Basic Information On Ionizing Radiation

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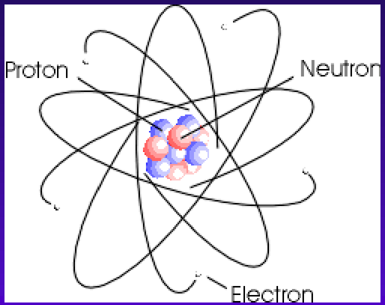
Content



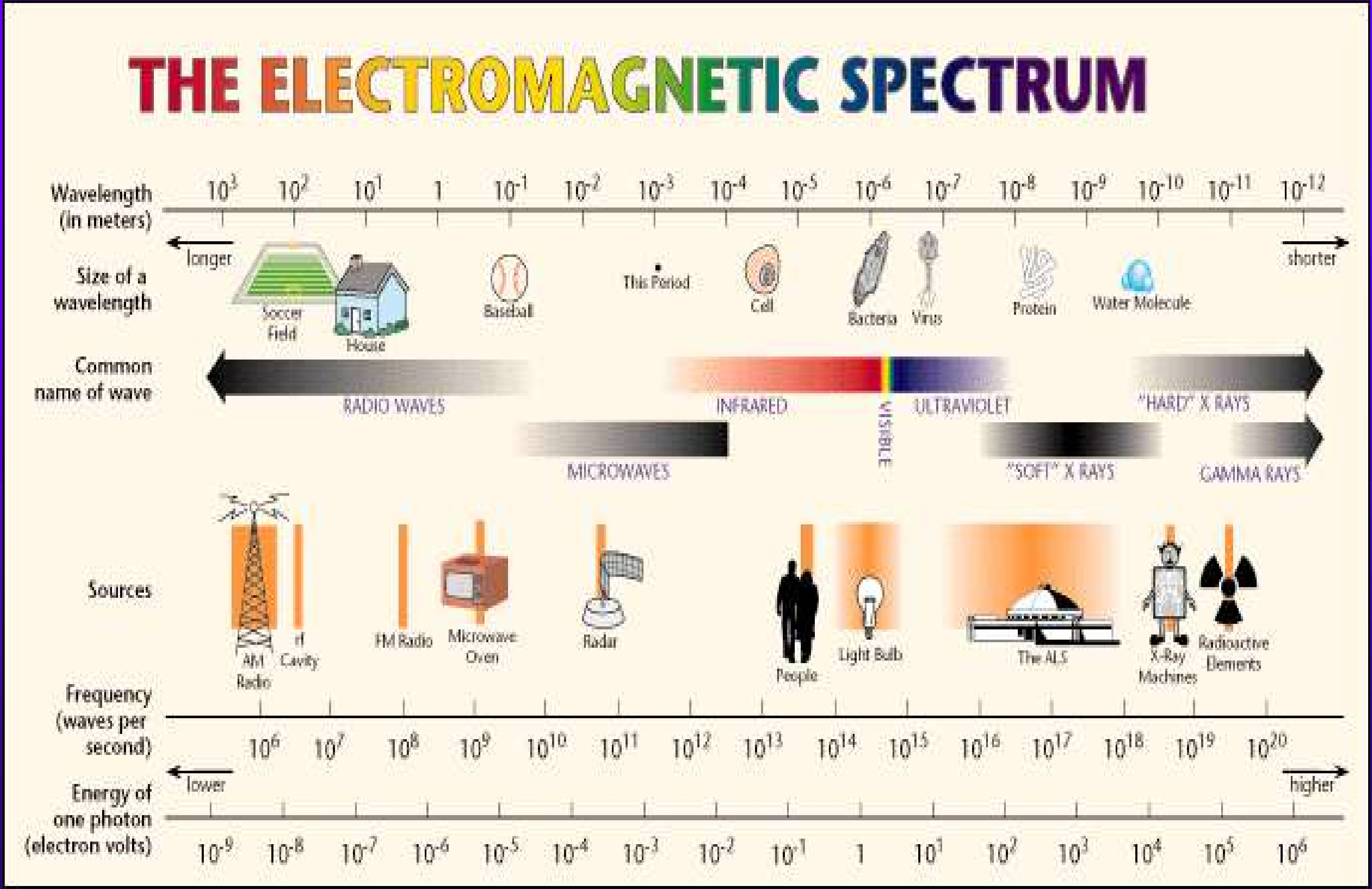
1. Concept of ionizing radiation
2. Atomic Structure
3. Origin, Nature, Properties & Sources of Ionizing Radiation
4. Radiation Units
5. Radiation in everyday life

Concept of Radiation

- Energy emitted and transmitted in the form of electromagnetic waves or particles

- Radiation
  - Ionizing
    - α β n γ x
  - non-ionizing
    - microwave, radio, visible light, IR

The characteristics of electromagnetic radiation

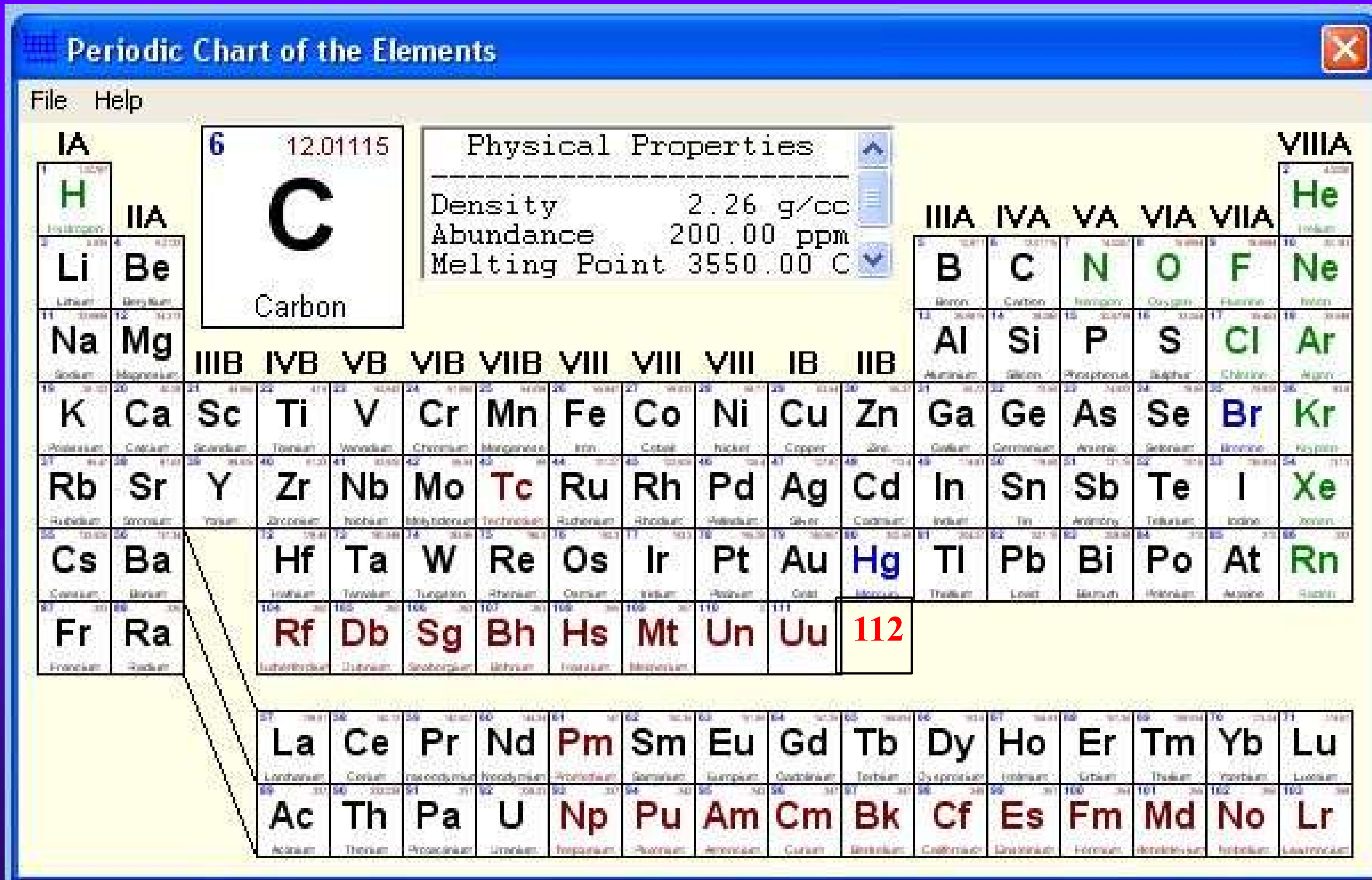


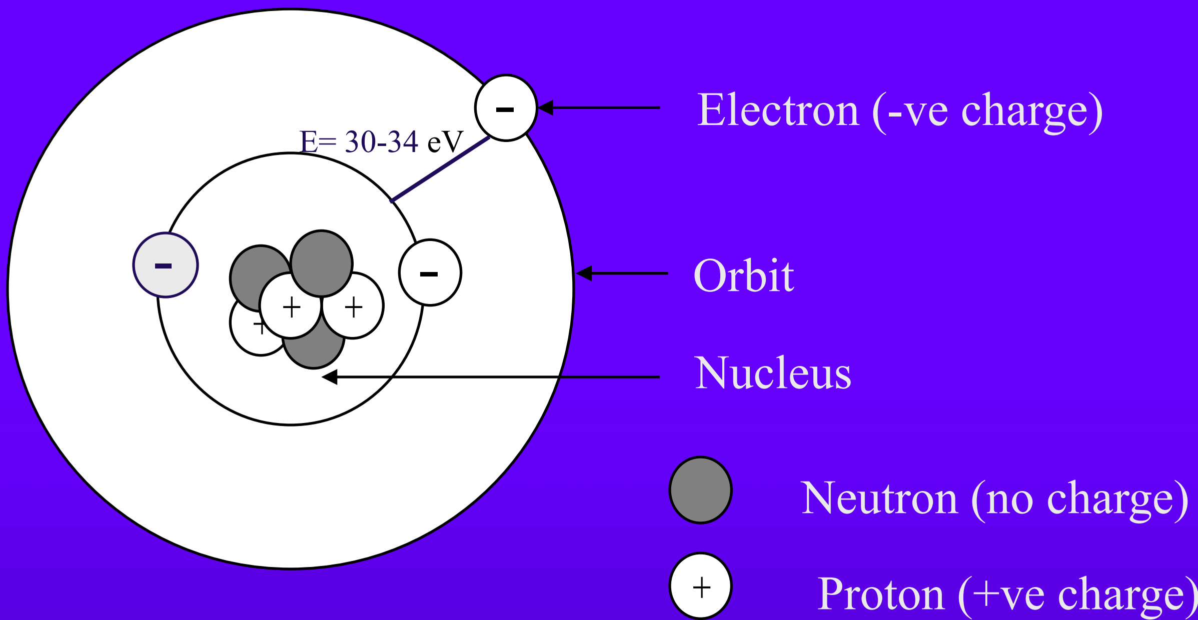
2) Atomic Structure

- Atom – a small nucleus surrounded by orbital *electrons*
- Nucleus – consist of nucleons:

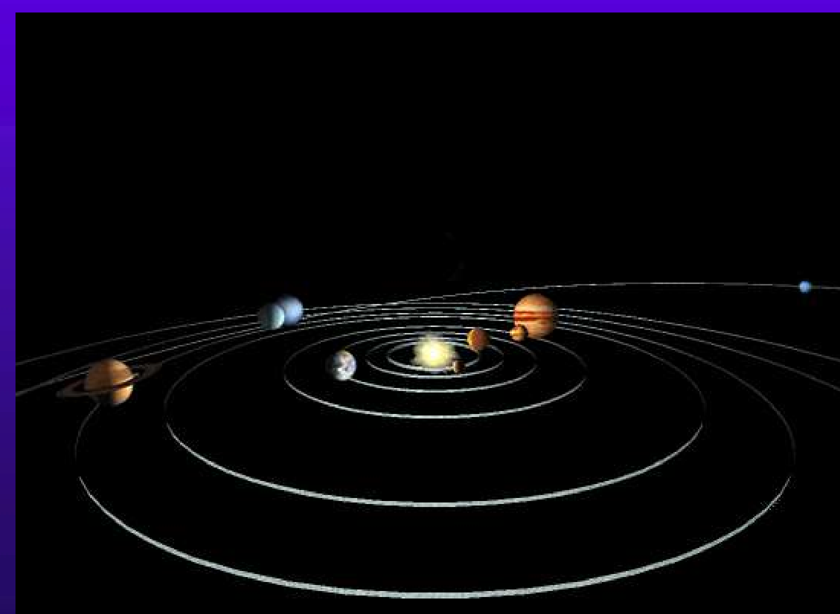
  i.e. neutrons and *protons*
- An atom is *neutral*, Number of p = Number of e = **Z** (*atomic number)*
- Number of n and p = **A** (*mass number*)
- Number of n in an atom = A-Z

Periodic Table





Structure of Li-6 Atom



Atomic Structure

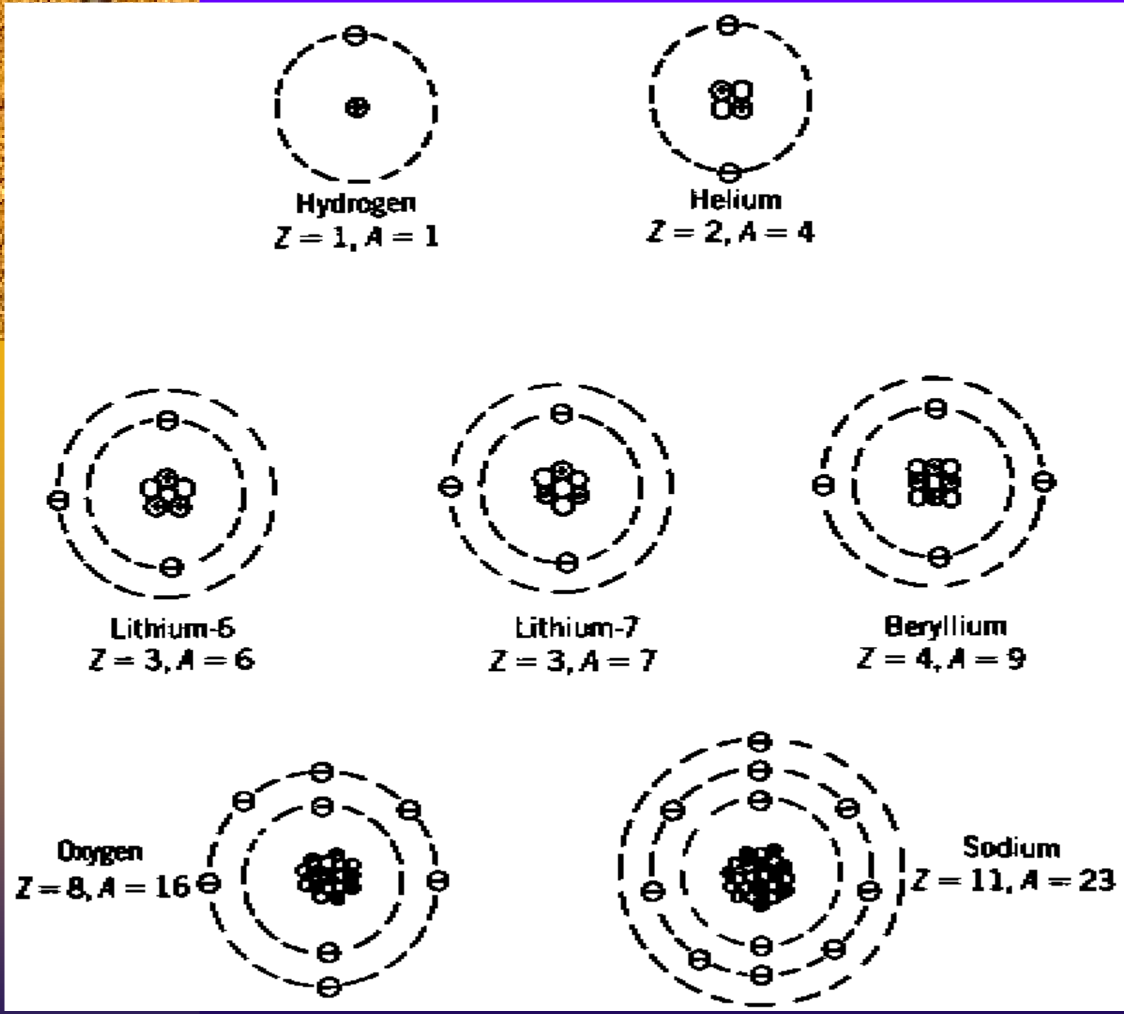
- *Nuclide* - a specific species of an element with a specific no. of neutrons & protons
- Representation of nuclide X:

  ${}^{A}_{Z}X$ or ${}^{A}X$ or X-A

  [e.g. ${}^{7}_{3}Li$ or ${}^{7}Li$ or lithium-7(Li-7)]

  ${}^{7}_{3}Li$ has 3 protons (p) and 3 electrons (e), 4 neutrons (n)

Atomic Structure



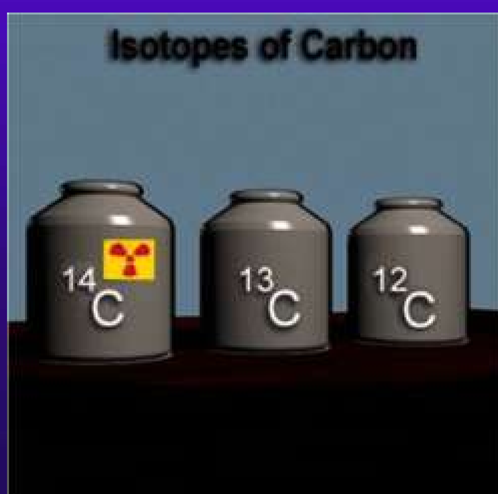
- ◯ neutron
- ⊖ electron
- ⊕ proton

Nuclide	Z	A	e	p	n
Hydrogen	1	1			
Helium	2	4			
Lithium-6	3	6			
Lithium-7	3	7			
Beryllium	4	9			
Oxygen	8	16			
Sodium	11	23			

Isotopes

- *Isotope* - Nuclides of an element with same Z (# of p) but different A. Have very *similar chemical* but may have very *different nuclear* properties.
- Isotopes of carbon: C-12, C-13, C-14
- Unstable isotope → radioisotope

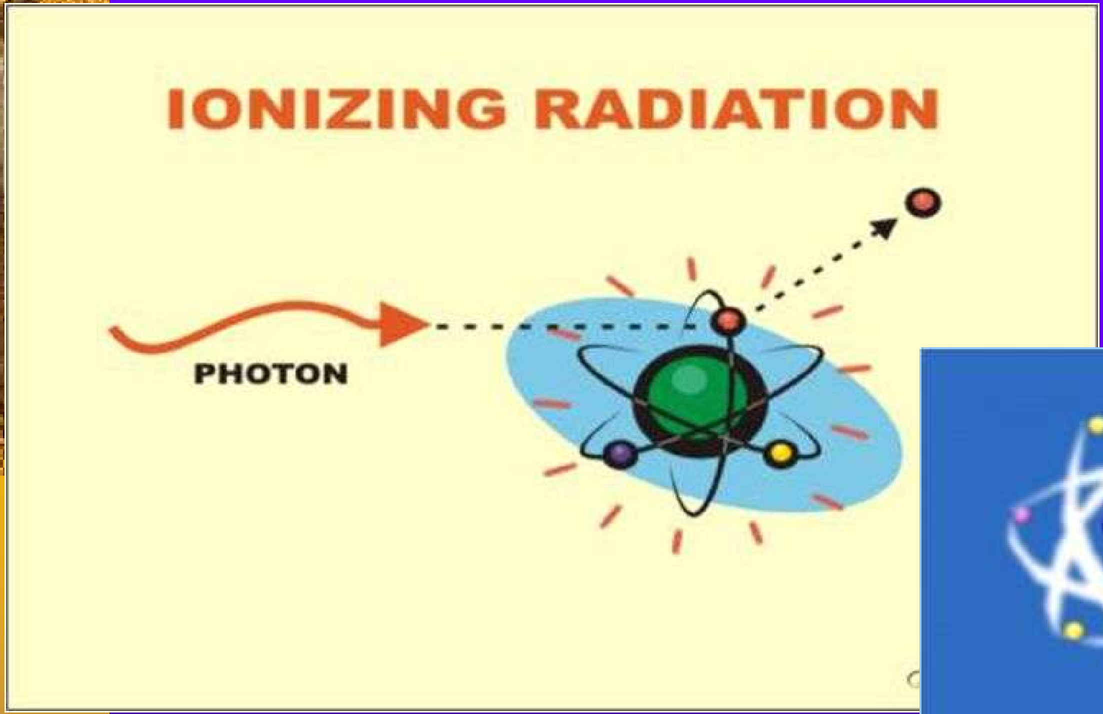
(emit ionizing radiation)

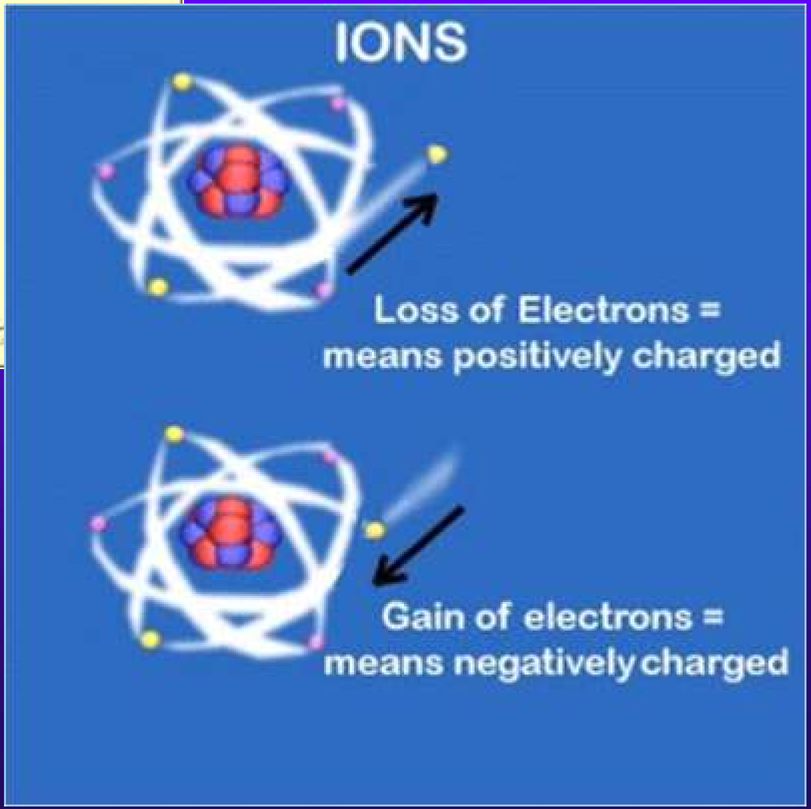


Ionization

- Removal of e^- from atom (normally outer orbit); Atom – positive ion
- Free e^- capture by other atom – negative ion
- Ionizing radiation – radiation that carry sufficient energy to cause ionization when pass through matter
- Such ionization process when taking place in human body may cause damage to tissue and organs

Ionization


IONIZING RADIATION
PHOTON


IONS
Loss of Electrons =
means positively charged
Gain of electrons =
means negatively charged

Radioactivity

- Radioactive is a phenomenon whereby an unstable nucleus emits ionizing radiation to achieve stability through a process known as decay.
- Emit ionising radiation (alpha, beta, gamma, etc.)

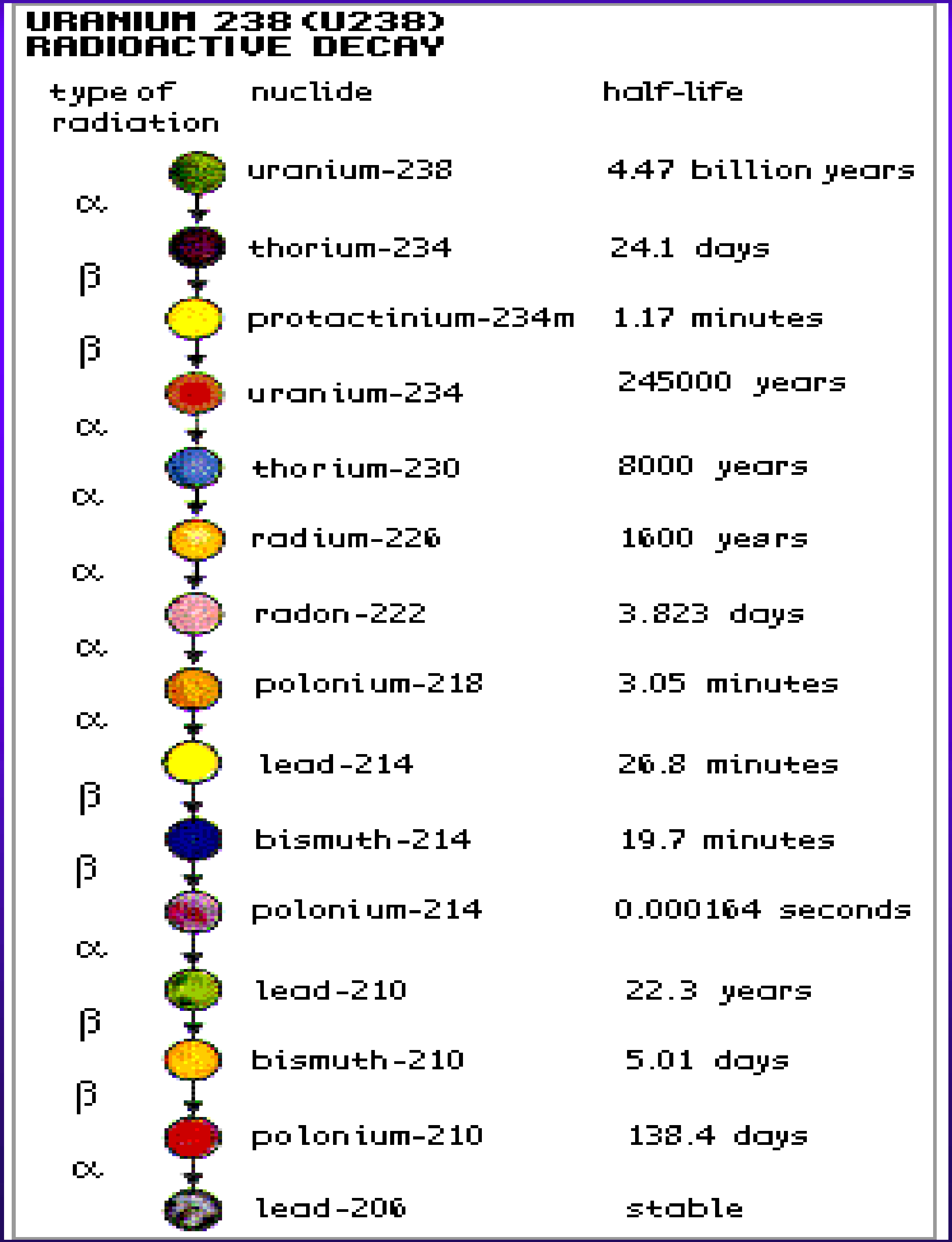
e.g. $^{64}_{25}Cu \rightarrow {}^{64}_{24}Fe + {}^{0}_{-1}\beta$

$^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He + \gamma$

- Activity - Disintegration rate

  S.I. Units: *Becquerel* (Bq), 1 Bq = 1 dps (s^{-1})

  old units: *Curie* (Ci), 1 Ci=3.7 x 10^{10} Bq
- Specific activity - activity per unit mass (Bq/g)


URANIUM 238 (U238)
RADIOACTIVE DECAY
type of radiation
nuclide
half-life
uranium-238
4.47 billion years
α
thorium-234
24.1 days
β
protactinium-234m
1.17 minutes
β
uranium-234
245000 years
α
thorium-230
8000 years
α
radium-226
1600 years
α
radon-222
3.823 days
α
polonium-218
3.05 minutes
α
lead-214
26.8 minutes
β
bismuth-214
19.7 minutes
β
polonium-214
0.000164 seconds
α
lead-210
22.3 years
β
bismuth-210
5.01 days
β
polonium-210
138.4 days
α
lead-206
stable

Half Life

- Time for activity to reduce by half
- Ranges from very short to very long

  e.g. U-235 (7.13×10^8 y), N-16 (7.13 s)

$A_t = A_0/2^n$; $n = t/T_{1/2}$; n = no. of half-lives

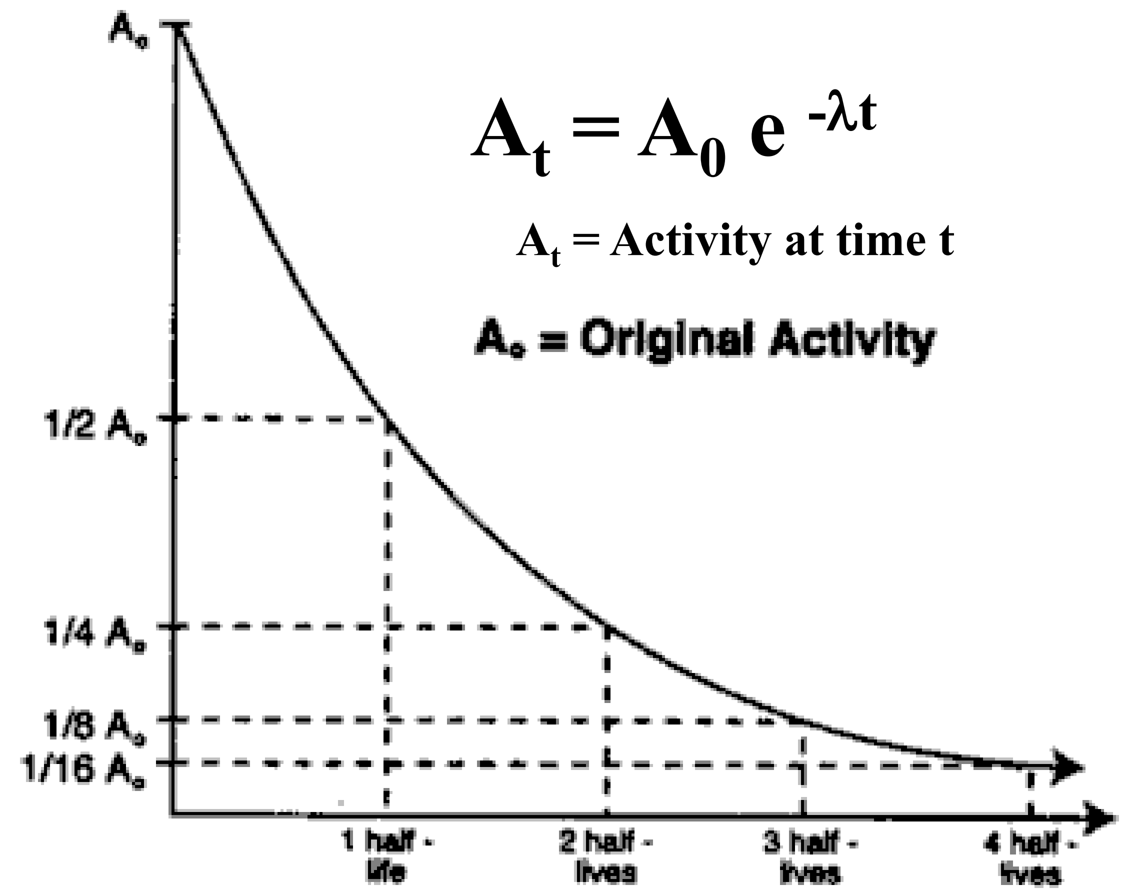
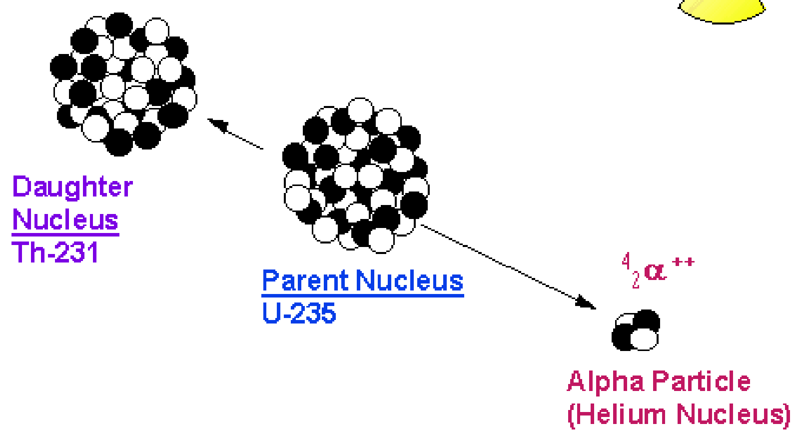


Figure 2-X. Radioactive Decay Plotted in Linear Form

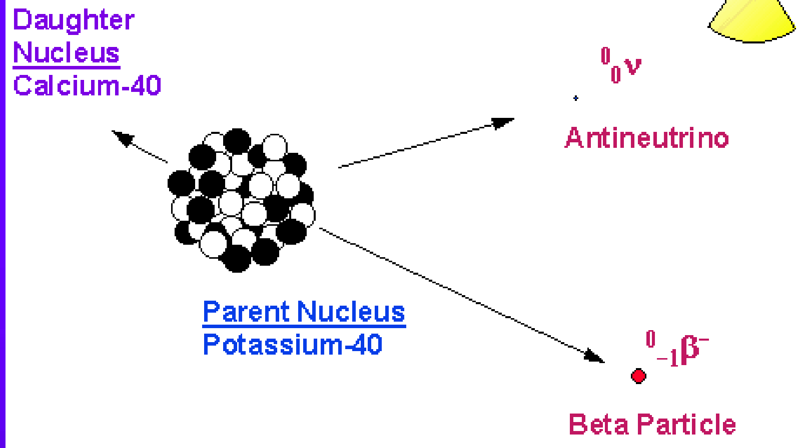
where λ (decay constant) = $\ln(2)/T_{1/2} \cong 0.6931/T_{1/2}$;

3) Origin, nature, properties & source of ionizing radiation

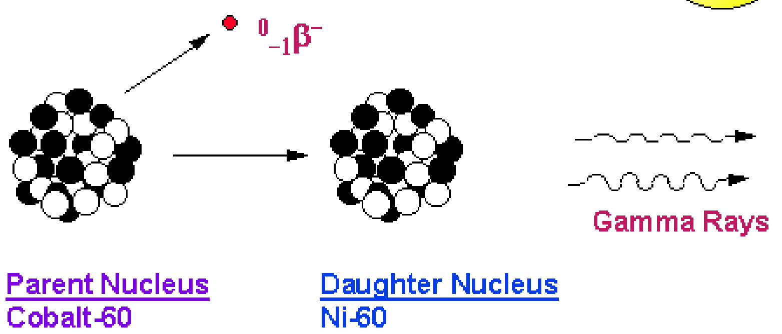
Alpha Particle Radiation



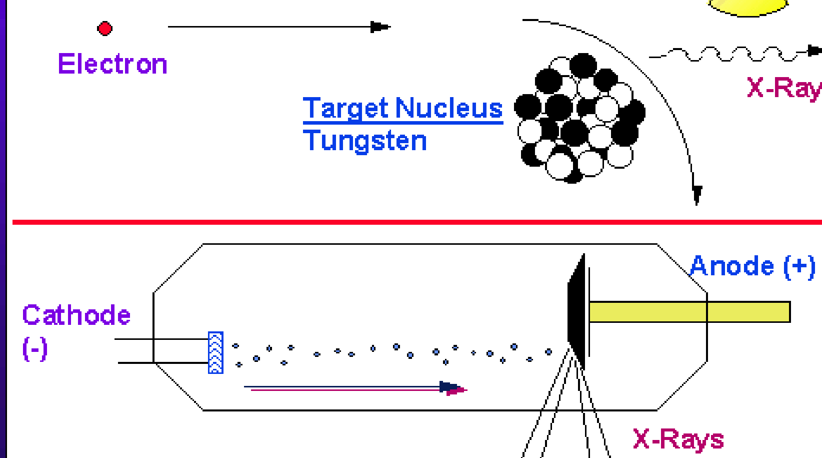
Beta Particle Radiation



Gamma-Ray Radiation

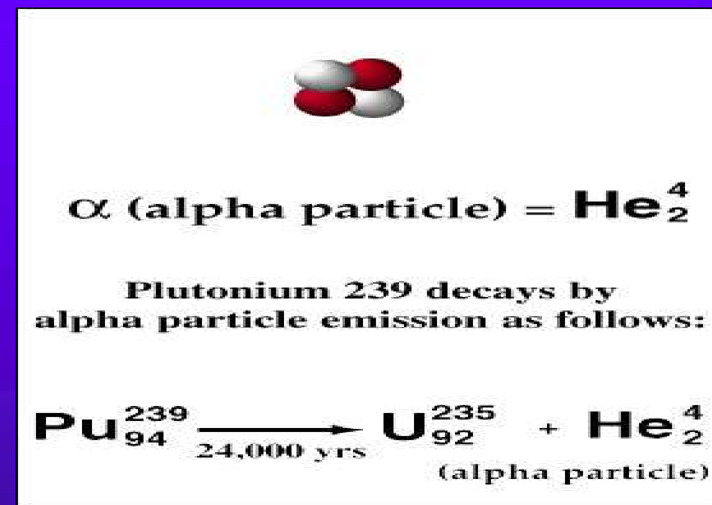


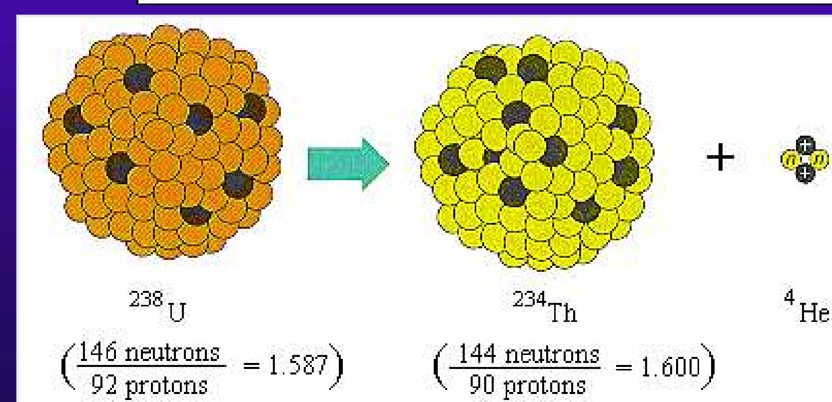
X-Ray Production (Bremsstrahlung)



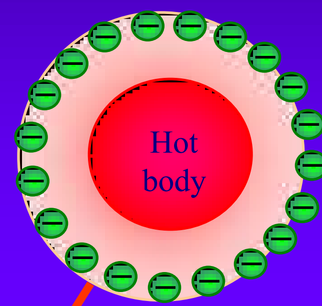
Alpha (α) Particles

- Helium nucleus (He^{2+}), high E (> 4 MeV)
- Short range (high mass and charge) - few cm in air
- Not an external hazard but an important internal hazard
- α emitters: ^{226}Ra, ^{241}Am, ^{239}Pu

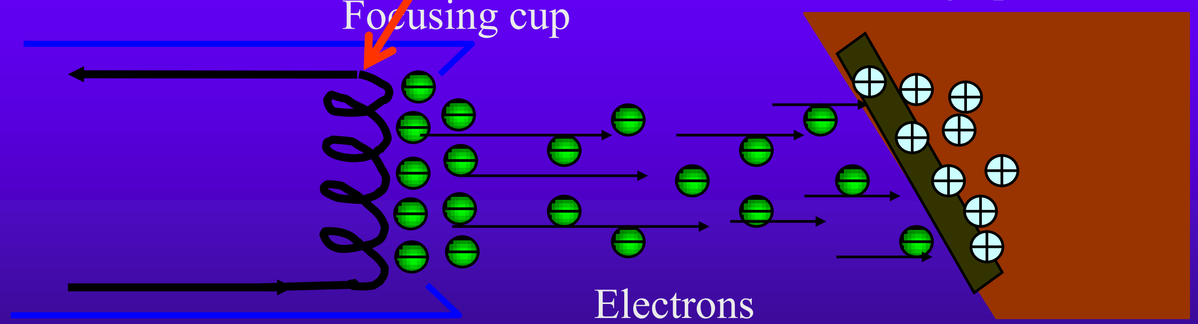




X-ray



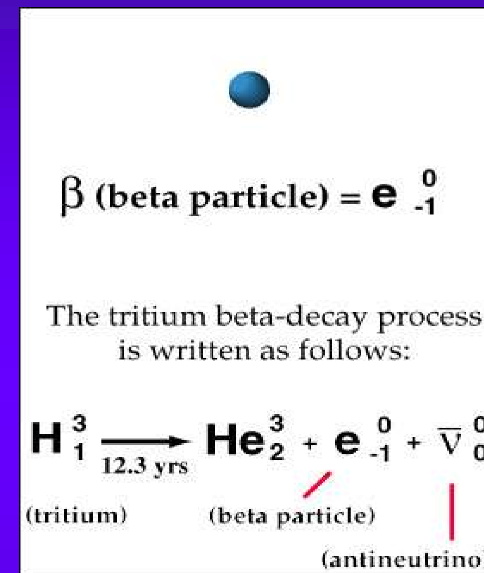
Electrons cloud around a heated filament



Electron bombardment at target material (usually tungsten)

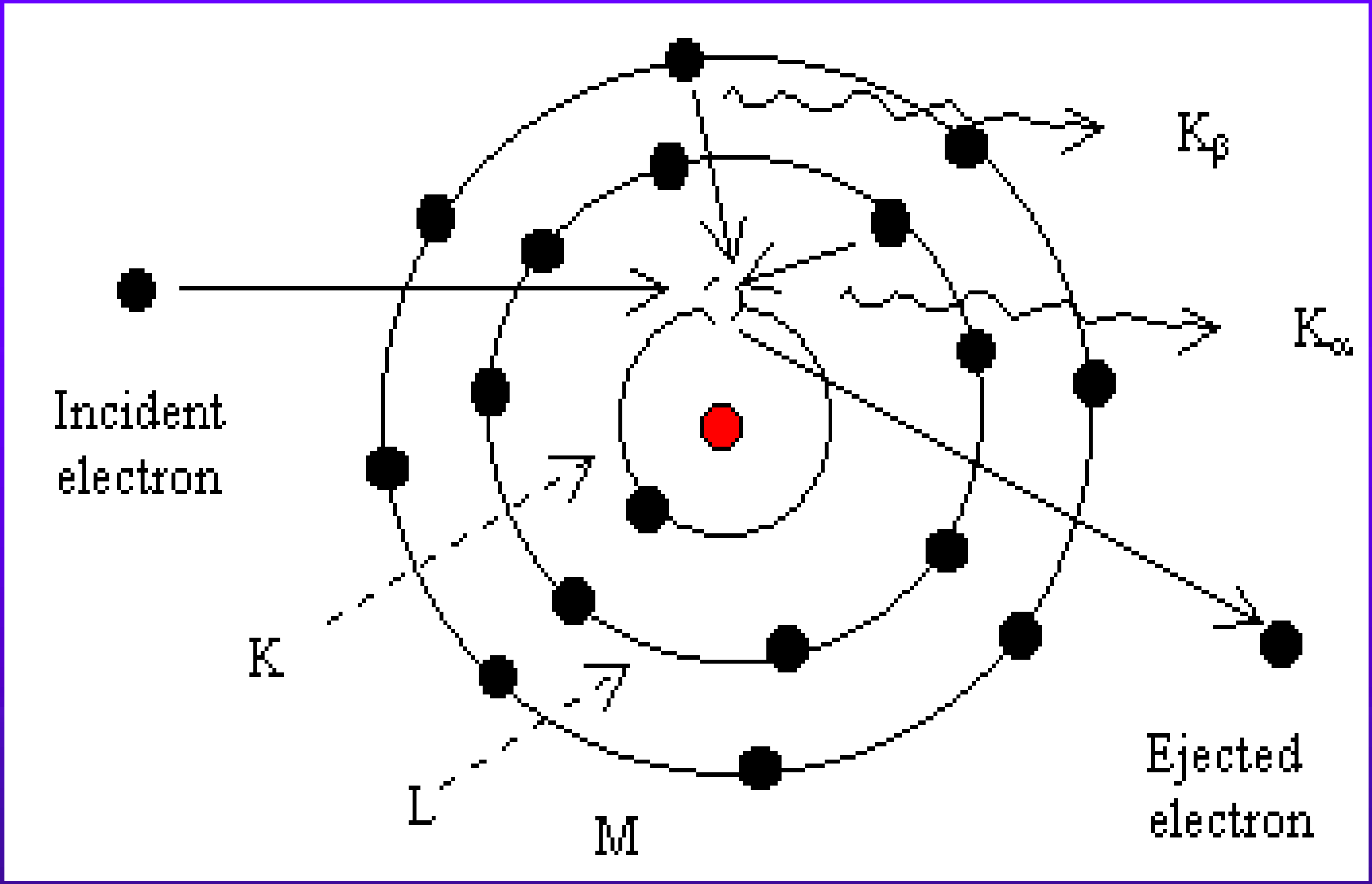
Beta (β^-) Particles & Positrons (β^+)

- β^- (negatron, e^-), positron (e^+, β^+), emitted when nuclides decay
- Cause ionisations and excitations in matter, accompanied by x rays (Bremsstrahlung - increasing with Z)
- An external hazard if E > 70 keV (penetrates dead skin layer).
- An internal hazard although not as harmful as alpha
- Pure β emitters: ^{3}H, ^{14}C, ^{90}Sr

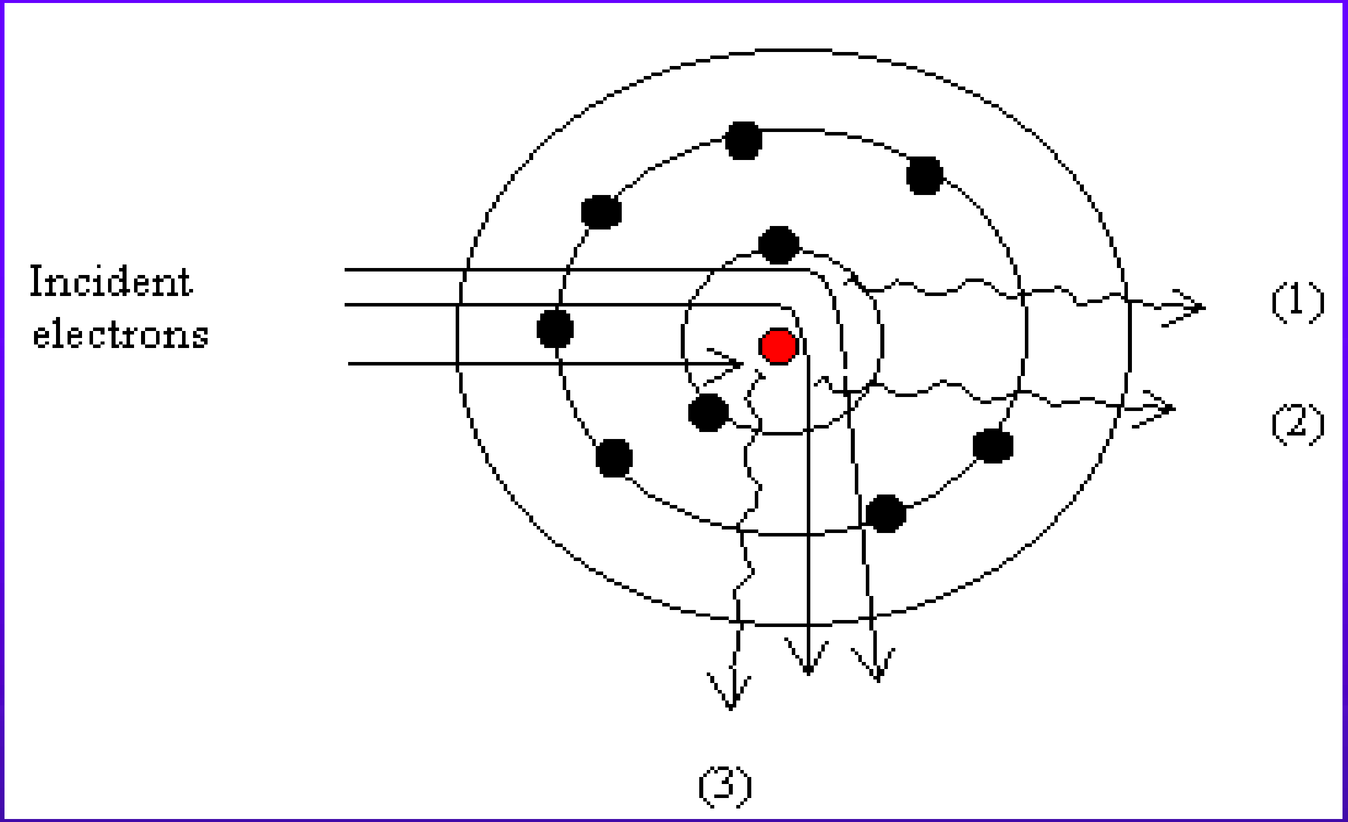


X- and gamma Rays

- E.M. radiation (photons), x rays originate from orbits, γ from excited nucleus; normally γ rays have higher E than x rays
- Characteristic x rays - de-excitation or transition of electrons in orbits of atoms
- Bremsstrahlung x rays - braking radiation, increase with Z
- In an x-ray machine, energy depends on voltage and the number of photons produced depends on current

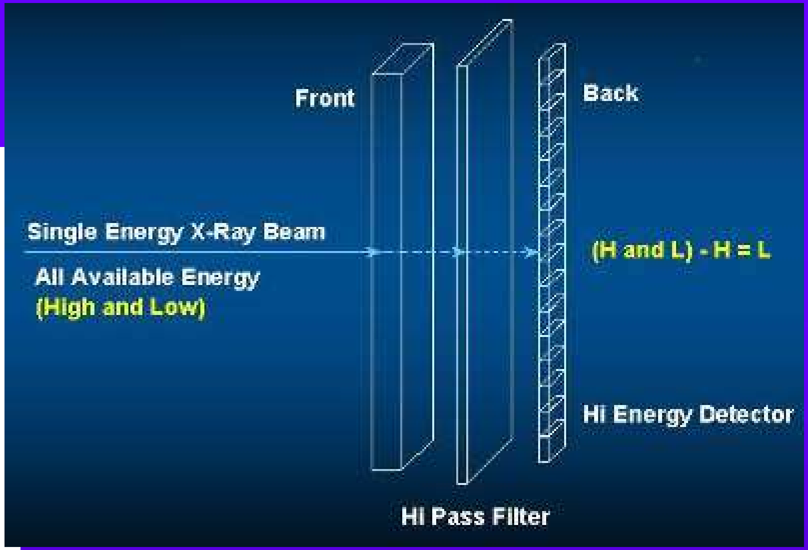


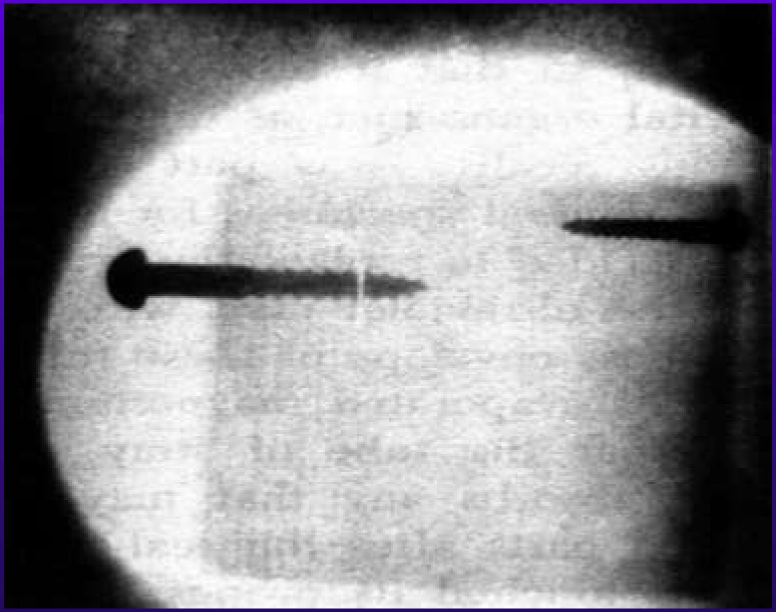
Production of characteristic x rays



Production of *bremsstrahlung* x rays: (1) Interaction at large distance from the nucleus produces low energy x ray, (2) interaction at intermediate distance from the nucleus produces intermediate energy x ray, and (3) direct collision with nucleus produces maximum energy x ray.

X-ray machine in electronic industry & airport





Neutrons

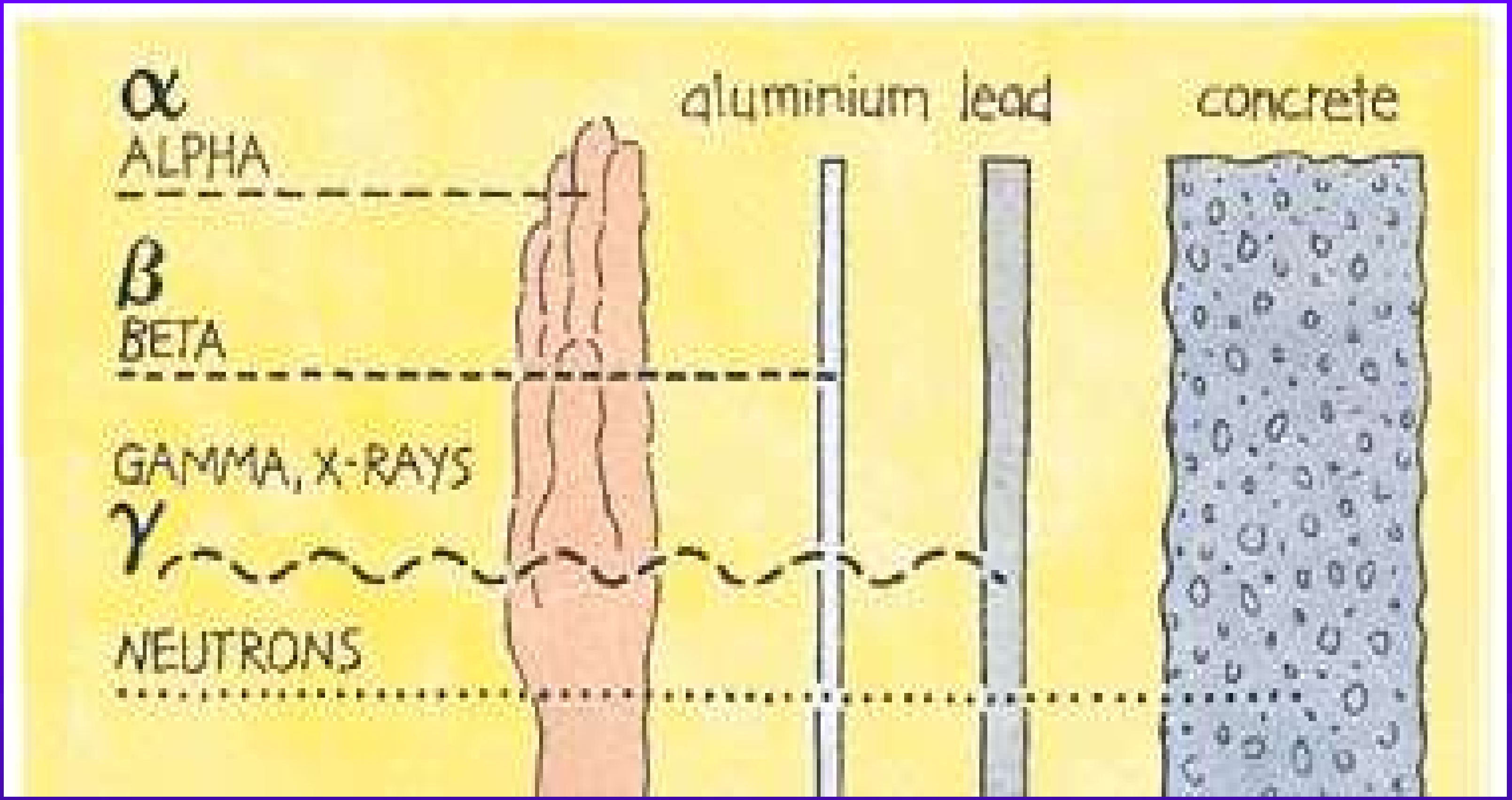
- Produced by nuclear fission etc
- Classify according to energy:
  - *Slow* or *thermal* (E ≤ 0.025 eV)
  - *Resonance* or *intermediate* (0.5 eV to about 100 keV)
  - *Fast* (≅ 100 keV to 10 MeV)
  - *Relativistic* (E > 10 MeV)
- Produce recoil nucleus that causes secondary ionizations (indirect)
- Neutron - long range, external hazard, much more damaging than γ

Production of neutron

- Spontaneous fission:, ^{244} Np & ^{252} Cf
- Induced nuclear fission:

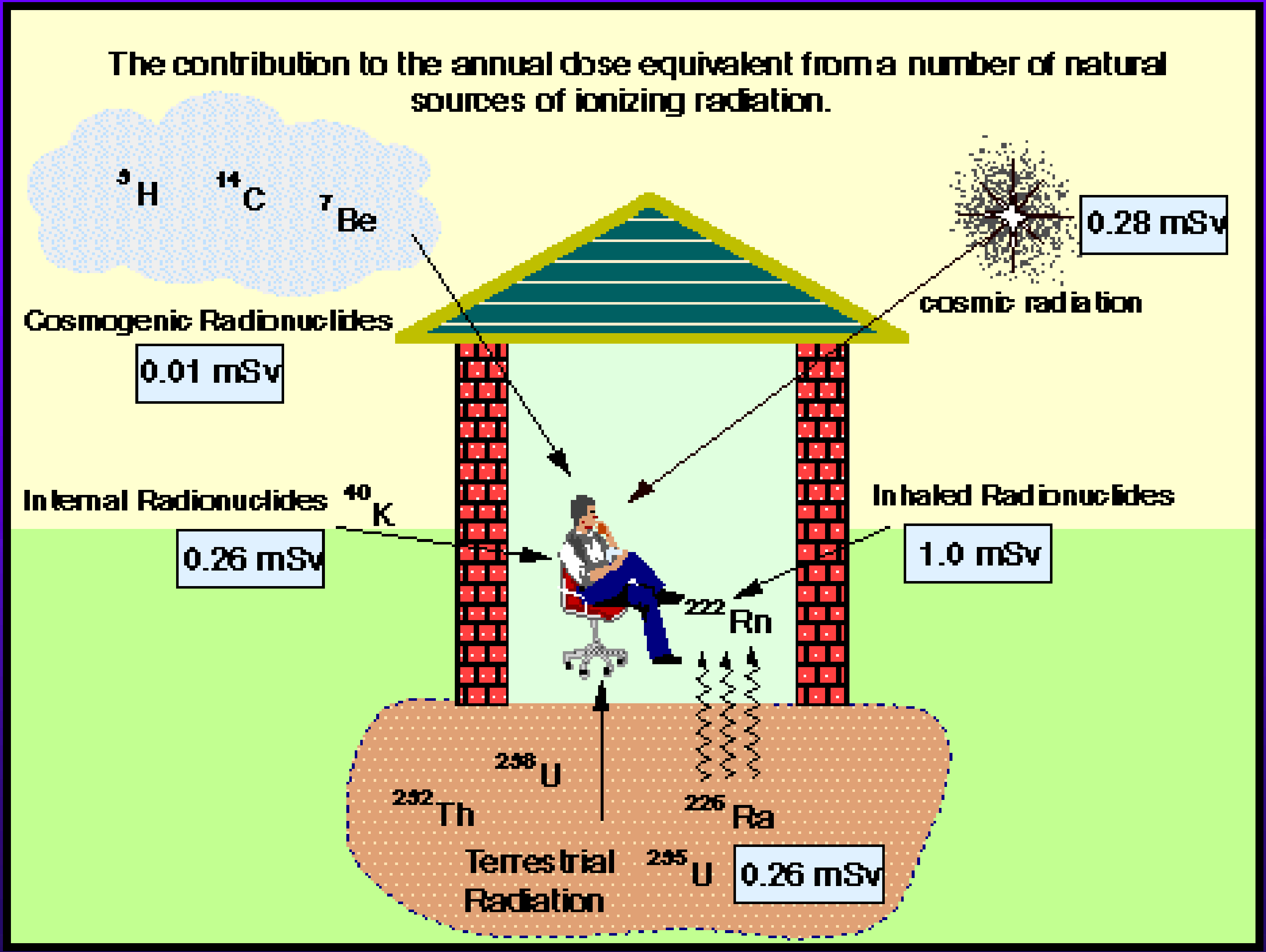
$$ {}^{1}_{0}n + {}^{235}_{92}U \longrightarrow {}^{148}_{55}Cs + {}^{93}_{37}Rb + 3\ {}^{1}_{0}n + 200\ \text{MeV} $$

- Machine generated neutron: ^{241} Am /^{7}Be
- Controlled nuclear fission : chain reaction in induced nuclear fission is controlled by graphite moderator & boron/cadmium control rod. Ratio of fission neutron produced is slightly more than 1
- Nuclear bomb : Naturally occurring uranium is 99% $^{238}_{92}$ U & 0.7% $^{235}_{92}$ U. In order to produce explosion requires the critical mass of > 70 kg (critical mass of $^{235}_{92}$ U = 70 kg)



Penetrating power of ionizing radiation

Radiation in everyday life



Natural Radiation

- Extraterrestrial - Primary cosmic rays (outer space), secondary cosmic rays (interactions between primary cosmic rays and atmosphere)
- Produce cosmogenic radioisotopes : ^{14}C, ^{3}H
- Cosmic ray dose increases with latitude (influence of magnetic field, strongest at the poles)
- Also increases with altitude (less shielding by atmosphere), Dose approx. doubled for every 1500 m up to a few km above the earth. Global yearly avg. ≈ 0.4 mSv (Radiation Safety, 96-00725 IAEA/PI/A47E, 1996)

Natural Radiation

- Terrestrial - from radionuclides in soil, rocks, atmosphere, food chain, etc.
- U-238, U-235, Th-232, K-40, Rb-87
- Three main natural decay series: Th-232, U-235, and U-238
- Each of the 3 decay series produces a radioactive gas (e.g. Rn-222 from U-238 decay series)

Natural Radiation

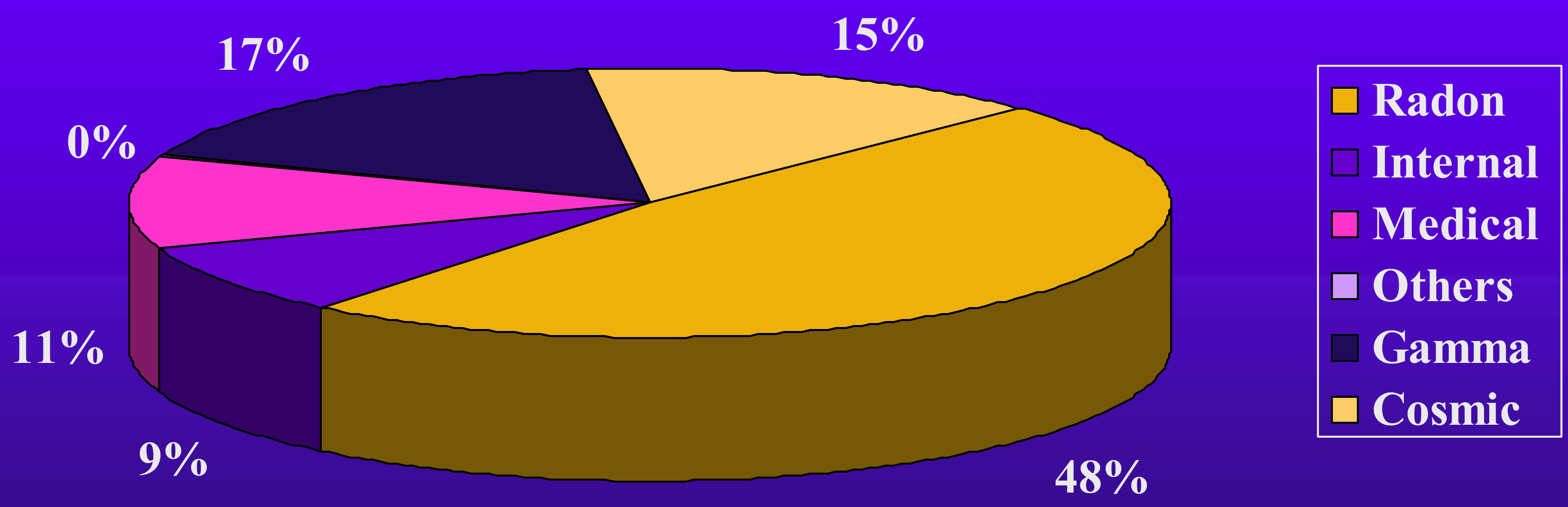
- World average ≅ 2.7 mSv/yr, whole body, from all sources
- Certain areas in India and Brazil ≅ 13 mSv/y and even ≥ 50 mSv/y. Areas with high background radiation: Kerala and Madras states in India, coastal areas of Brazil, Niue Island in the Pacific
- No significant higher rates of cancer and genetic disorder are observed even at places with much higher than normal background

Man-Made Radiation

- Medical X ray (0.1 mSv per chest x ray), nuclear medicine (diagnostic and therapeutic) [0.3 mSv/y]
- Nuclear weapon test - radioactive fall-out [6 μSv/y]
- Nuclear power [8 μSv/y to the public], industries [process control, QC]
- Consumer products: smoke detectors, luminous watches, gas mantles, TV. [very low]

Avg. Yearly Global Radiation Dose

(Source: UNSCEAR, 2.7 mSv total)



Avg. Yearly Global Radiation Dose

- 88.5% of annual dose is attributed to natural radiation (cosmic rays, gamma rays from rock and soil, radon, and internal dose from food and drink).
- 11% of annual dose is attributed to medical purposes

Thank You