SRI AKILANDESWARI WOMEN'S COLLEGE, WANDIWASH

NUCLEAR CHEMISTRY

Class : III UG CHEMISTRY

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The Nucleus

- The nucleus is composed of nucleons
  - protons
  - neutrons
- A nucleus is characterized by two numbers
  - atomic mass number(A; total # of nucleons)
  - atomic number (Z; number of protons)

$$_{Z}^{A}E$$

$^{27}_{13}Al$

- total number of nucleons is 27
- total number of protons is 13
- the number of neutrons is 14

Subatomic Particles

one atomic mass unit (u) is defined as 1/12th the mass of a carbon-12 atom

Particle	mass in kg	mass in u
electron	9.11×10^{-31} kg	5.485×10^{-4} u
proton	1.673×10^{-27} kg	1.0073 u
neutron	1.675×10^{-27} kg	1.0087 u

Mass Defect

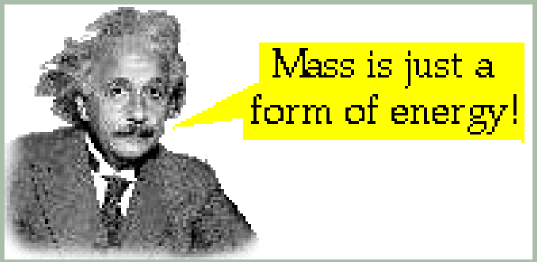
- Carbon-12 has a mass of 12.000 u
- Its nucleus contains 12 nucleons (6 p & 6n)
- Each nucleon has a mass >1 u
- The mass of a nucleus is slightly less than the mass of the individual nucleons
- The missing mass is called the mass defect
- mass defect: Δm = mass nucleons - mass nucleus

Einstein’s Equation

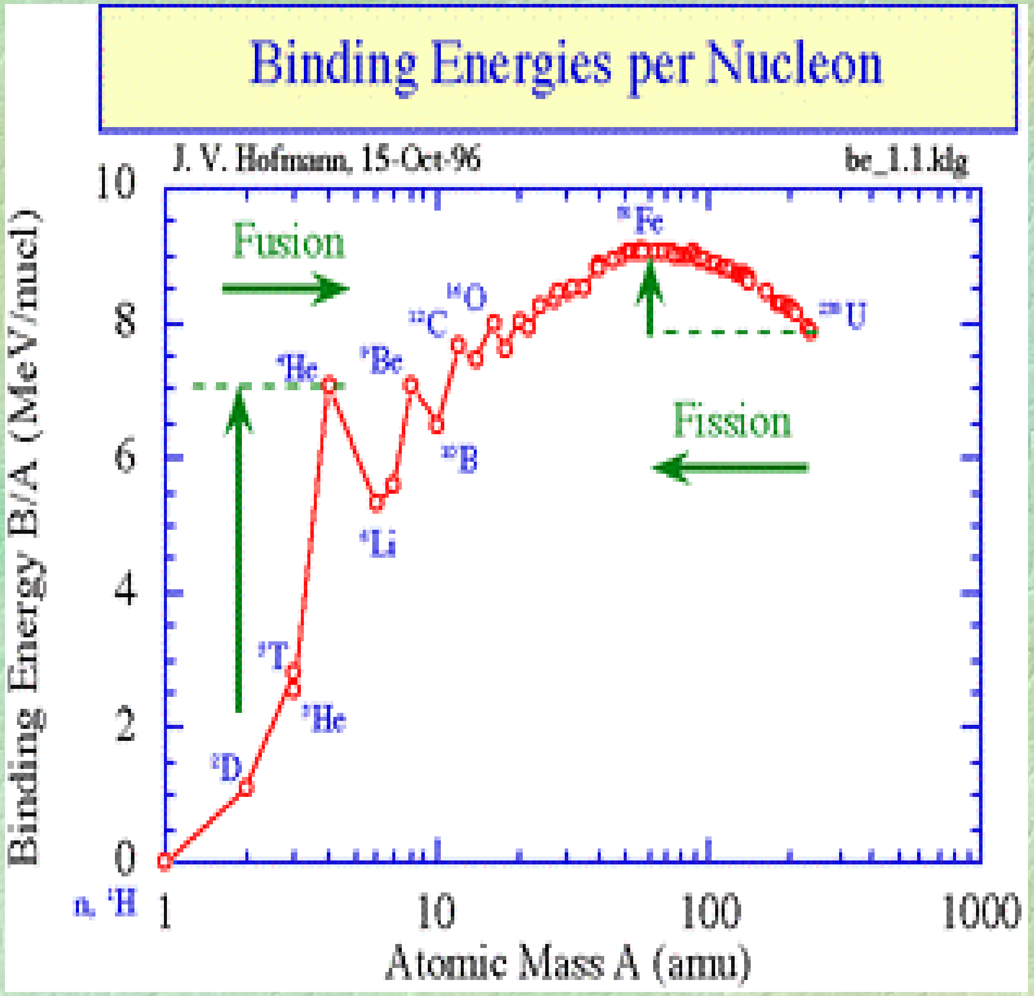
- Energy and mass can be interconverted
- $E = mc^2$
- When protons & neutrons are packed together to form a nucleus, some of the mass is converted to energy and released
- This amount of mass is equal to the force of attraction holding the nucleons together

Einstein's Equation

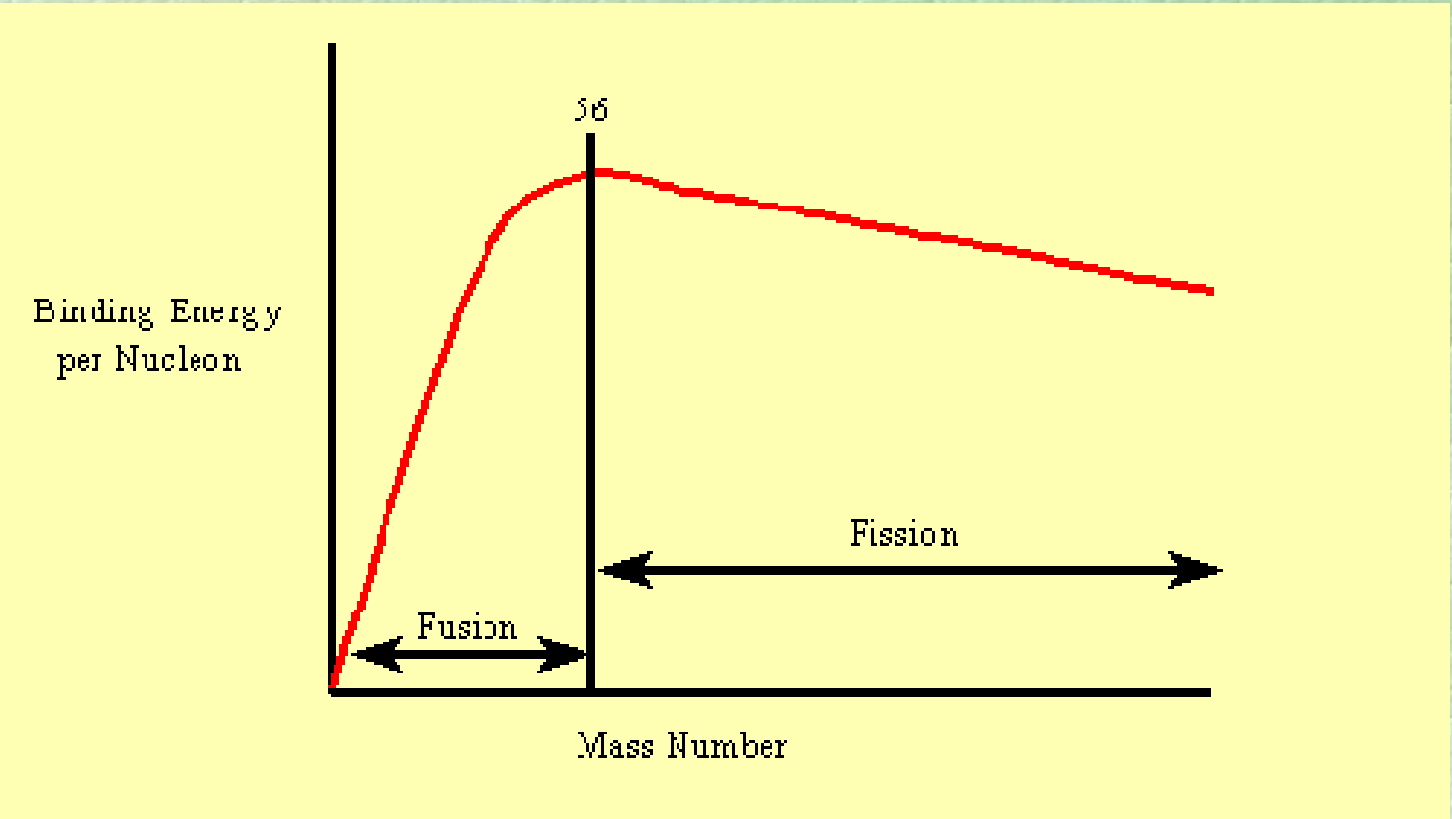
- The total energy required to break up a nucleus into its constituent protons & neutrons
- binding energy = Δmc^2
- The nuclear binding energy is measured in MeV which is much larger than the few eV required to hold electrons to an atom



Binding Energy Curve



- graph peaks at A=56
- the more BE released per nucleon, the more stable the nucleus
- mass number of 56 is maximum possible stability



- Theoretically, all nuclei will try to become larger or smaller to attain as mass number of nucleons
- To the right of 56 => want to become smaller
- To the left of 56 => want become larger

How Many Neutrons?

- The number of neutrons in a nucleus can vary
- Range limited by the degree of instability created by
  - having too many neutrons
  - too few neutrons
- Stable nuclei do not decay spontaneously
- Unstable nuclei have a certain probability to decay

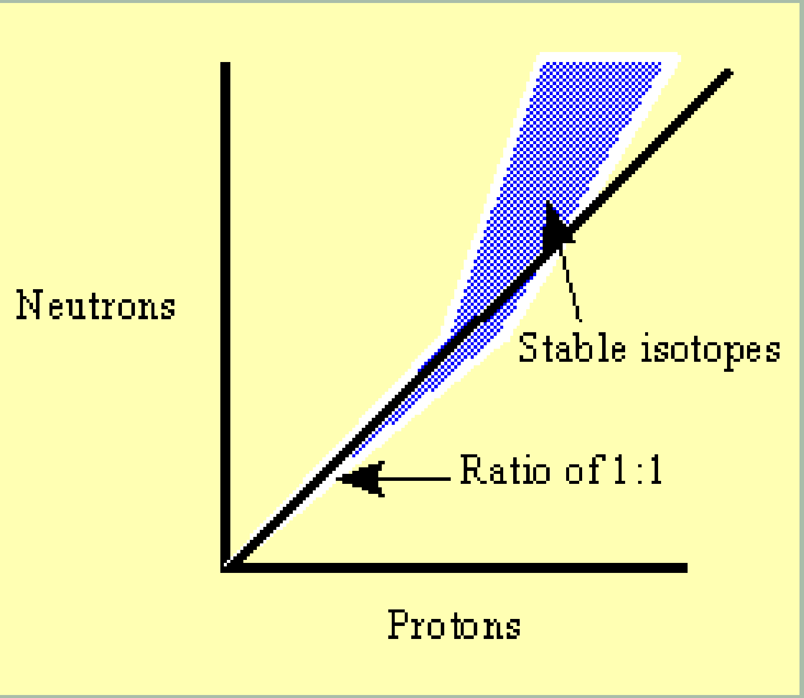
Nuclear Stability Facts

- 270 Stable nuclides
- 1700 radionuclides
- Every element has at least one one radioisotope
- For light elements ($Z \leq 20$), Z:N ratio is ~1
- Z:N ratio increases toward 1.5 for heavy elements
- For $Z > 83$, all isotopes are radioactive

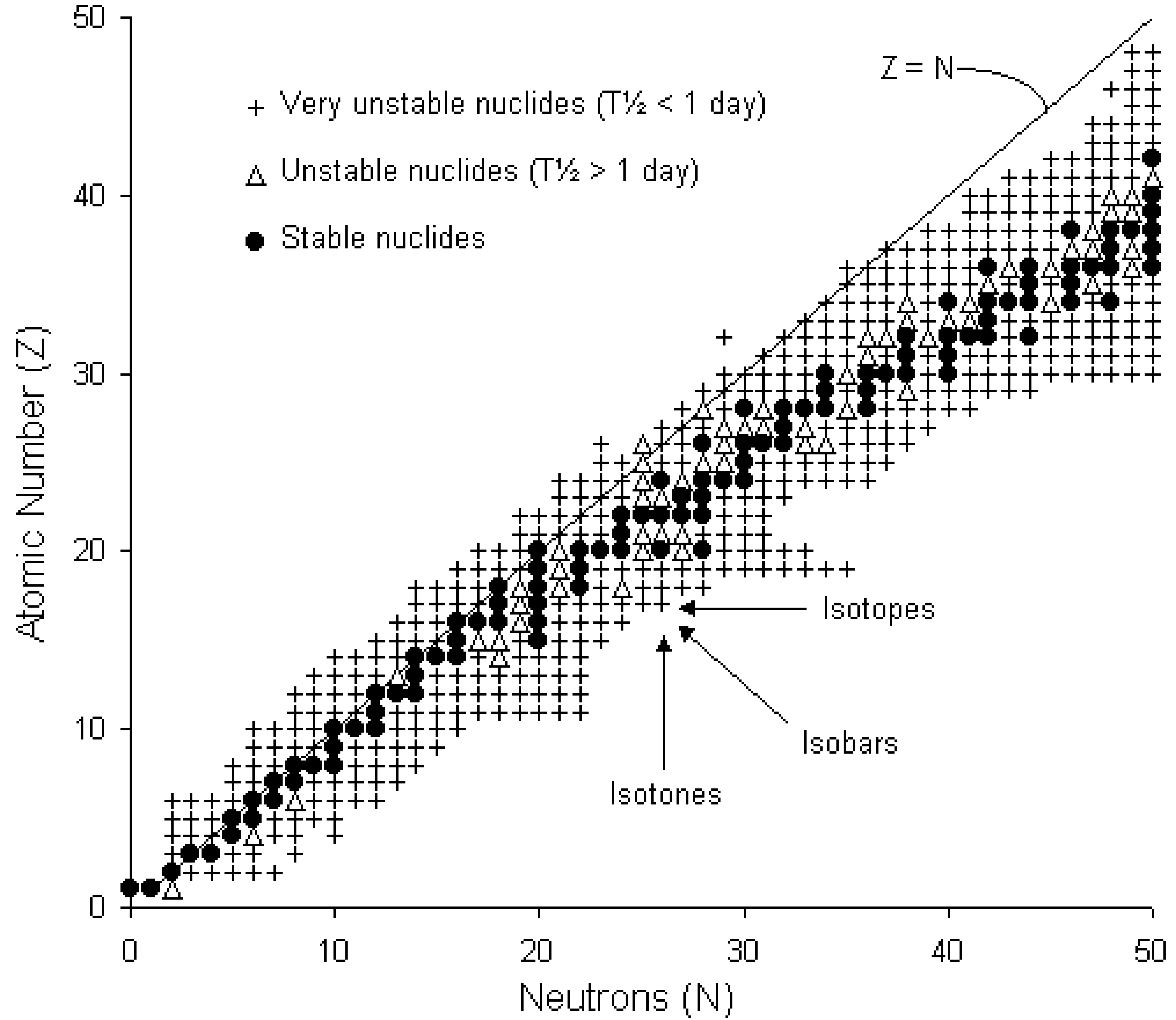
Nuclear Stability Facts

- The greater the number of protons, the more neutrons are needed
- “Magic numbers” of protons or neutrons which are unusually stable
  - 2, 8, 20, 28, 50, 82, 126
    - Sn (Z=50) has 10 isotopes; In (Z=49)& Sb (Z=51) have only 2
    - Pb-208 has a double magic number (126n, 82p) & is very stable

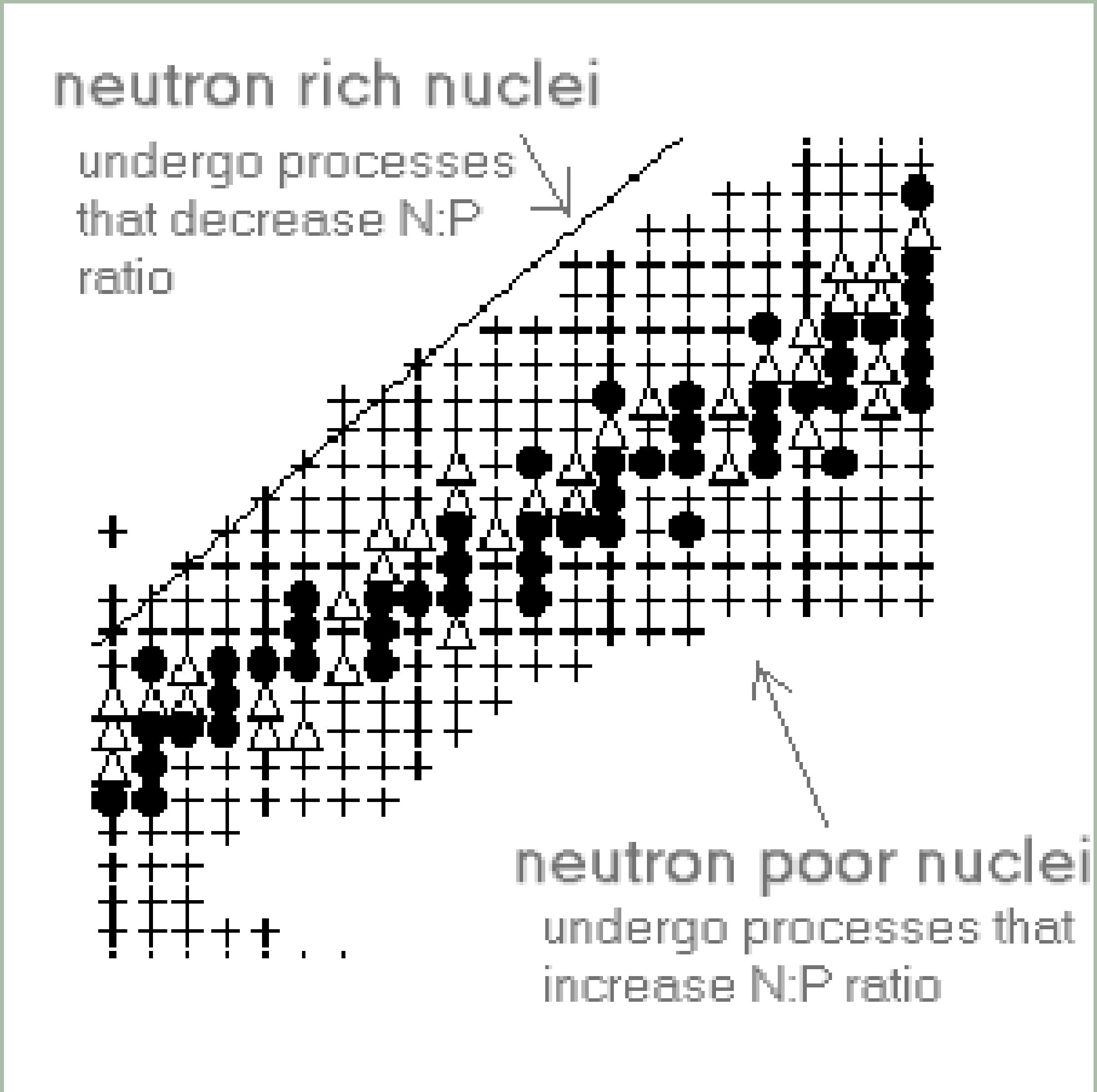
Band of Nuclear Stability



- A plot of the known isotopes on a neutron/proton grid gives
- Stable isotopes form a band of stability from H to U
- Z:N ratios to either side of this band are too unstable & are not known


Z = N
+ Very unstable nuclides (T½ < 1 day)
Δ Unstable nuclides (T½ > 1 day)
● Stable nuclides
Isotopes
Isobars
Isotones
Atomic Number (Z)
Neutrons (N)
0
10
20
30
40
50

Nuclear Band of Stability



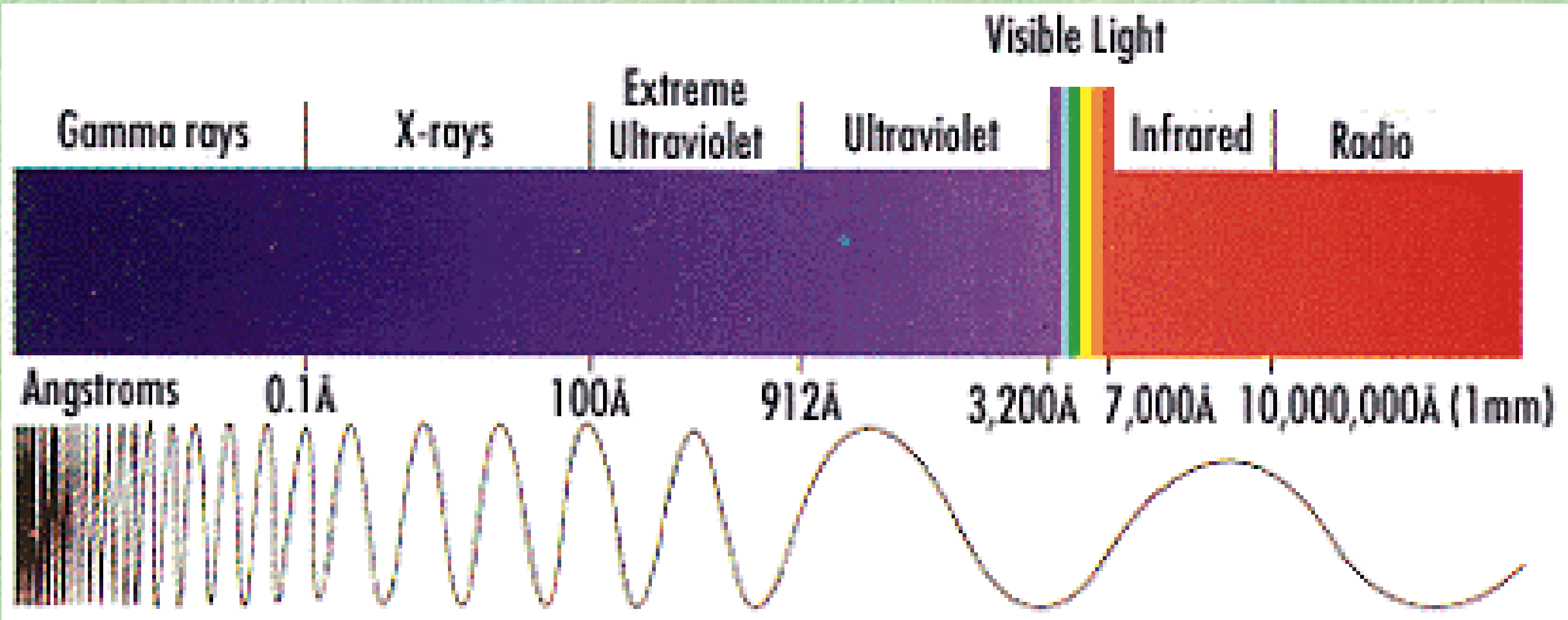
Radioactivity

- The spontaneous decomposition of an unstable nucleus into a more stable nucleus by releasing fragments or energy.
- Sometimes it releases both.

Electromagnetic Radiation

- Electromagnetic radiation is a form of energy that can pass through empty space
- It is not just a particle, and it is not just a wave. It may be both.

Electromagnetic Radiation

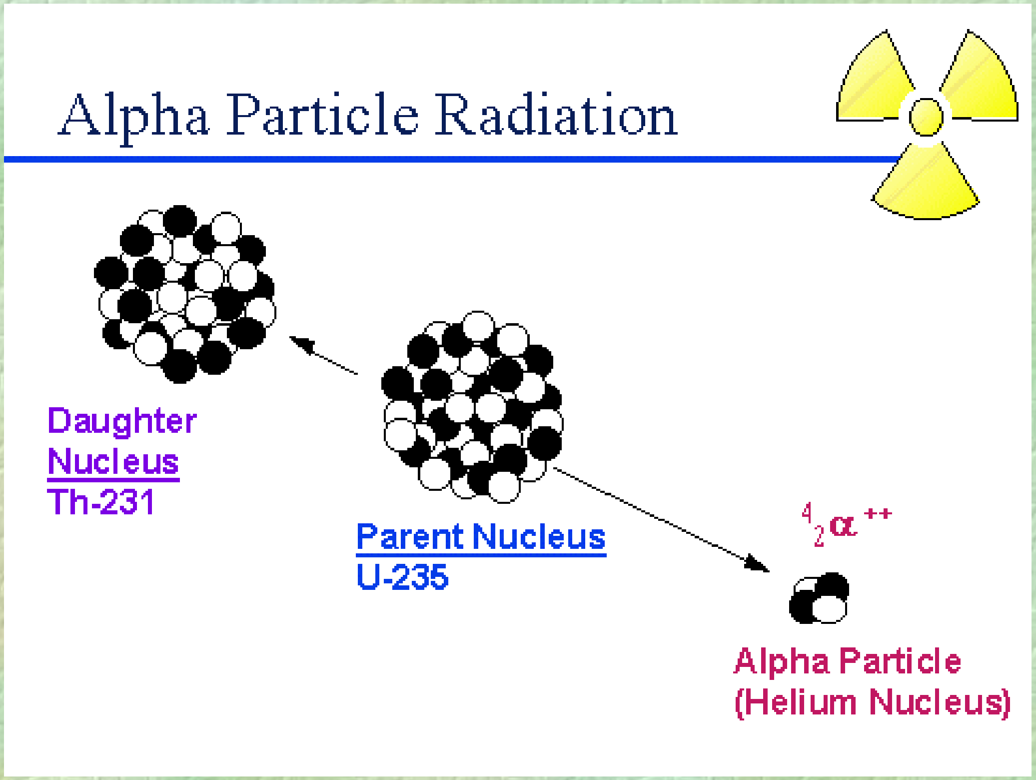


- The shorter the wavelength, the more energy it possesses
- gamma rays are very energetic
- radio waves are not ver energetic

Some Types of Radioactive Decay

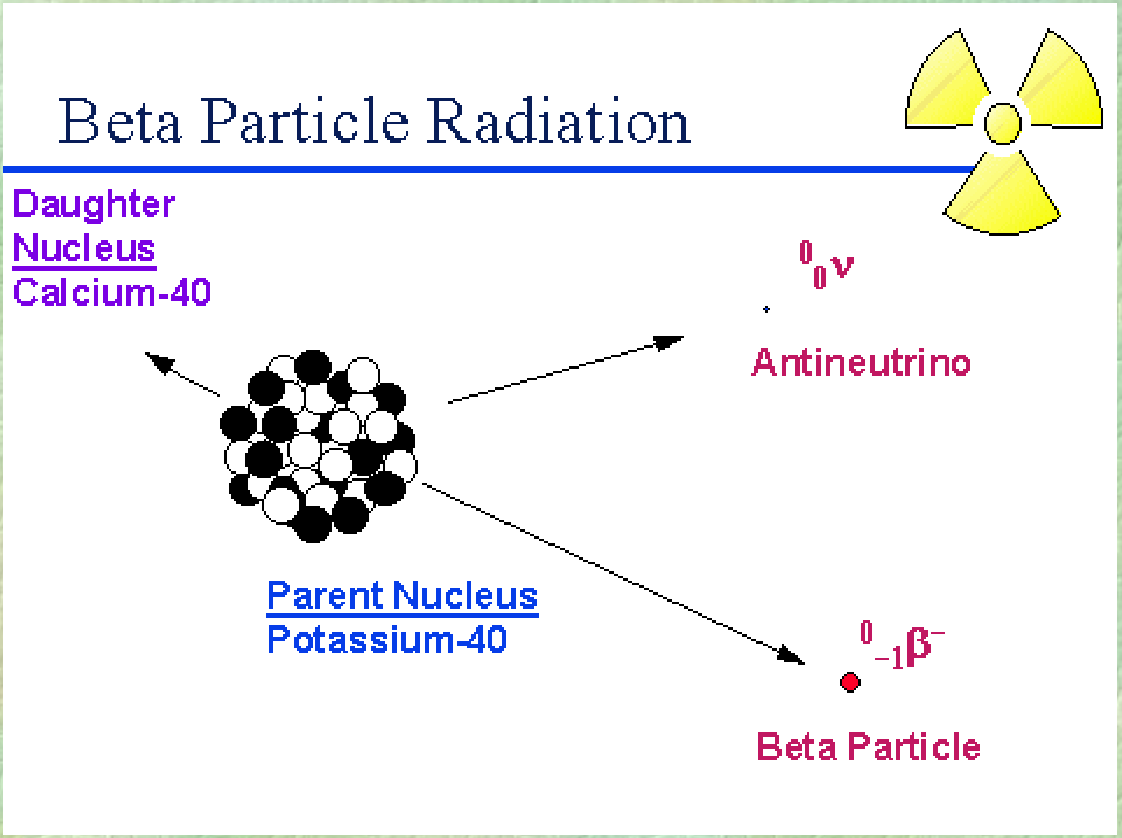
- Alpha Decay (increases N:Z ratio)
- Beta Decay (decreases N:Z ratio)
- Gamma Decay

Alpha Emission



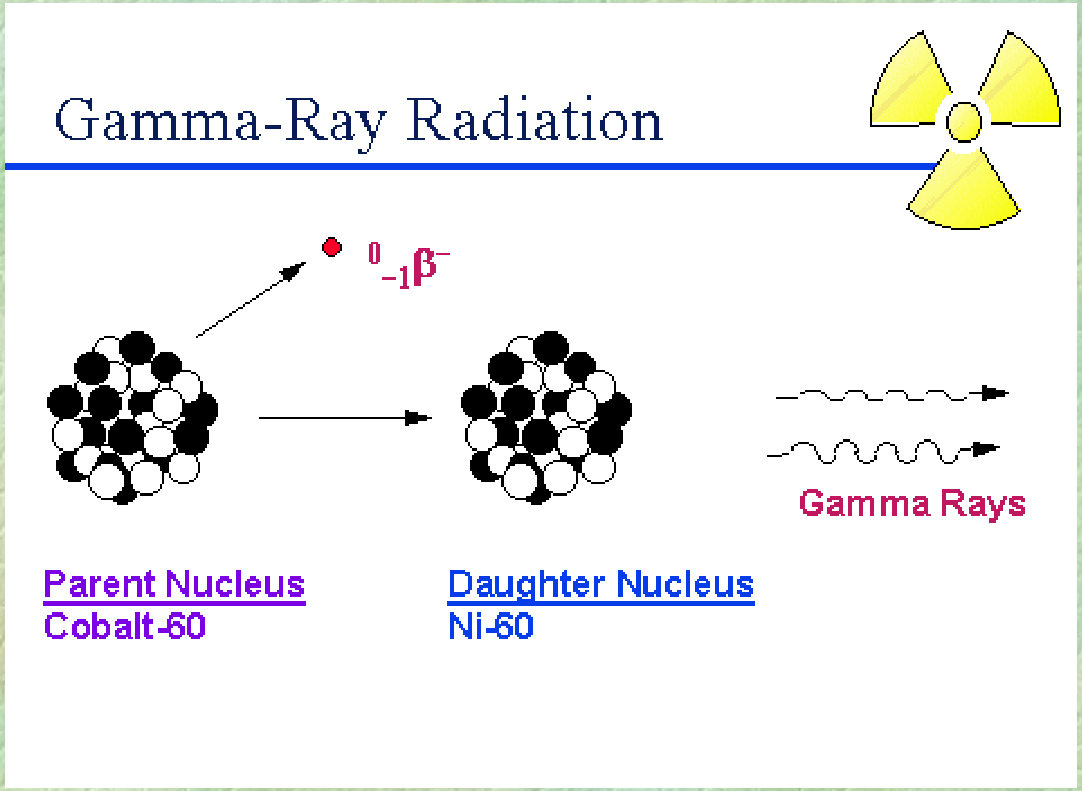
- $_{Z}^{A}X \longrightarrow {}_{Z-2}^{A-4}Y + {}_{2}^{4}\alpha$
- Identity of the atom changes
- $_{92}^{235}U \longrightarrow {}_{90}^{231}Th + {}_{2}^{4}\alpha$
- Quick way for a large atom to lose a lot of nucleons

Beta Emission



- Ejection of a high speed electron from the nucleus
- ${}_{Z}^{A}X \longrightarrow {}_{Z+1}^{A}Y + {}_{0}^{-1}B$
- ${}_{19}^{40}K \longrightarrow {}_{20}^{40}Ca + {}_{0}^{-1}B$
- Identity of atom changes

Gamma Emission

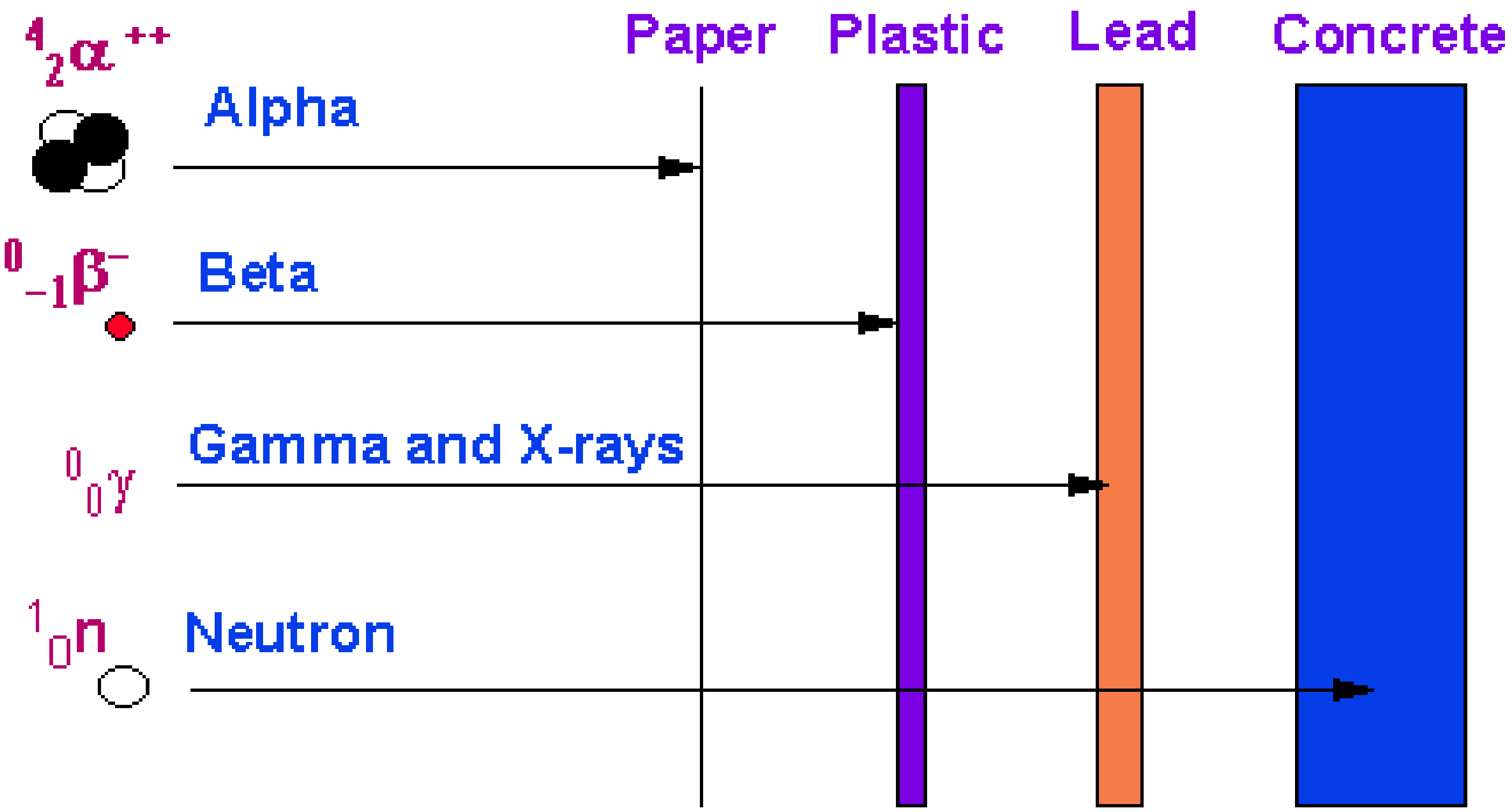


- Emission of high energy electromagnetic radiation
- Usually occurs after emission of a decay particle forms a metastable nucleus
- Does not change the isotope or element

Radiation Energetics

- Alpha Particles
  - relatively heavy and doubly charged
  - lose energy quickly in matter
- Beta Particles
  - much smaller and singly charged
  - interact more slowly with matter
- Gamma Rays & X-rays
  - high energy
  - more lengthy interaction with matter

Penetrating Distances



Hazards of Radiation Types

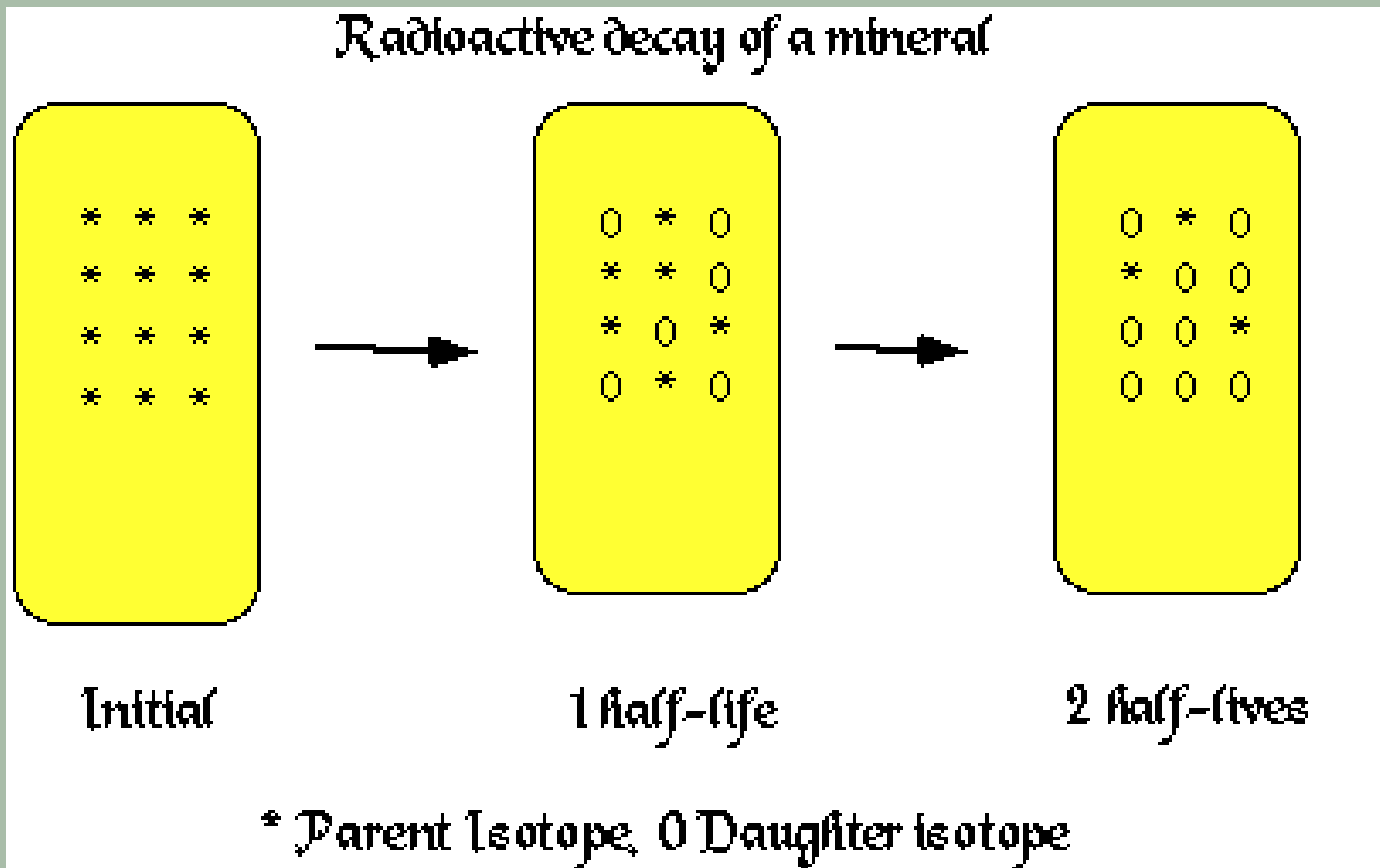
- Alpha Emissions
  - easily shielded
  - considered hazardous if alpha emitting material is ingested or inhaled
- Beta Emissions
  - shielded by thin layers of material
  - considered hazardous is a beta emitter is ingested or inhaled
- Gamma Emissions
  - need dense material for shielding
  - considered hazardous when external to the body

Radioactive Decay Rates

- Relative stability of nuclei can be expressed in terms of the time required for half of the sample to decay
- Examples: time for 1 g to decay to .5 g
  - Co-60 5 yr
  - Cu-64 13 h
  - U-238 4.51×10^{9} yr
  - U-235 7.1×10^{8} yr

Half-Life

The time required for half of a sample to decay

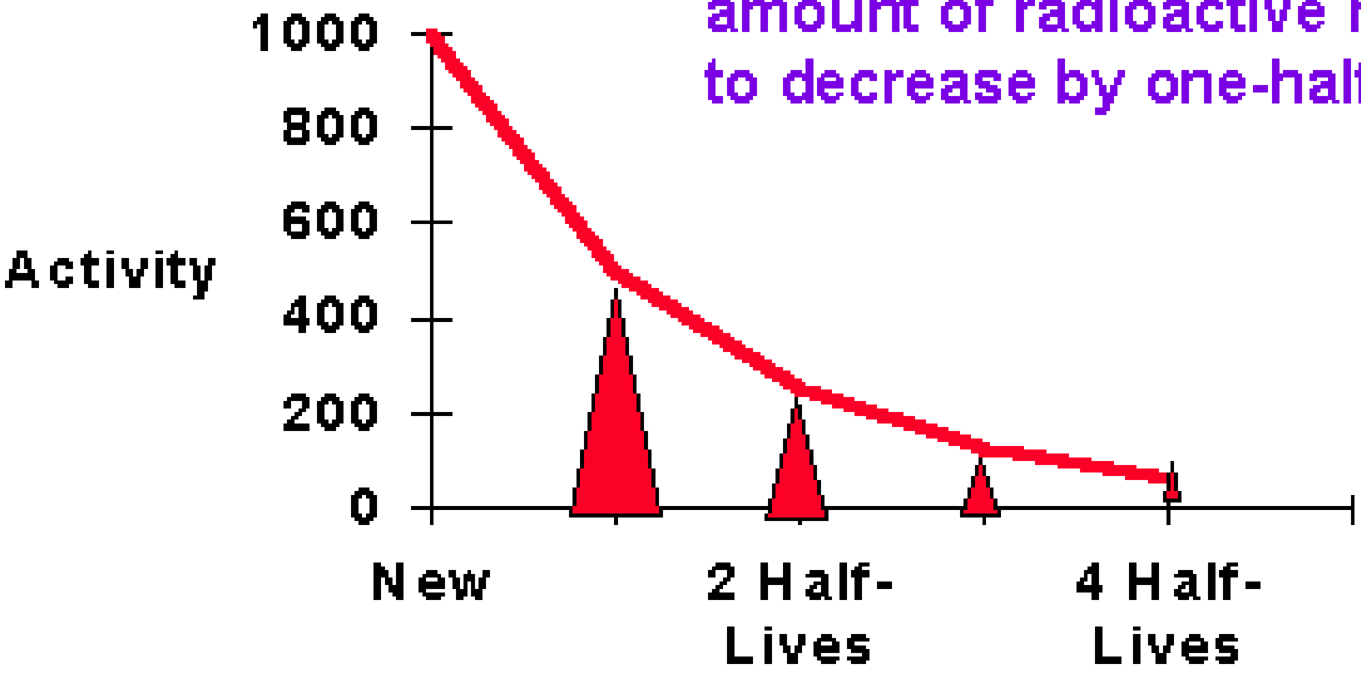


Half-Life

- The level of radioactivity of an isotope is inversely proportional to its half-life.
  - The shorter the half-life, more unstable the nucleus
- The half-life of a radionuclide is constant
- Rate of disintegration is independent of temperature or the number of radioactive nuclei present

Half-Life

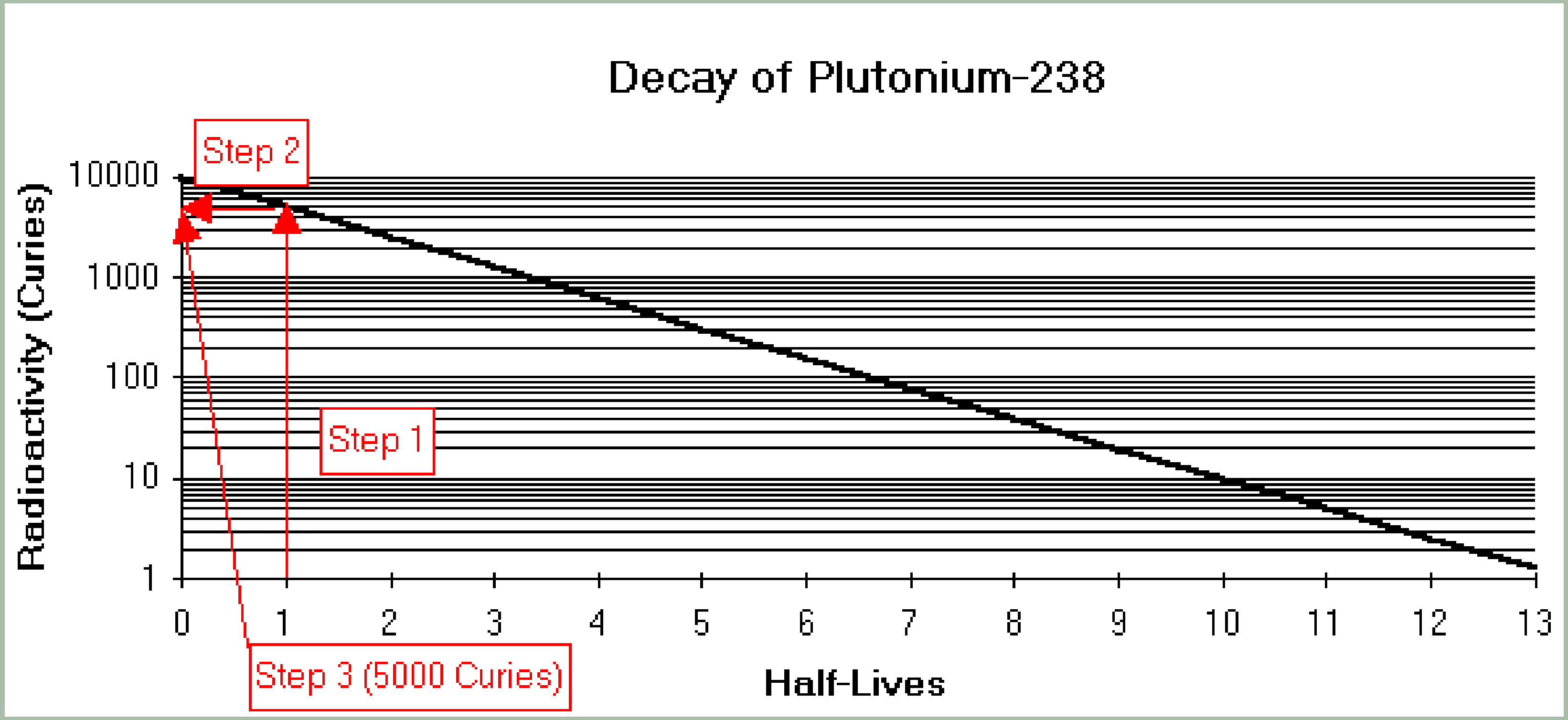
The time required for the amount of radioactive material to decrease by one-half



Half-Life

Number of Half-Lives	Fraction of Initial Amount Remaining	Amount Remaining (mg)
0	1	20.00 (initial)
1	1/2	10.00
2	1/4	5.00
3	1/8	2.50
4	1/16	1.25
5	1/32	0.625

Half-Life



- A plot the logarithm of activity vs. the time is a straight line.
- The quantity of any radioactive element will diminish by a factor of 1000 during a 10 half-life span

Trying To Reach Nuclear Stability

- Some nuclides (particularly those $Z>83$) cannot attain a stable, nonradioactive nucleus by a single emission.
- The product of such an emission is itself radioactive and will undergo a further decay process.
- Heavy nuclei may undergo a whole decay series of nuclear disintegrations before reaching a nonradioactive product.

Decay Series

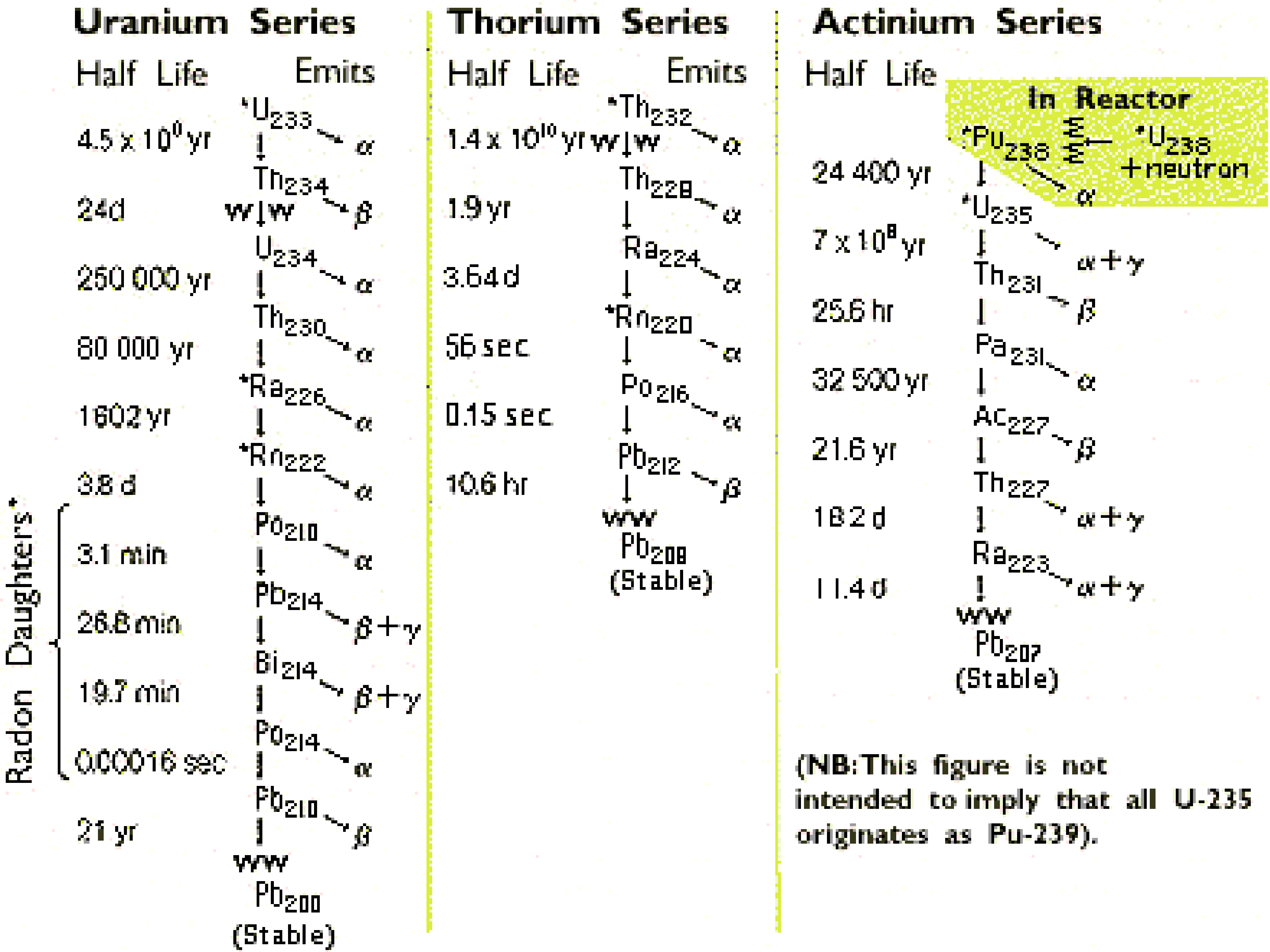
A series of elements produced from the successive emission of alpha & beta particles

URANIUM 238 (U238) RADIOACTIVE DECAY

type of radiation	nuclide	half-life
	uranium—238	4.5×10^{9} years
α		
	thorium—234	24.5 days
β		
	protactinium—234	1.14 minutes
β		
	uranium—234	2.33×10^{5} years
α		
	thorium—230	8.3×10^{4} years
α		
	radium—226	1590 years
α		
	radon—222	3.825 days
α		
	polonium—218	3.05 minutes
α		
	lead—214	26.8 minutes
β		
	bismuth—214	19.7 minutes
β		
	polonium—214	1.5×10^{-4} seconds
α		
	lead—210	22 years
β		
	bismuth—210	5 days
β		
	polonium—210	140 days
α		
	lead—206	stable

The Four Known Decay Series

Parent Radioisotope	# of Decay Steps	Final Product of Series
Uranium-238	14	Lead-206
Thorium-232	10	Lead-208
Uranium-235	11	Lead-207
Plutonium-241	13	Bismuth-209

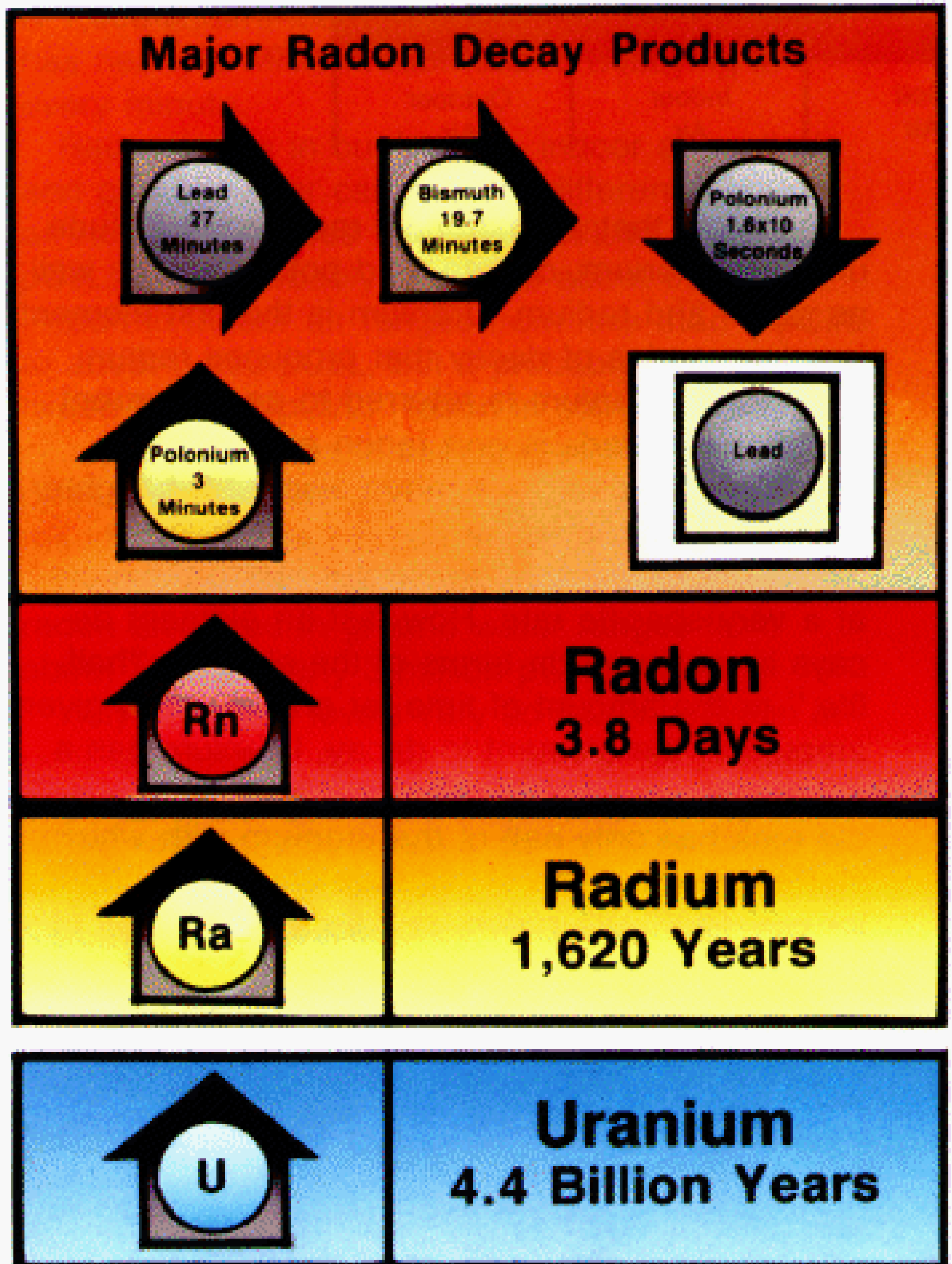


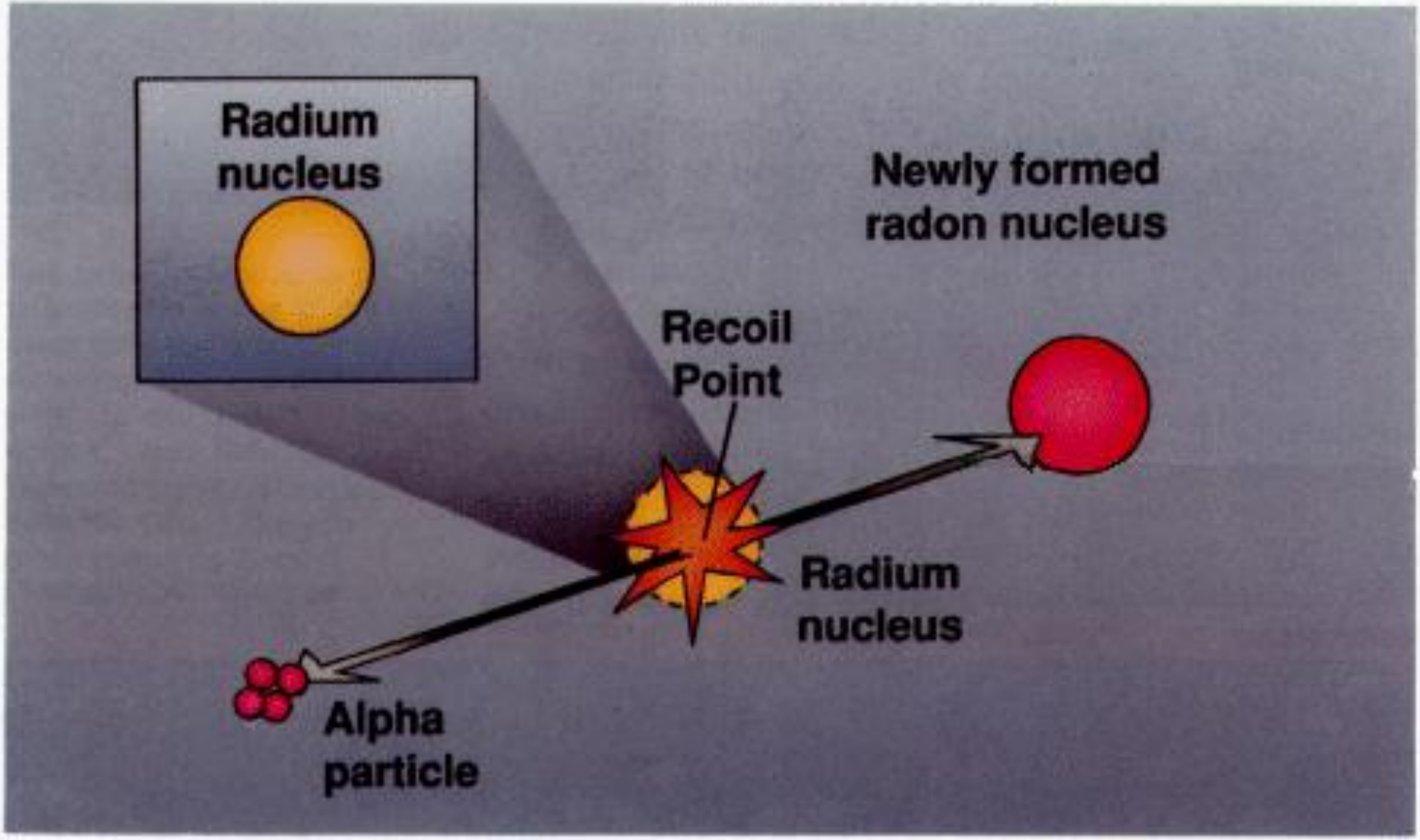
Uranium Series
Half Life
Emits
*U238
4.5 x 10^9 yr
α
Th234
24d
β
U234
250 000 yr
α
Th230
80 000 yr
α
*Ra226
1602 yr
α
*Rn222
3.8 d
α
Radon Daughters*
Po218
3.1 min
α
Pb214
26.8 min
β + γ
Bi214
19.7 min
β + γ
Po214
0.00016 sec
α
Pb210
21 yr
β
Pb206
(Stable)
Thorium Series
Half Life
Emits
*Th232
1.4 x 10^10 yr
α
Th228
1.9 yr
α
Ra224
3.64 d
α
*Rn220
56 sec
α
Po216
0.15 sec
α
Pb212
10.6 hr
β
Pb208
(Stable)
Actinium Series
Half Life
In Reactor
*Pu239
*U238
+ neutron
α
24 400 yr
*U235
7 x 10^8 yr
α + γ
Th231
25.6 hr
β
Pa231
32 500 yr
α
Ac227
21.6 yr
β
Th227
18.2 d
α + γ
Ra223
11.4 d
α + γ
Pb207
(Stable)
(NB: This figure is not intended to imply that all U-235 originates as Pu-239).

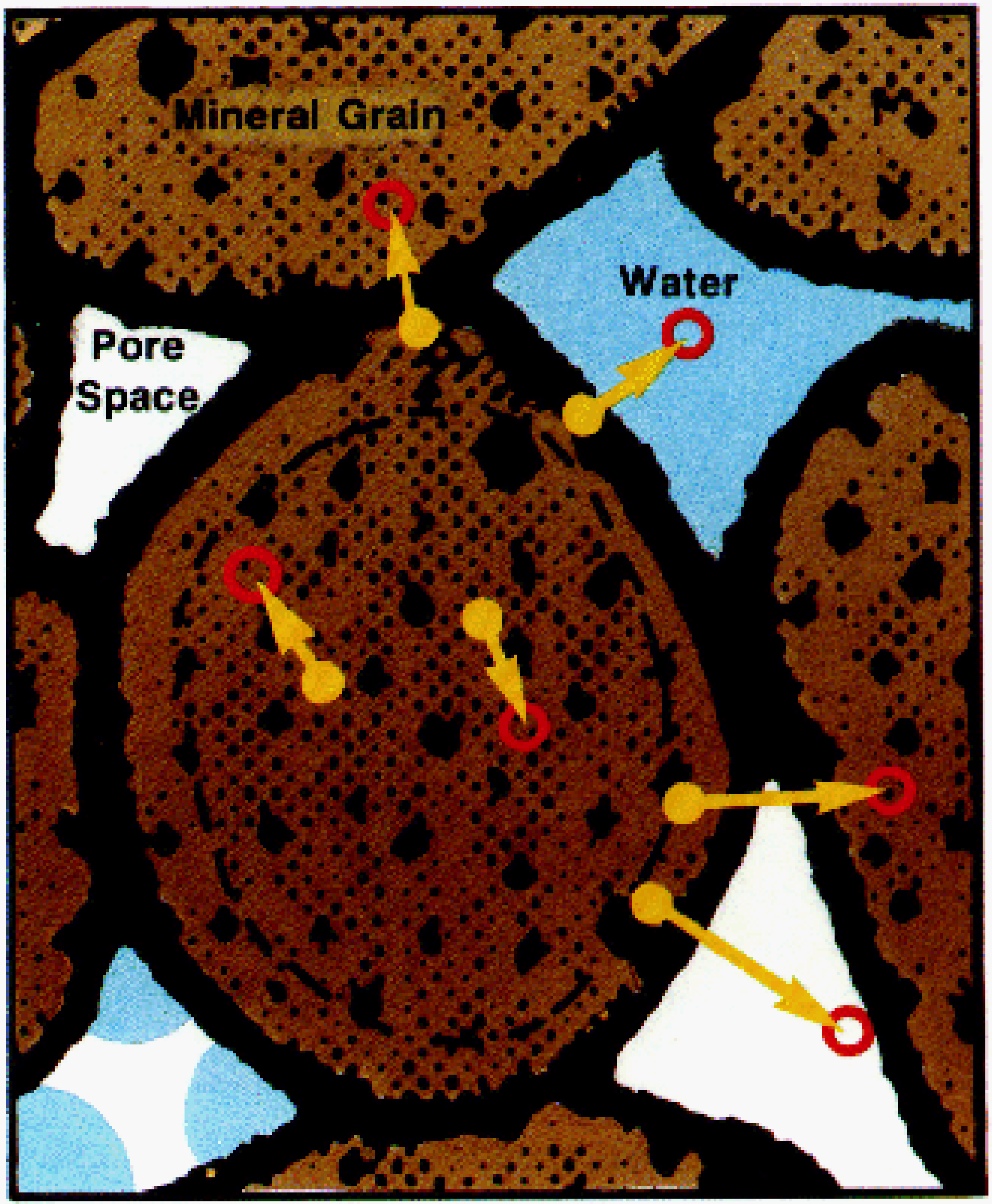
The Radon Story

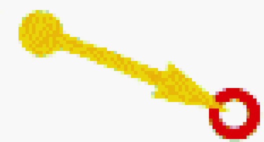
Radon-222

- Originates from U-238 which occurs naturally in most types of granite
- Radon-222 has a half-life of 3.825 days
- It decays via alpha emissions
- This isotope is a particular problem because it is a gas which can leave the surrounding rock and enter buildings with the atmospheric air


Major Radon Decay Products
Lead 27 Minutes
Bismuth 19.7 Minutes
Polonium 1.6x10 Seconds
Polonium 3 Minutes
Lead
Rn
Radon
3.8 Days
Ra
Radium
1,620 Years
U
Uranium
4.4 Billion Years

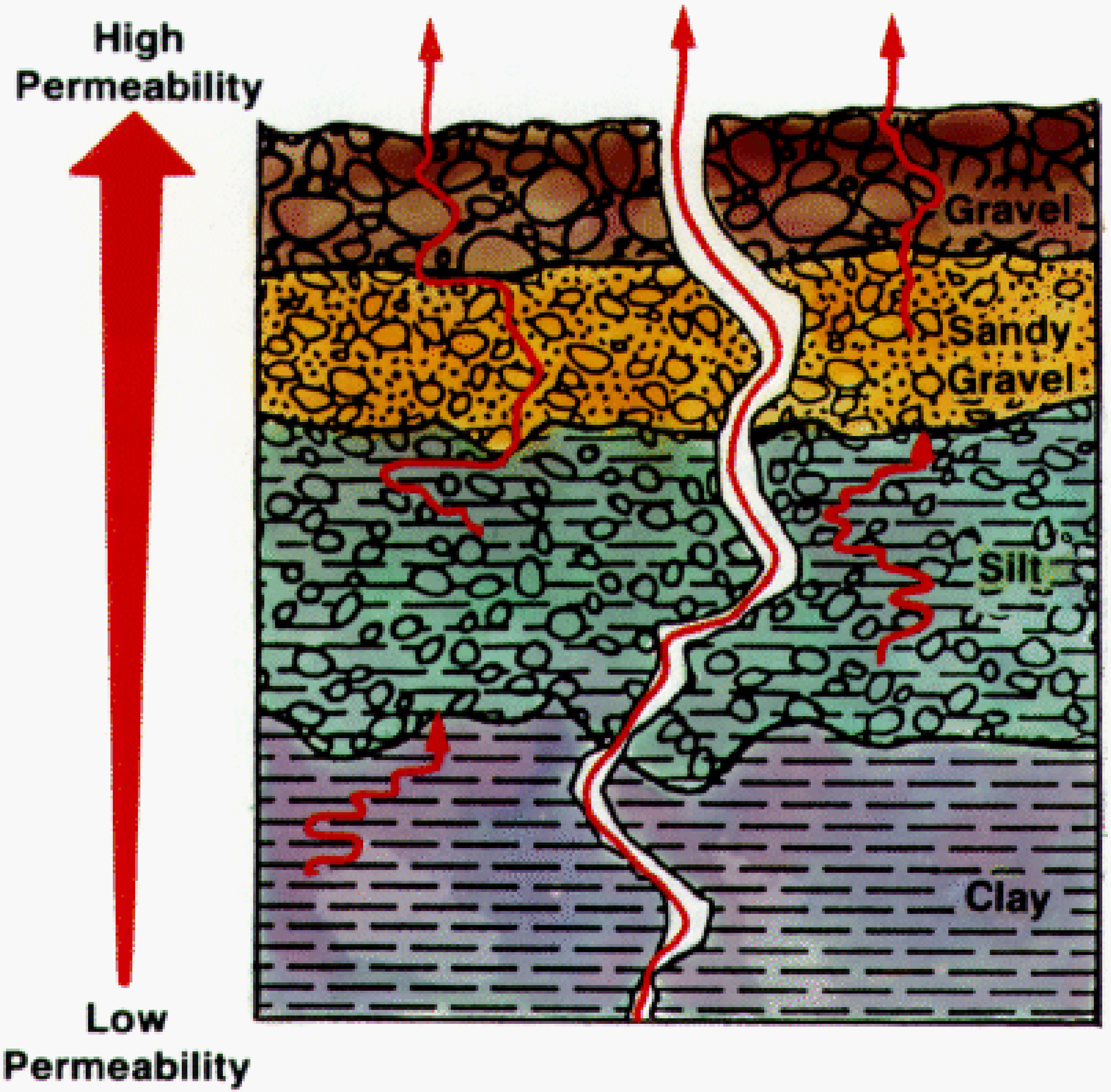

Radium nucleus
Newly formed radon nucleus
Recoil Point
Radium nucleus
Alpha particle

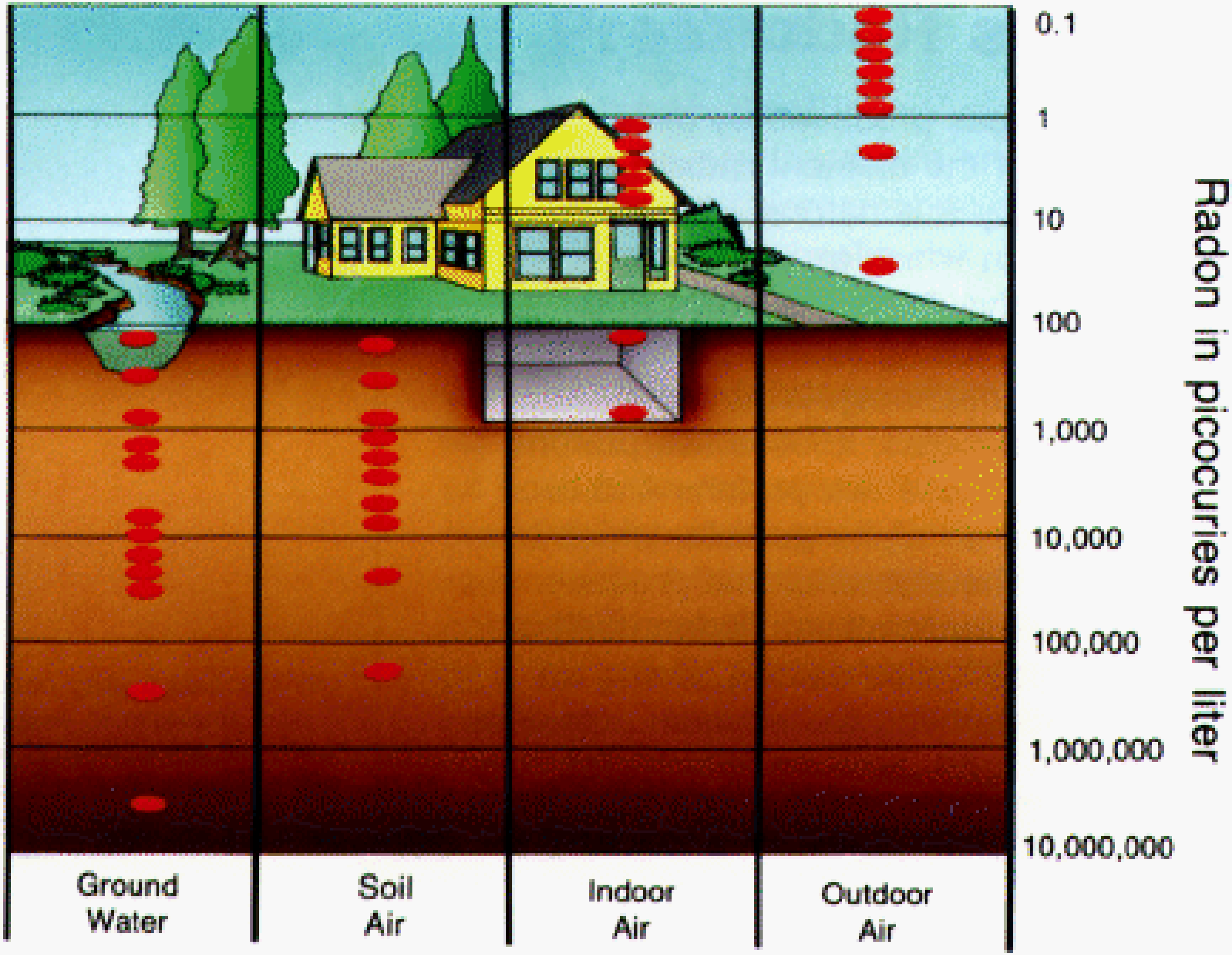


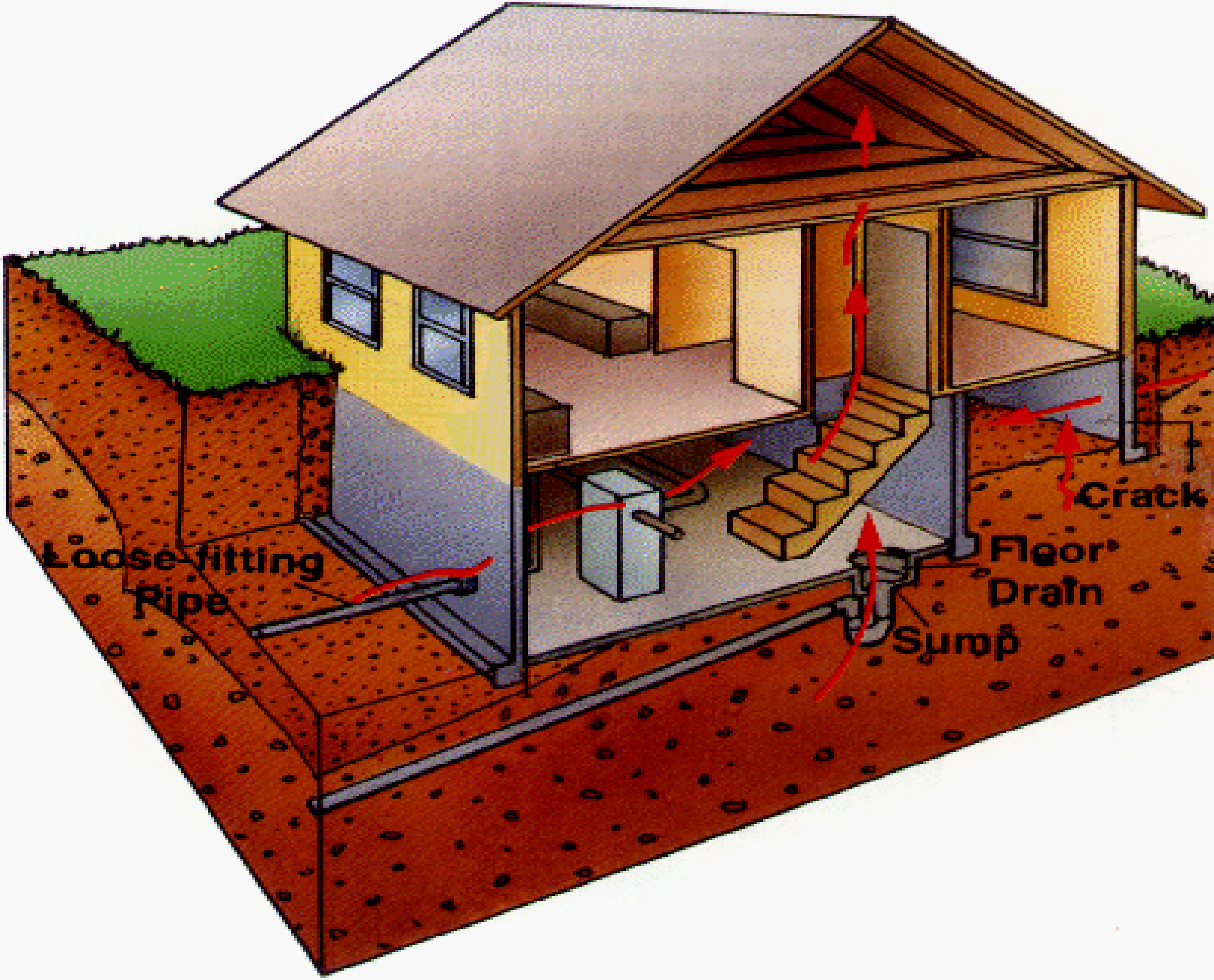


Most of the radon produced within a mineral grain remains embedded in the grain, only 10 to 50 percent escapes to enter the pore space. If water is present in the pore space, the radon atom can more easily remain in the pore space; if the pore space is dry, the radon atom may shoot across the pore and embed in another grain where it cannot move.

atom deeper into the mineral if the direction of


High
Permeability
Low
Permeability
Gravel
Sandy
Gravel
Silt
Clay


0.1
1
10
100
1,000
10,000
100,000
1,000,000
10,000,000
Radon in picocuries per liter
Ground Water
Soil Air
Indoor Air
Outdoor Air


Loose-fitting Pipe
Crack
Floor Drain
Sump