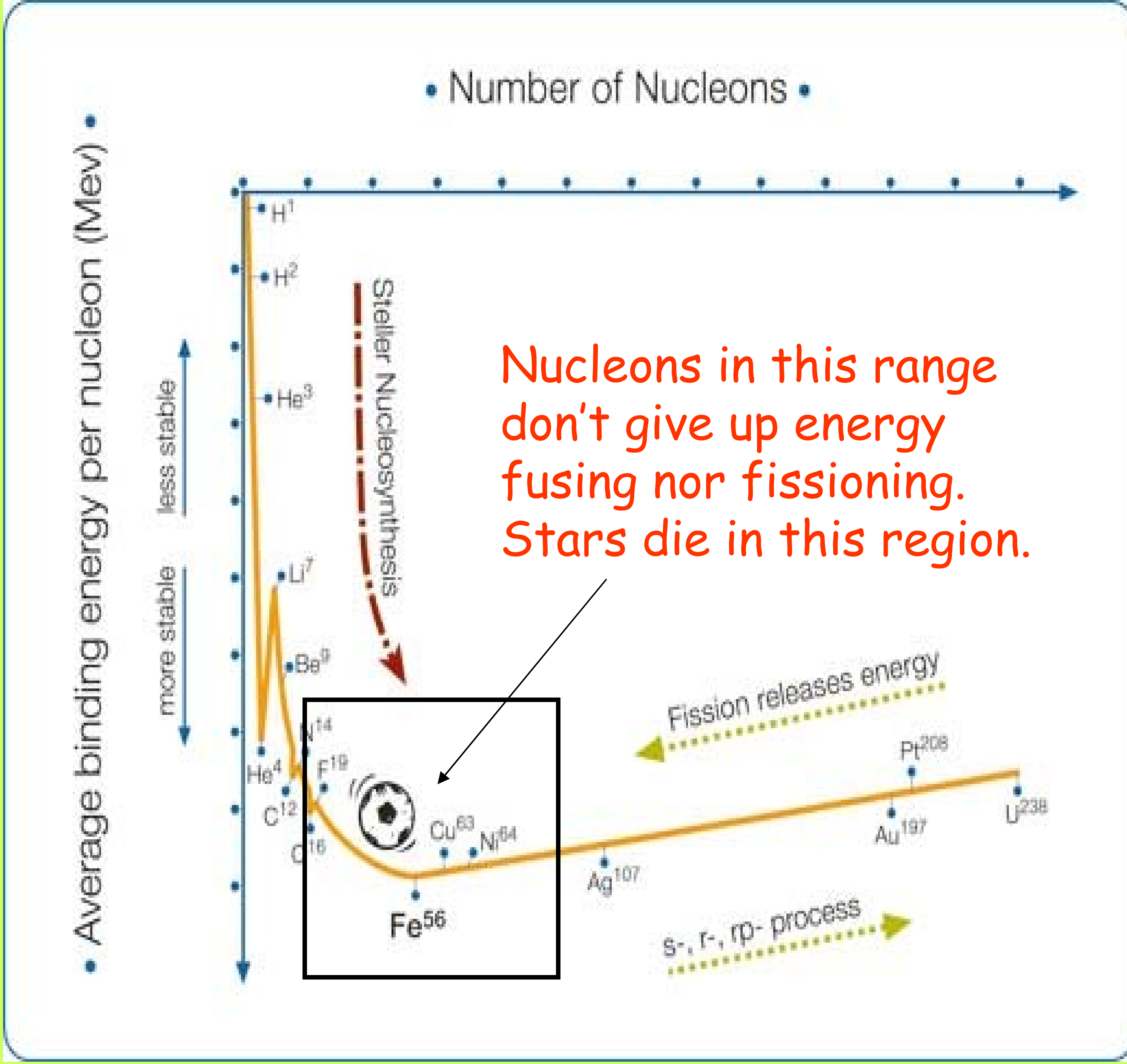
Mass Defect not a gene for weight gain

- The reverse relationship is true of heavy nuclides. The heavy nuclides are heavier than the sum of their part, so if you split them.
- Viola… you get a mass defect…
- $E=mc^2$ and go boom!

Breaking up or making up, which releases Energy?

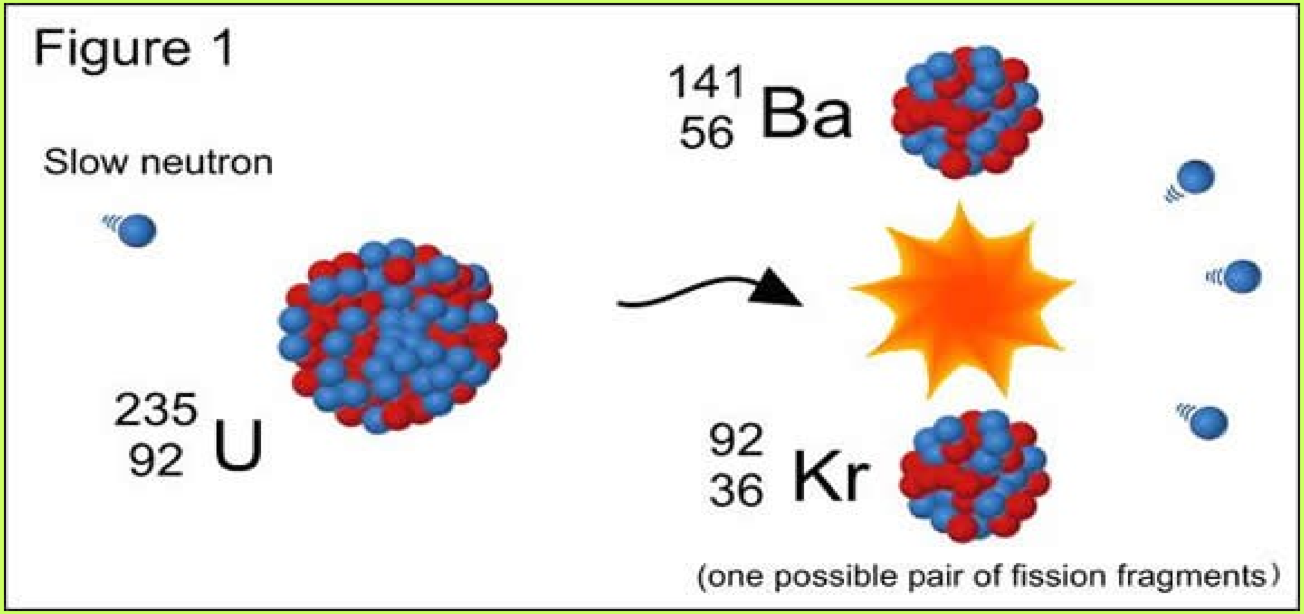


Breaking up or making up, which releases Energy?



Nucleons in this range don't give up energy fusing nor fissioning. Stars die in this region.

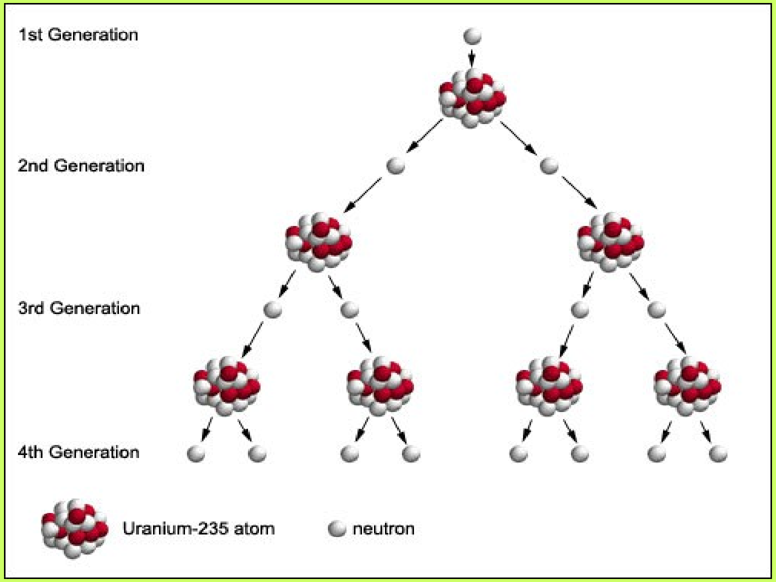
Fission not Fishin'



- Only about 4 of 2000 isotopes are fissionable. They split approximately in two if hit by a low enery neutron. They give off more neutrons. Hence more fissioning.

Chain fission reactions

KE fission products	165 MeV
gamma rays	7 MeV
KE neutrons	6 MeV
energy from fission products	7 MeV
gamma rays from fission products	6 MeV
antineutrinos from fission products	9 MeV
Total per fission	**200 MeV**



1 MeV (million electron volts) = 1.609×10^{-13} joules

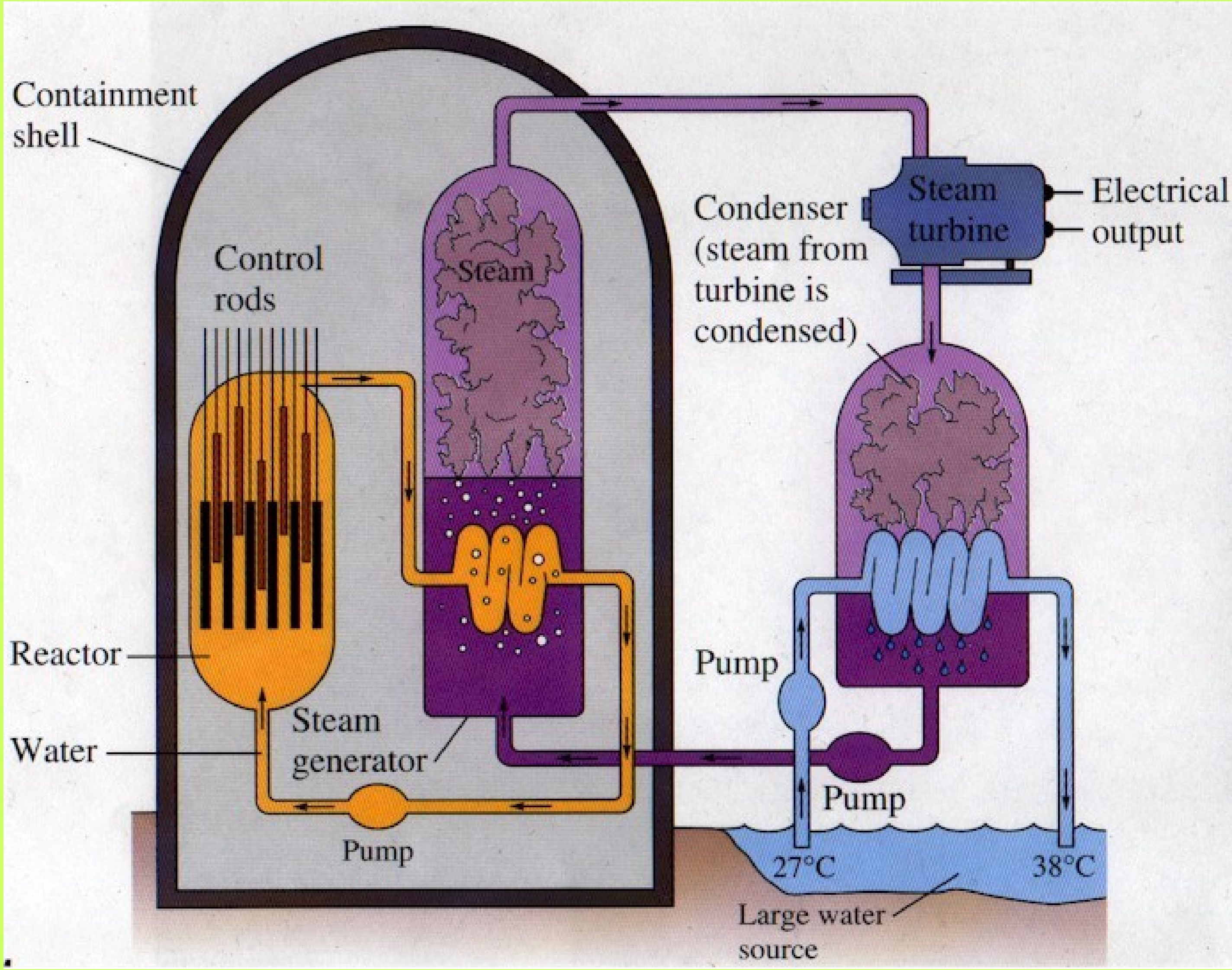
Fission

- After a heavy nucleus is split, some "nuclear" glue is converted to energy. This mass defect is the m in $E = mc^2$
- For $^{235}_{92}U$ this energy release is approximately 26 million times more energy released than combustion of methane. This energy can be destructive...


R-55 F-31

Or constructive...

Nuclear Steam Kettle



All this fissioning leads to WASTE

- The fission fragments are not all the same size, nor the same half-live, but the many daughters are radioactive.
- The shorter the half-life, the more radioactive, but no longer useful for fissioning.
- Sometimes heavier trans-uranics are produced.

All this fissioning leads to WASTE

- $^{90}_{38}Sr$ $t_{1/2}$ = 29 years
- $^{137}_{55}Cs$ $t_{1/2}$ = 30 years

- These nuclides are both hot and will be incorporated in animals and people as Sr mimics Ca and Cs mimics K in biological processes.

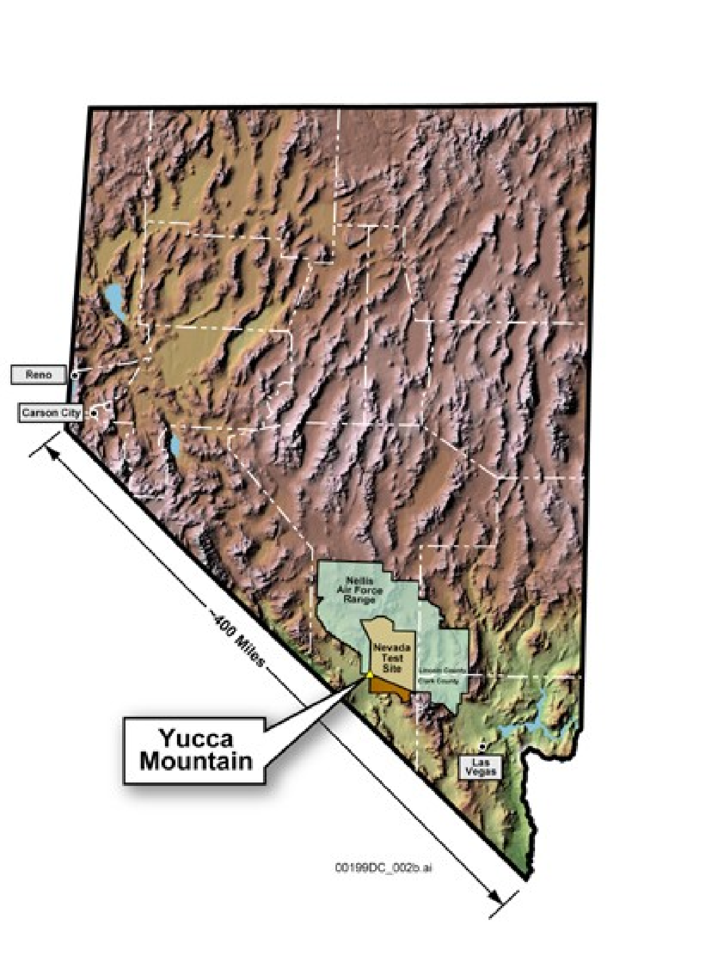
Nuclear Waste

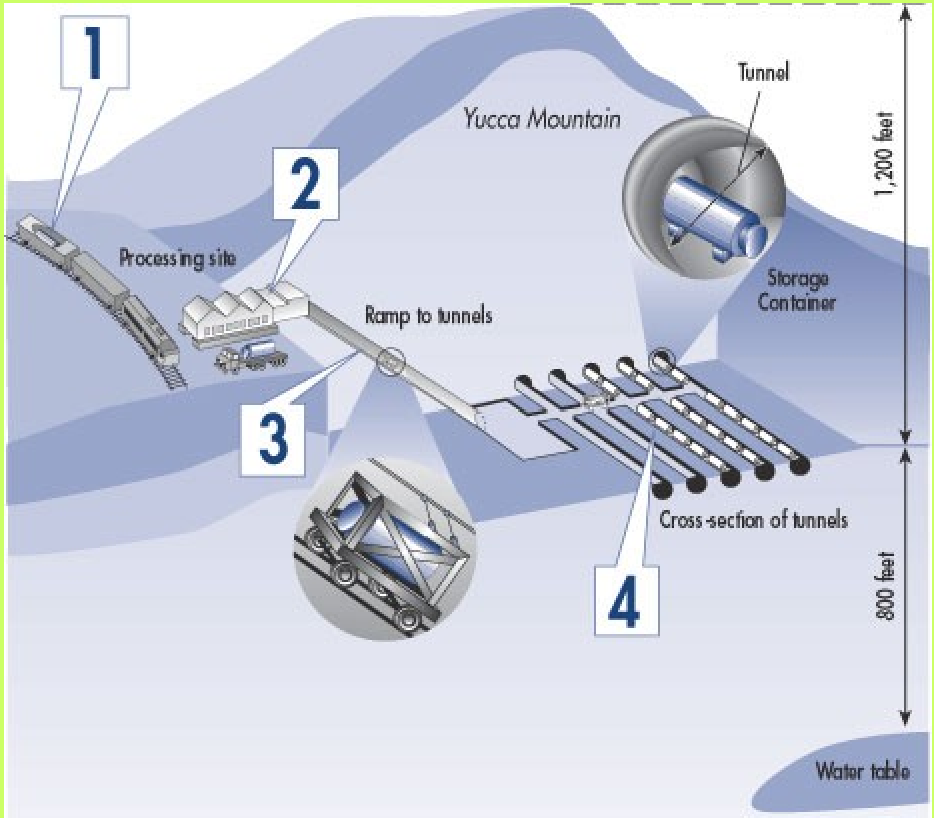
- Isolate: from biosphere, underground water sources.
  - Radioactivity itself tends to damage materials like steel and other metals.
  - Furthermore, a large quantity of radioactive matter tends to get very hot.
  - Incorporate waste in certain kinds of glass and ceramic materials.

Nuclear Waste

- Underground storage
- Shoot into space
- Do nothing.
- These seem like the major options

Yucca Mountain





Yucca Mountain

- Pros
  - Low population
  - Dry
- Cons
  - Geologic activity
  - Tranportation distance

Do Nothing?

- Continue to store waste at reactor facilities
  - near population
  - above water table
  - security?
  - never designed for long term storage