SEMINAR ON RADIATION PROTECTION

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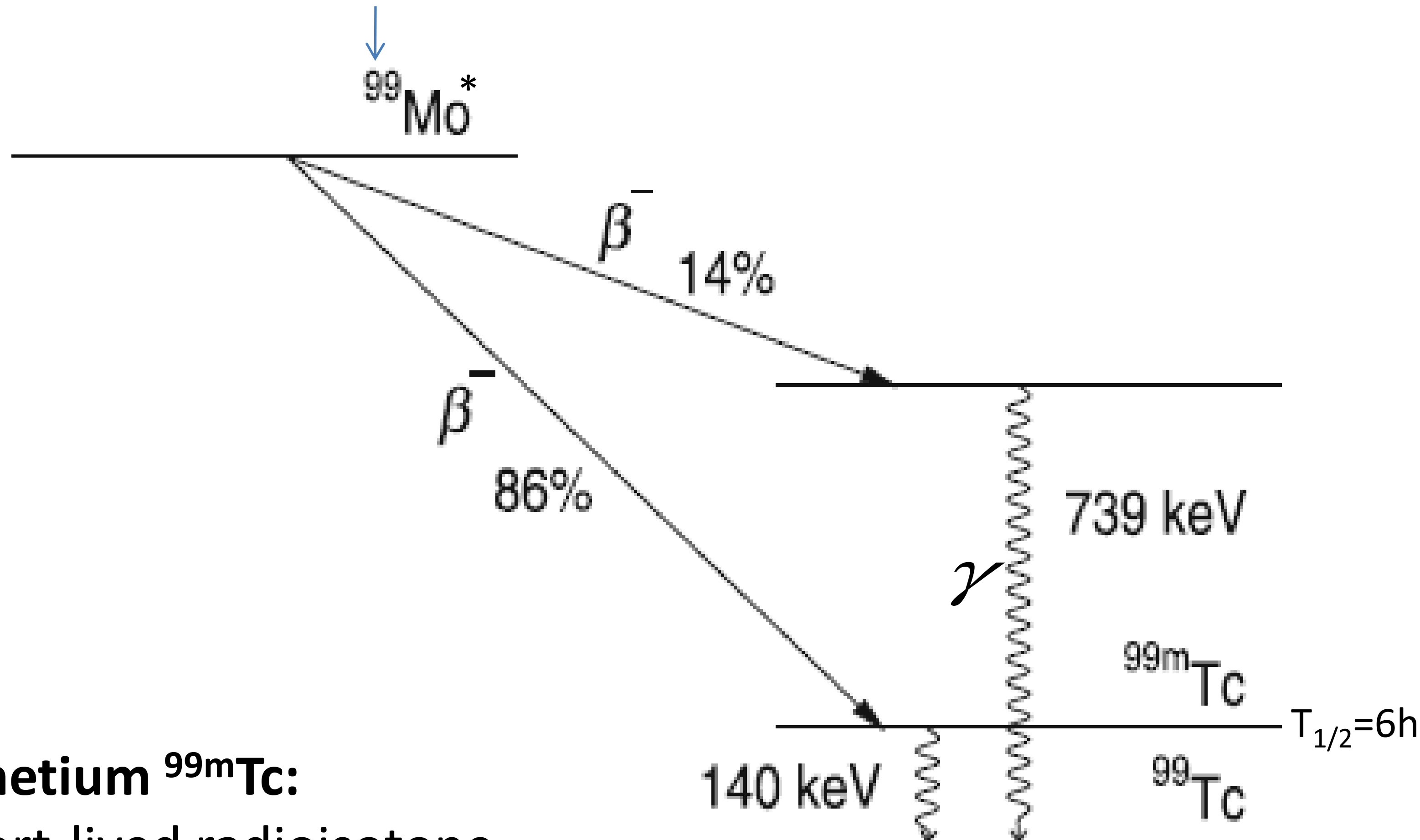
❖ Definitions.

- **Radiation** is an energy in the form of electro-magnetic waves or particulate matter, traveling in space or in material.
- Radiation is emitted from unstable atoms
- **Unstable atoms** differ from stable atoms because they have an excess of energy or mass or both.
- Unstable atoms are said to be radioactive. In order to reach stability, these atoms give off, or emit, the excess energy or mass. These emissions are called radiation

❖ Example

Neutron activation
^{98}Mo to

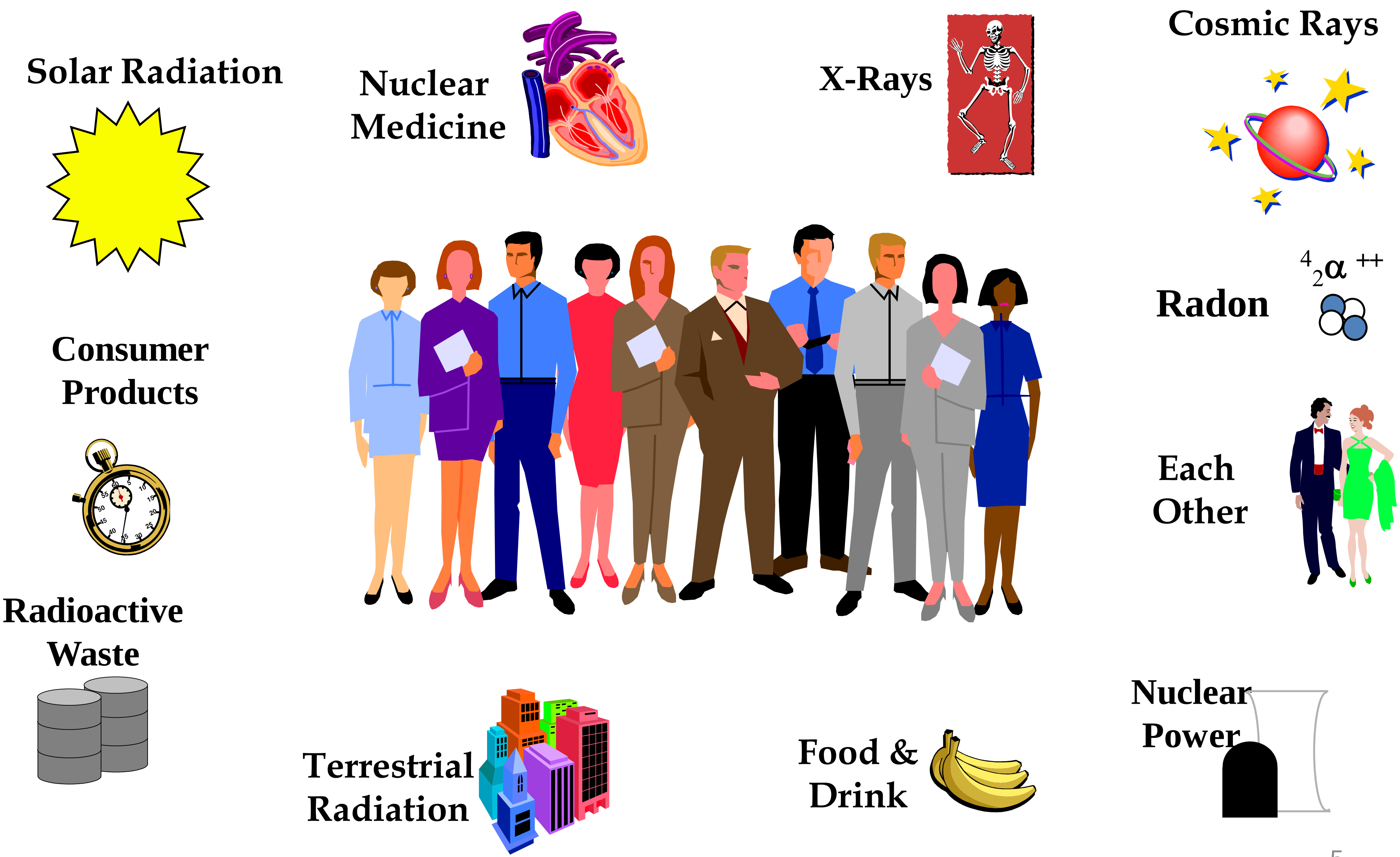


Technetium ^{99m}Tc:

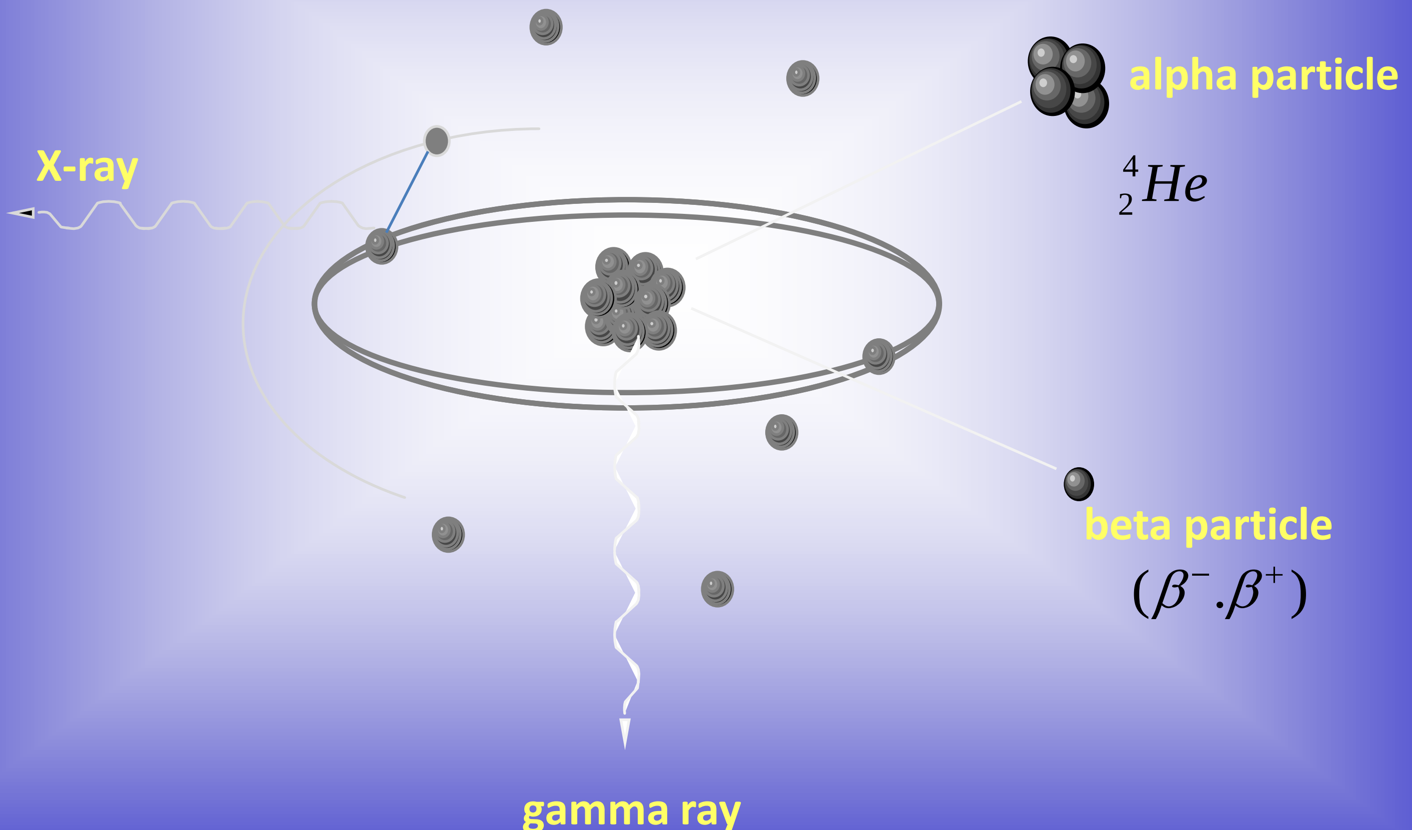
✓ short-lived radioisotope

✓ preferred in the field of radiotherapy instead of ^{131}**I** ($T_{1/2}$=8d)

❖Sources of radiation

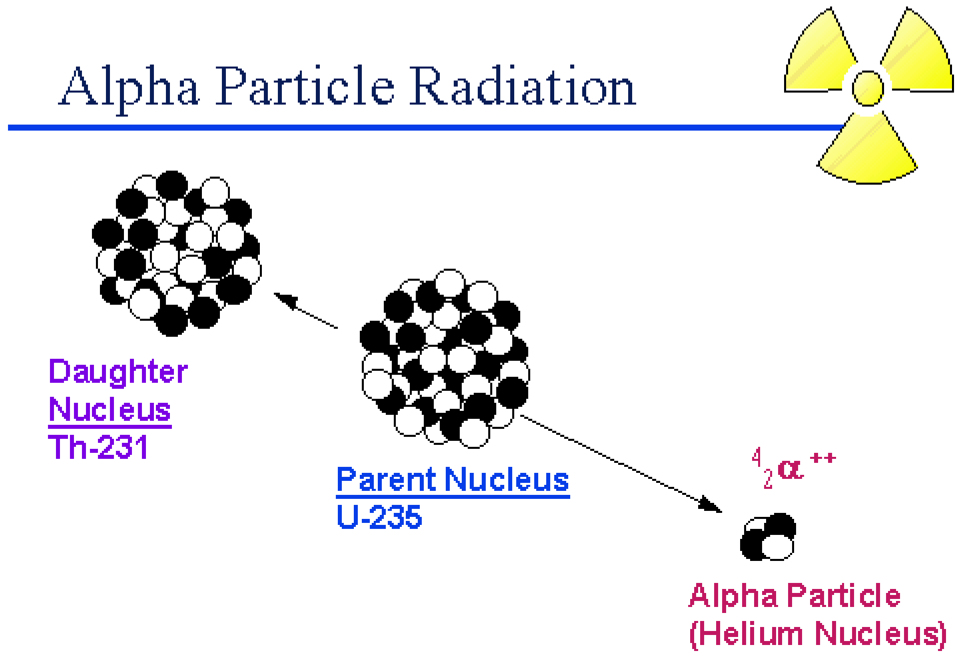


Radioactive Atom



❖Sources of radiation

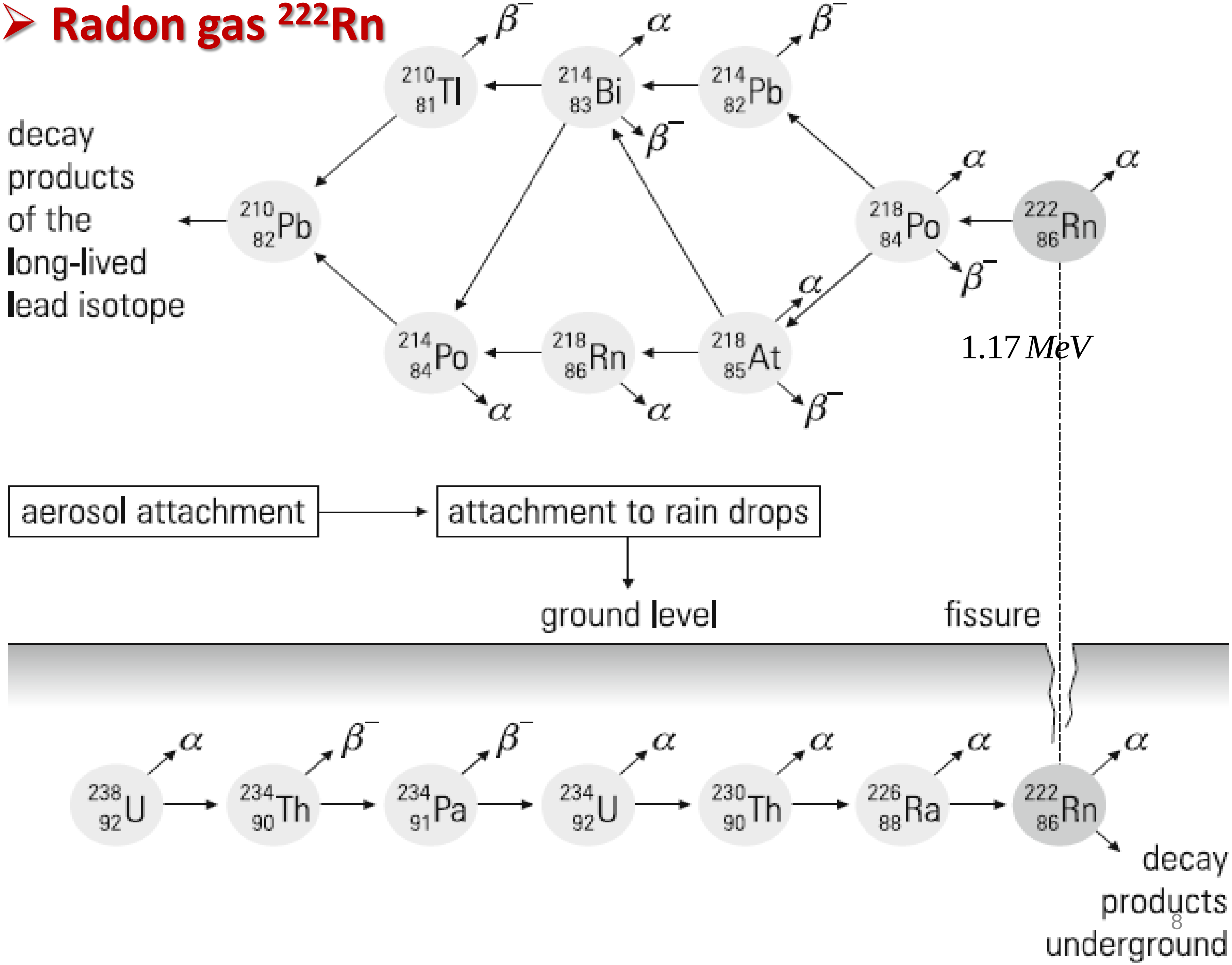
➢Alpha



$$E_\alpha \approx MeV$$

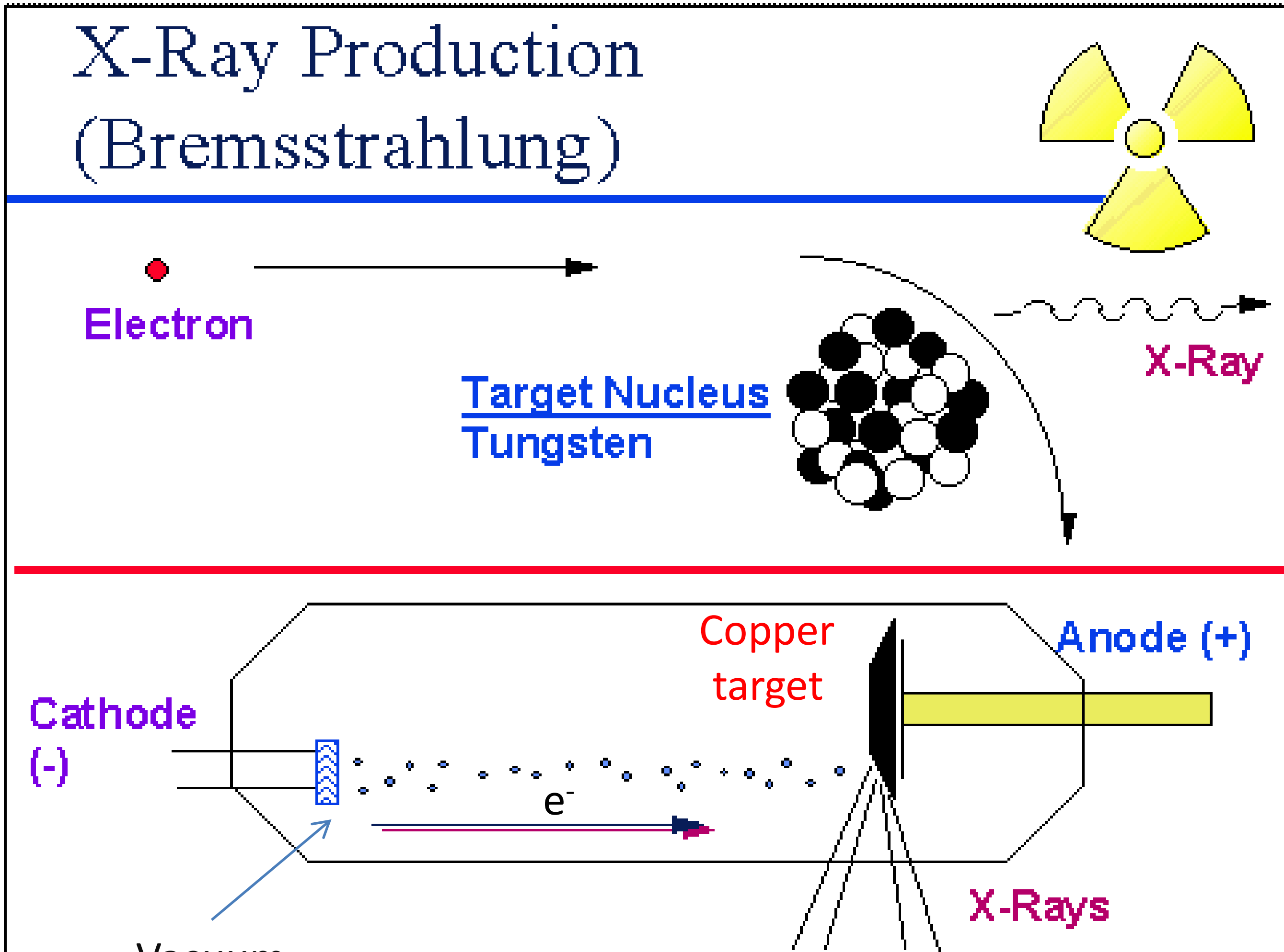
- Occurring in heavy nucleus
- Alpha particle pre-exited inside parent nucleus
- Its kinetic energy is beyond binding energy to its parent
- Due to high mass, it travels few cm of air and easily be stopped by piece of paper

➢ Radon gas ^{222}Rn



❖Sources of radiation

➢ **X - Ray**

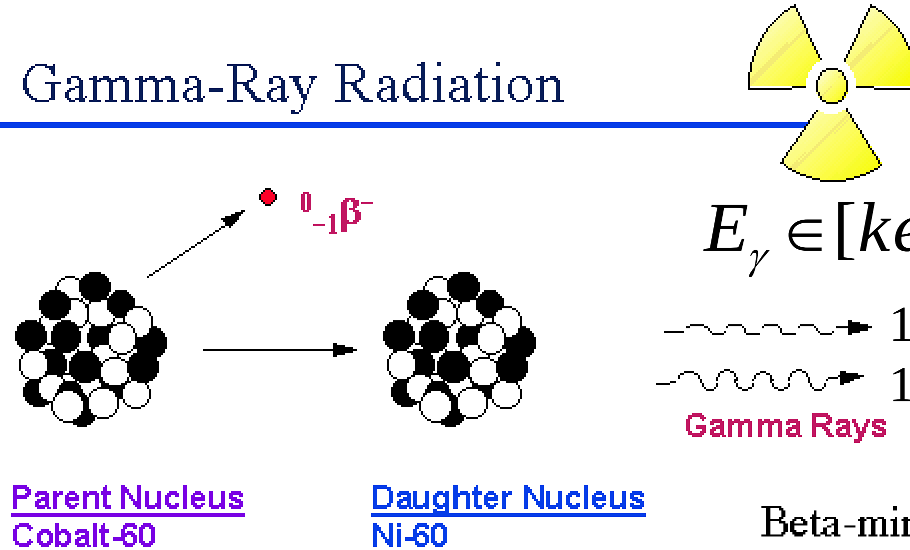


Crooke's tube

+ Discovered by Roentgen in 1895

❖Sources of radiation

➤Gamma

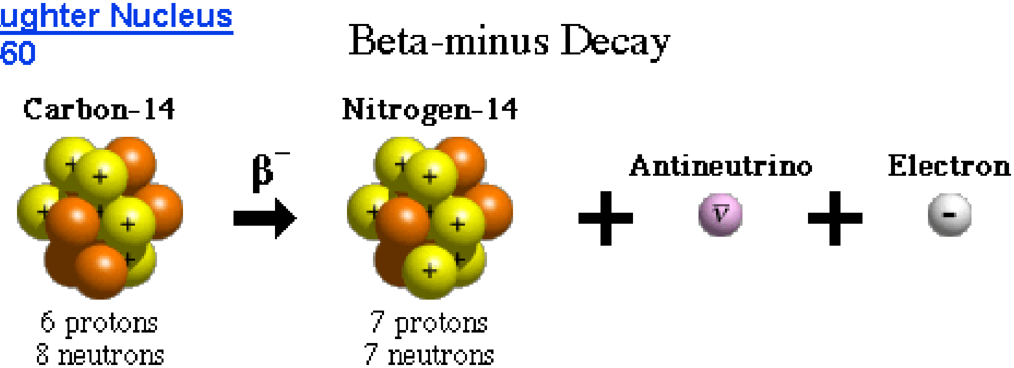


$$E_{\gamma} \in [keV, MeV]$$

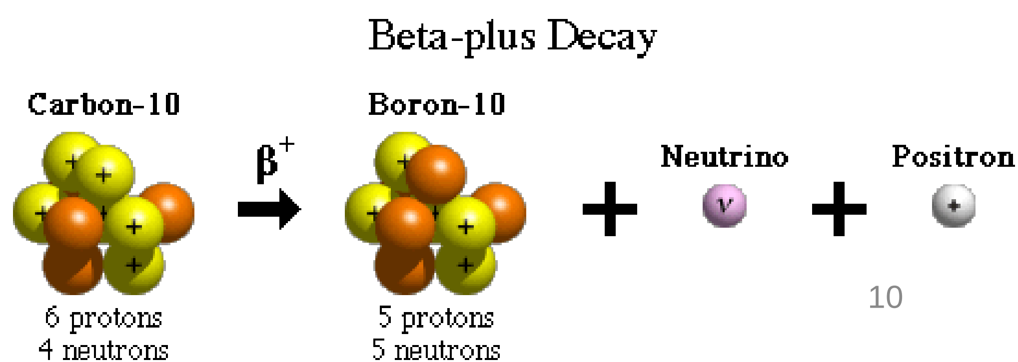
➤ Beta

$$n \rightarrow p + \bar{\upsilon} + \beta^{-}$$

$T_{1/2}$=14.77’

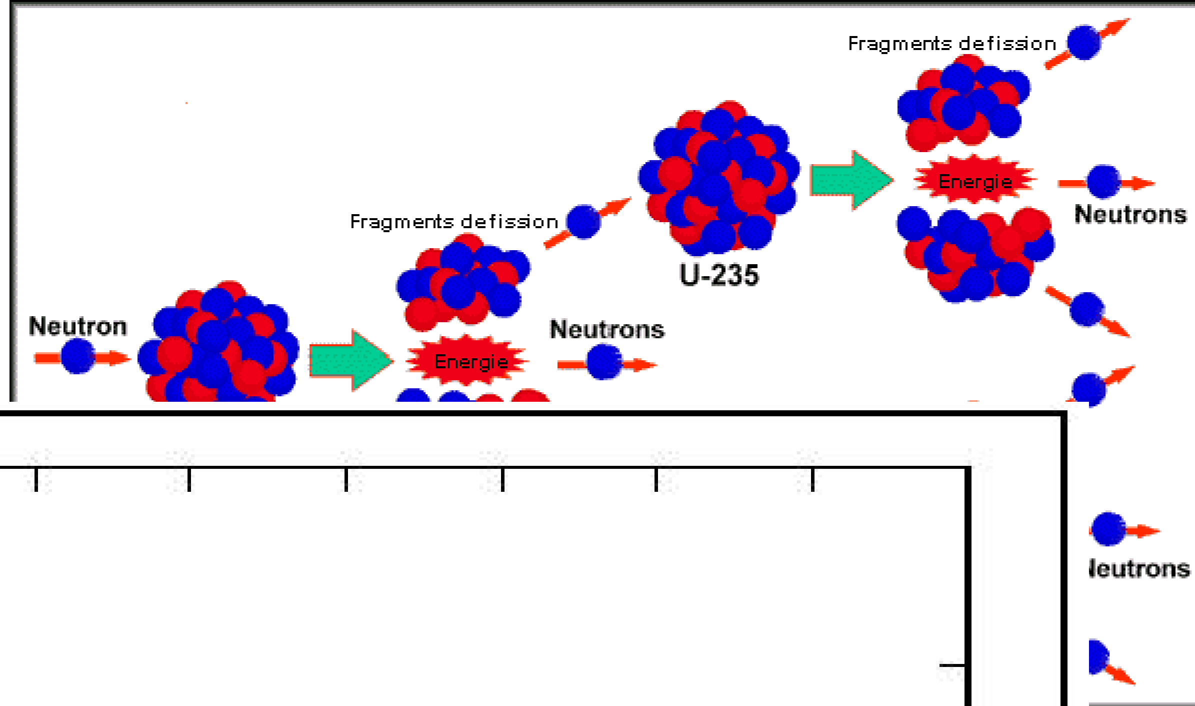


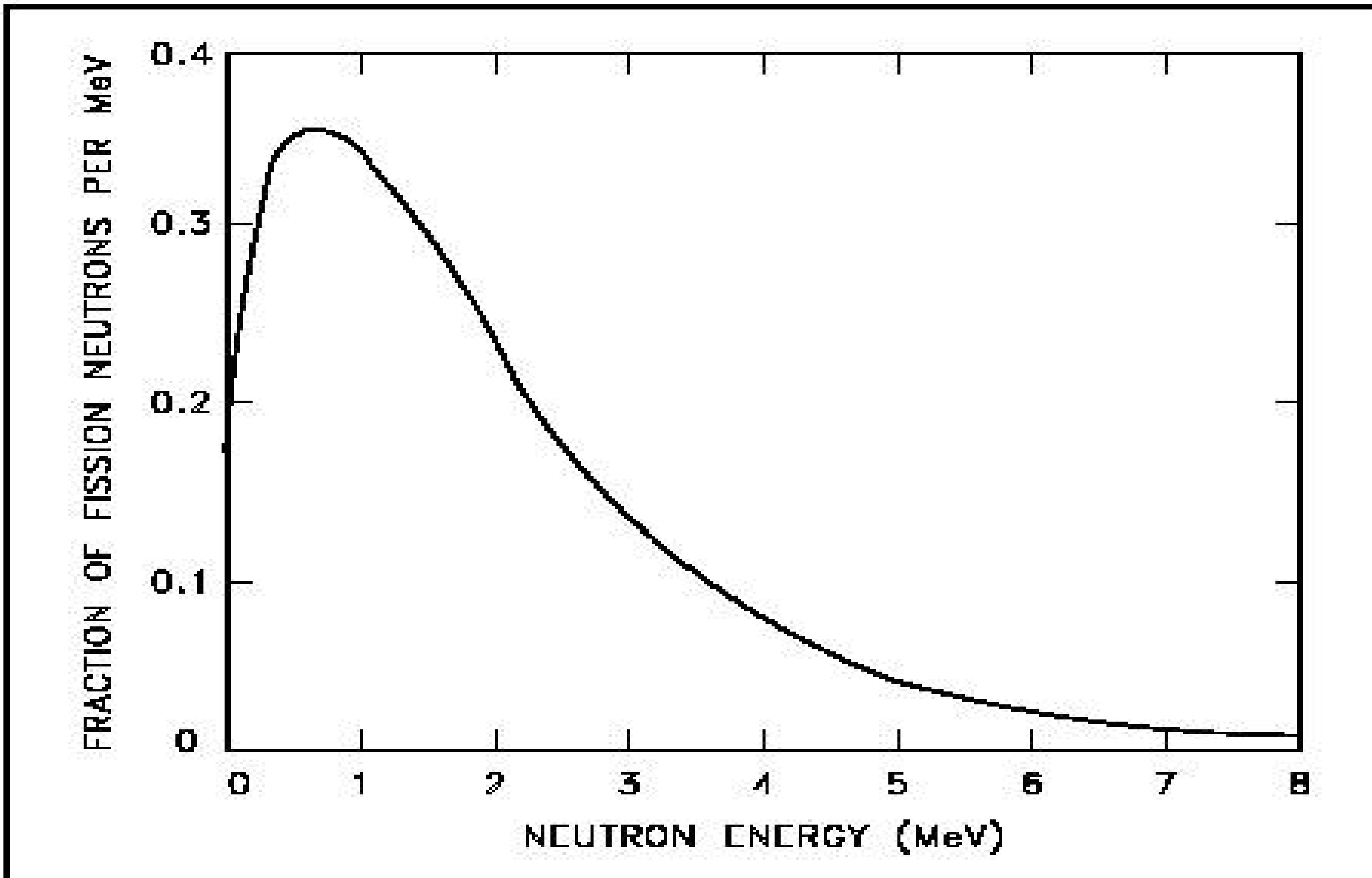
$$p \rightarrow n + \upsilon + \beta^{+}$$



❖Neutron

Neutron fission:





➢ Cosmic - Ray

electron

positron

photon

Soft component

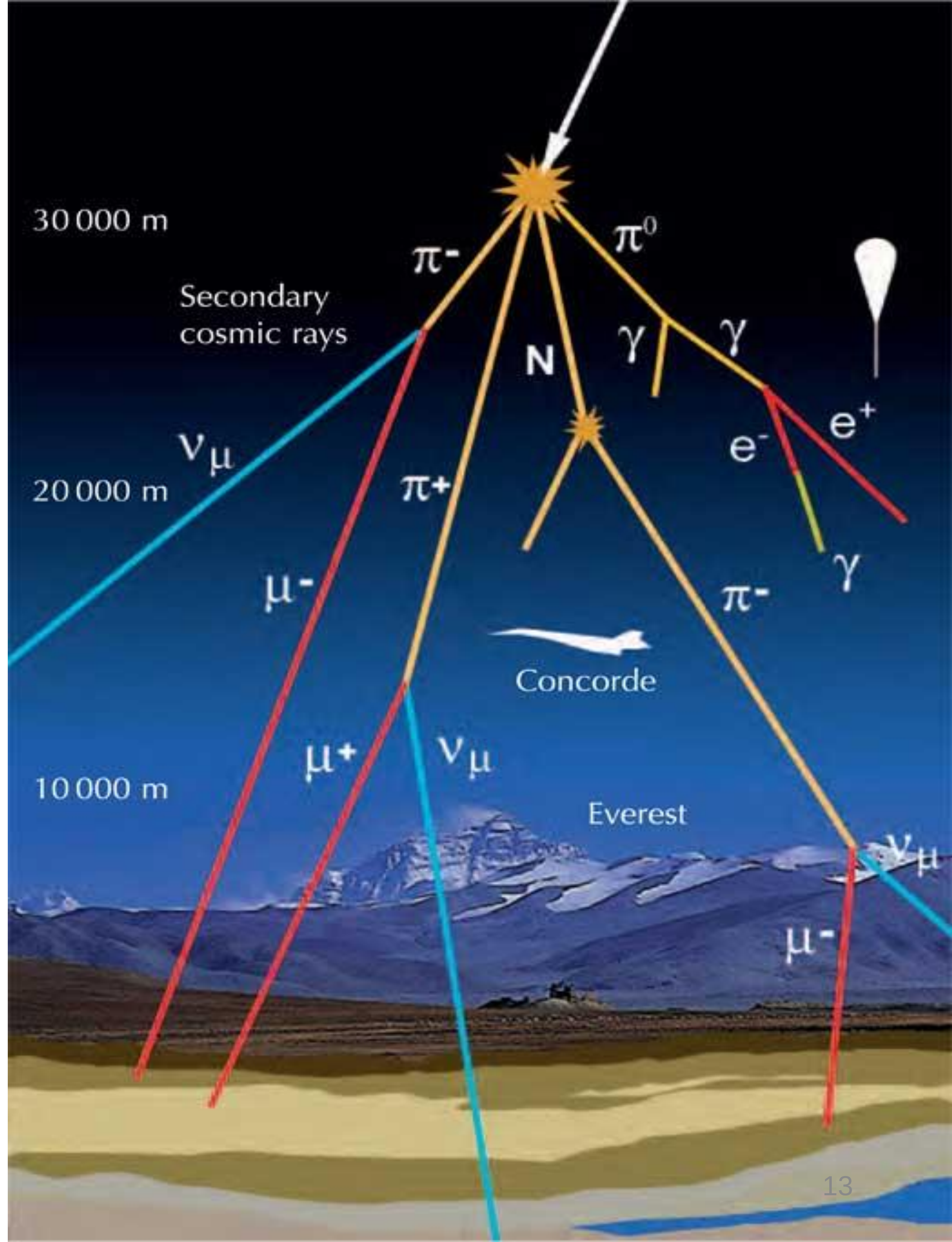
Primary cosmic rays

85% of protons

12% alpha

3% heavy nuclei

Interaction with atom in atmosphere to produce secondary cosmic rays



❖Statistical in US (6.2 mSv)

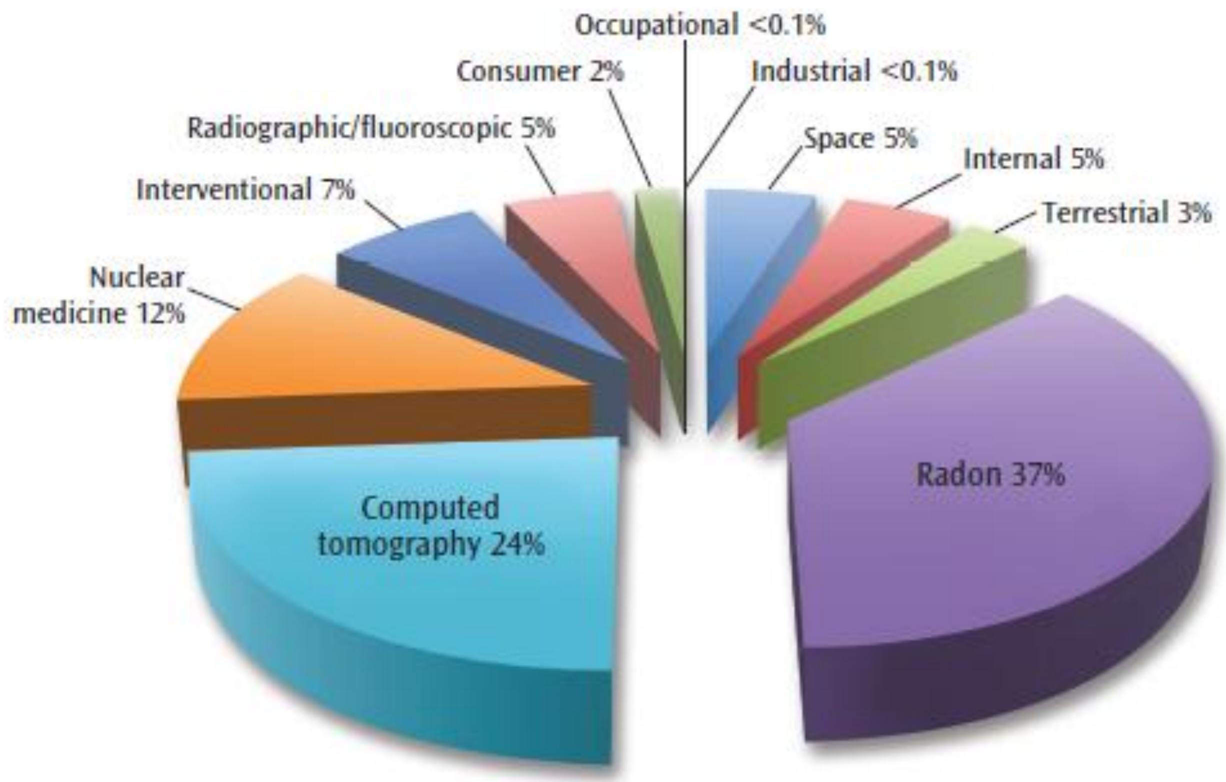


Figure 1. Annual per-capita radiation dose to the US population is 6.2 mSv. Of this, 3.1 mSv is ubiquitous background exposure and 2.98 mSv is from diagnostic procedures.[1]

Dimensions of Dental Hygiene June 2012

❖Radiation controls

❑ **Basic control methods for external radiation**

➢ **Decrease Time**: *Minimize time of exposure to minimize total dose. Rotate employees to restrict individual dose*

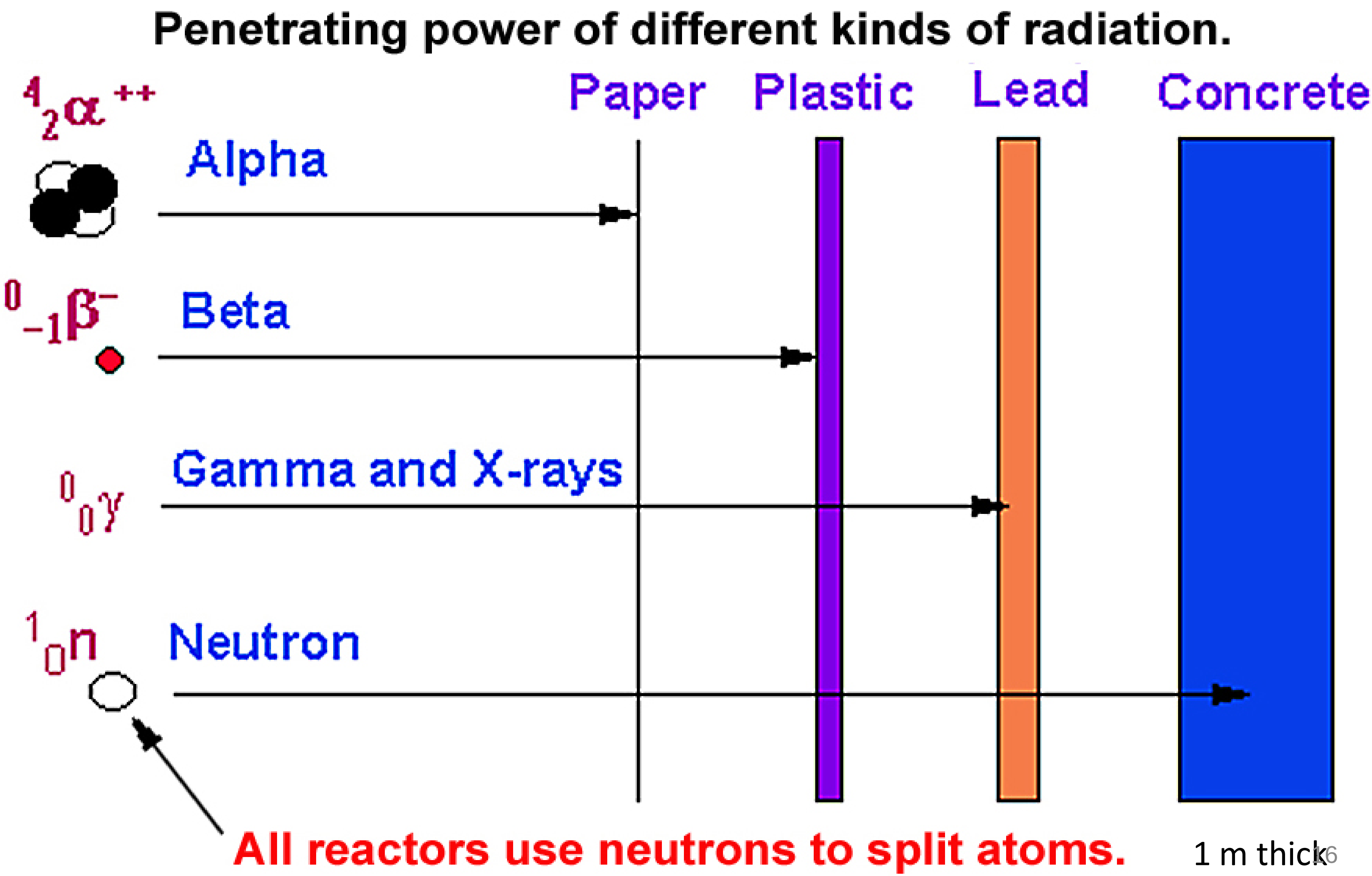
➢ **Increase Distance**: *Maximize distance to source to maximize attenuation in air. The effect of distance can be estimated as function is* $\approx \frac{1}{r^2}$

➢ **Increase Shielding**: *Minimize exposure by placing absorbing shield between worker and source*

❑ **Minimize Dose**

❑ **"ALARA: As Low As Reasonably Achievable"**

❖ Shielding



Penetrating power of different kinds of radiation.
$^{4}_{2}\alpha^{++}$
Alpha
$^{0}_{-1}\beta^{-}$
Beta
$^{0}_{0}\gamma$
Gamma and X-rays
$^{1}_{0}n$
Neutron
Paper
Plastic
Lead
Concrete
All reactors use neutrons to split atoms.
1 m thick

❖Electron - shielding

- Electrons of high energy (several MeV, e.g. from an accelerator) **are best shielded with** a sandwich consisting of a material of low atomic number followed by a layer of lead

- In the absorber of low atomic number (ex: Hydrogen, Carbon … the electrons lose their energy by ionization and excitation almost without producing bremsstrahlung, and then the electrons are stopped in lead.

- In a pure lead absorber energetic electrons would produce bremsstrahlung against which it is very difficult to shield.

❖Dosimeter


CAUTION
RADIOACTIVE MATERIALS


WARNING
X-RAY
RADIATION


CAUTION
RADIATION
AREA
AUTHORIZED
PERSONNEL ONLY


CAUTION
RESTRICTED
AREA


CAUTION
X-RAY
KEEP OUT


CAUTION
RADIATION
HAZARD


RESTRICTED
AREA
NO ADMISSION
WITHOUT
RADIATION BADGE


CAUTION
HIGH
RADIATION
AREA


CAUTION
FILM BADGE
REQUIRED
AUTHORIZED
PERSONNEL ONLY


CAUTION
RADIATION
AREA
KEEP OUT

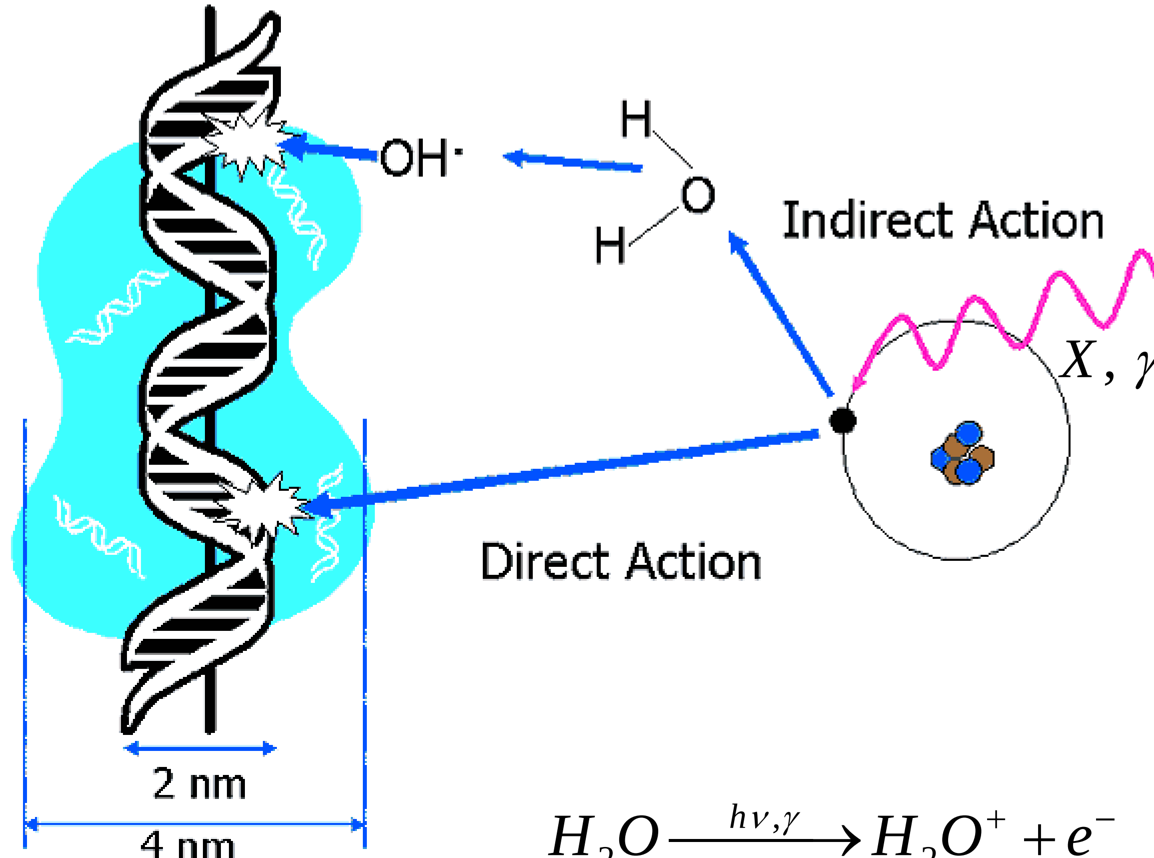
❖ Dosimetric Quantities

Dose is a measure of the amount of energy from an ionizing radiation deposited in a mass of some material. **Unit (Gy)**

Quantity	Definition	Unit
Absorbed dose to tissue T from radiation of type R: $D_{T,R}$	Energy absorbed per unit mass of tissue T . 1 Gy = 1 joule/kg	**Gy**
Equivalent dose to tissue T : H_T	Sum of contributions of dose to T from different radiation types, each multiplied by the radiation weighting factor ω_R $$H_T = \sum_R \omega_R D_{T,R}$$	**Sv**
Effective Dose H_{eff}	Sum of equivalent doses to organs and tissues exposed, each multiplied by the appropriate tissue weighting factor ω_T $$H_{eff} = \sum_T \omega_T H_T$$	**Sv**

❖Biological Effects of Ionizing Radiation

- **Direct action-** It involves absorption of radiation energy by target molecules, such as **DNA** or **RNA**, resulting in molecular damage.



- **Indirect action** – it alters the chemical environment around the cells due to more free radicals are produced by the radiolysis of water.

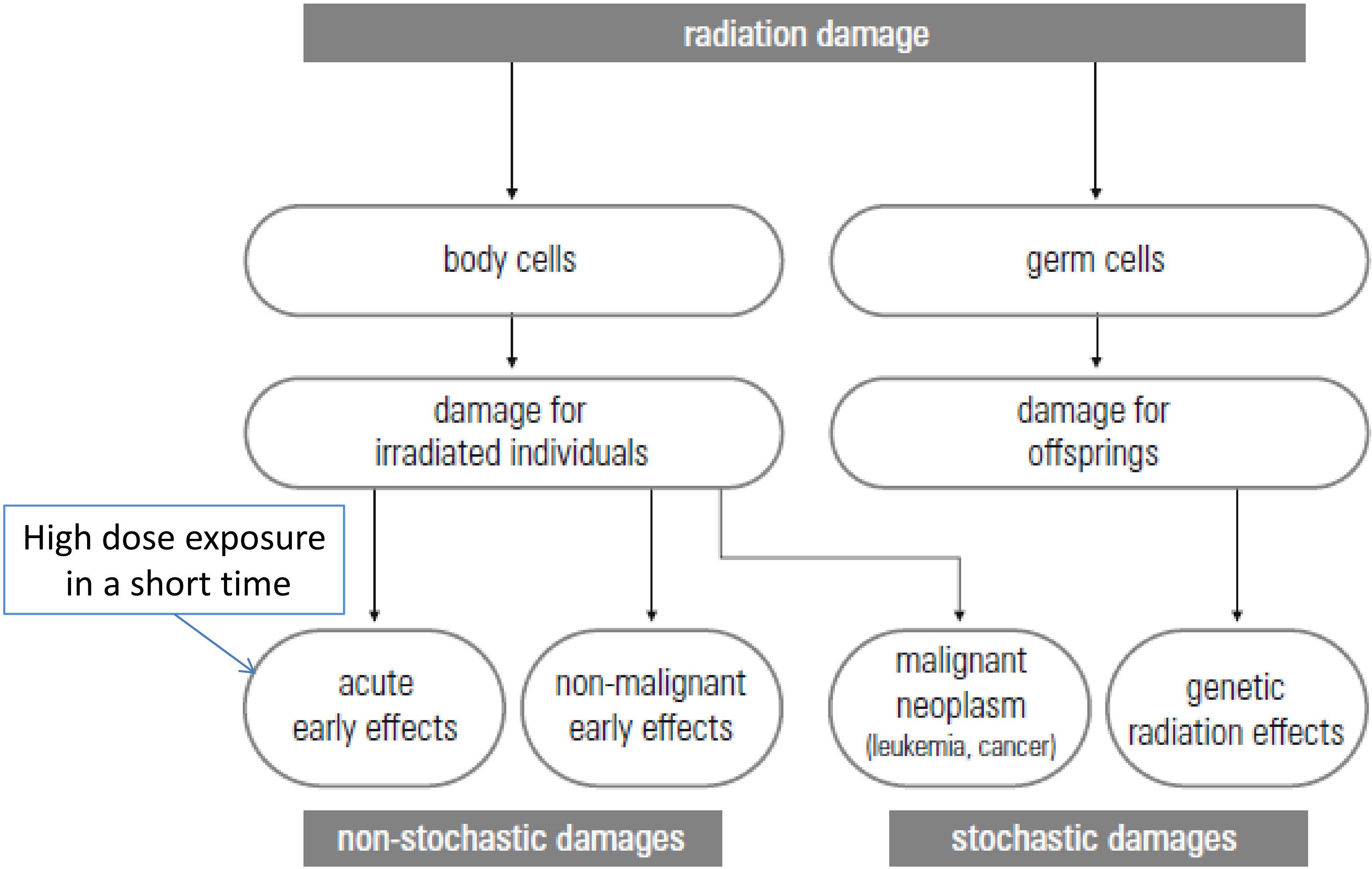
$$H_2O \xrightarrow{h\nu,\gamma} H_2O^+ + e^-$$

$$H_2O^+ \longrightarrow H^+ + OH$$

$$H_2O + e^- \longrightarrow H_2O^-$$

$$H_2O^- \longrightarrow H + OH^-$$

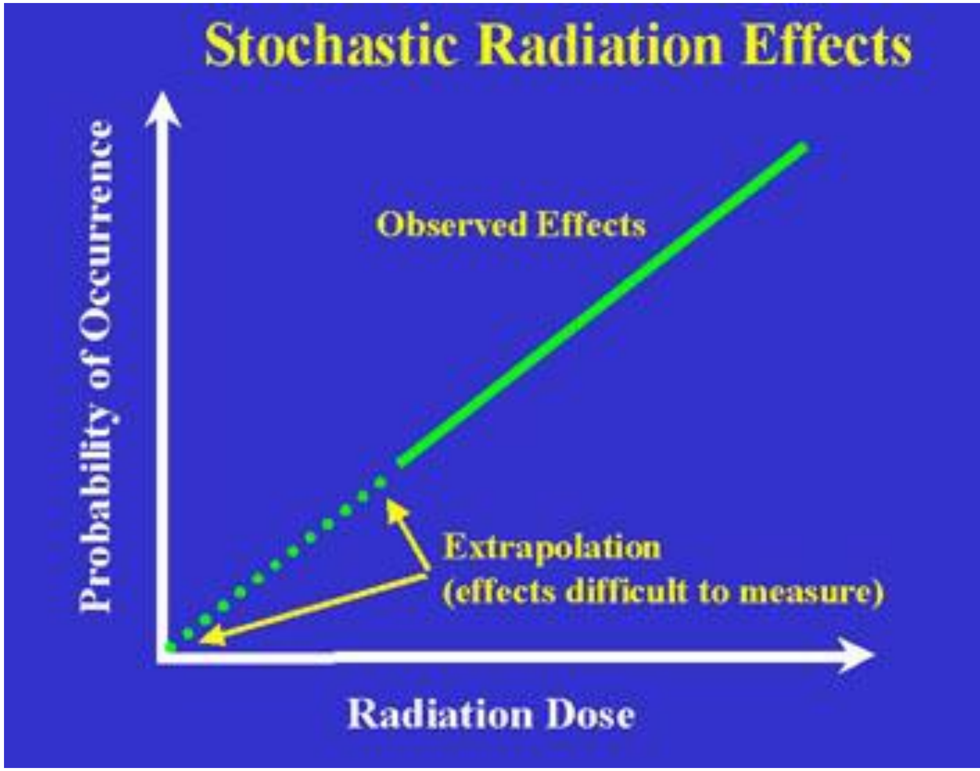
❖Biological Effects of Ionizing Radiation



❖Stochastic effect

- Increased **probability of occurrence** with increased dose, but whose **severity** of the effect does not depend on the dose

- **Example**: **skin cancer** and **sunlight**. The probability of getting skin cancer increases with increasing exposure to the sun (UVA)



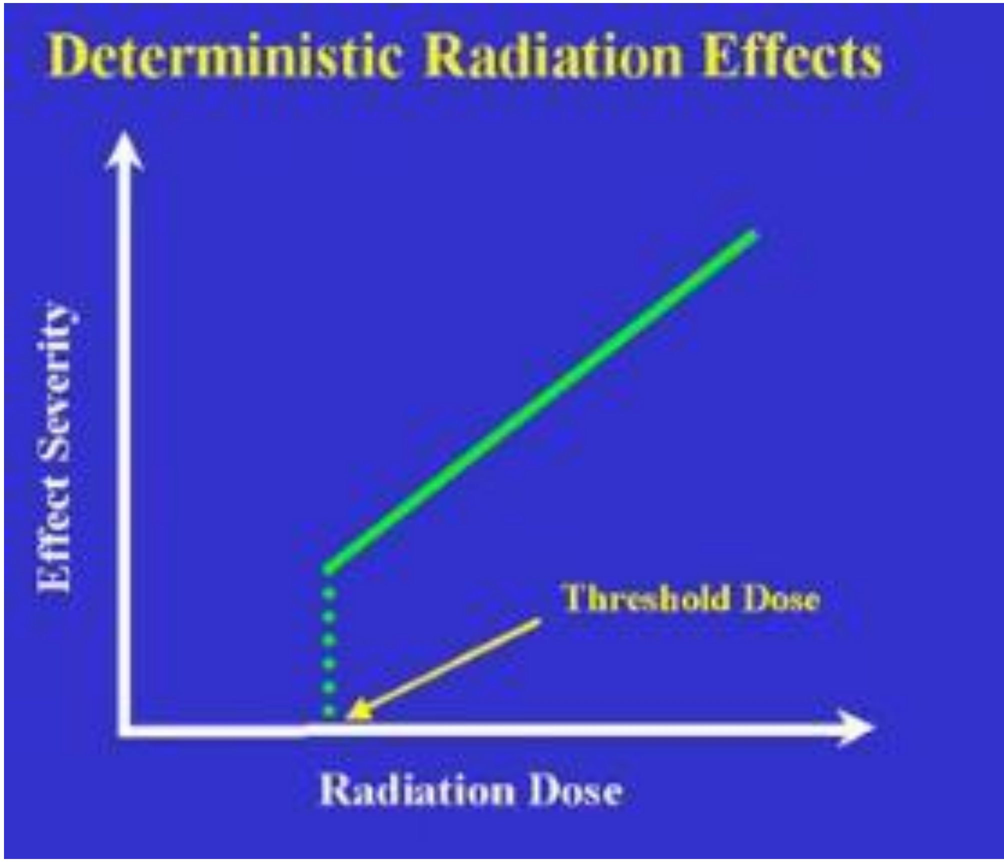
- Survivors of Hiroshima, Nagasaki, and Fukushima constitute the most important material in the study of this effects

❖Deterministic effect

- Develop due to cell killing by high dose radiation, appear above a given **threshold dose**

- The effects increase in severity with increased dose

- **For example**: **sunburn**. The more you're exposed to the sun (UVB), and the higher the dose of sunlight you receive, the more severe the sunburn



❖Example 1: Chest X-Ray

❖Chest X-Ray

$\overline{E_X} = 130\, keV$

- V = 100 – 160 kV
- It = 0.4 – 1.2 mAs
- Tungsten target: Z=74
- Angle: Max = 80^0

✓ The number of electrons N_e hitting the anode:

$$N_e = \frac{It}{e} = \frac{1.2*10^{-3}}{1.6*10^{-19}} = 7.5*10^{15}$$

M_{chest} = 18 kg

✓ Small fraction of electron energy is emitted in the form X rays:

$$\eta_1 = 10^{-6}\, U\, Z = 11.84*10^{-3}$$

✓ This yields a number of X-ray photons: $N_X = \eta_1 N_e = 8.88*10^{13}$

✓ Opening angle: 60^0; distance to patient: 1 m; chest area: 30*30 cm², only $\eta_2 = 8{,}5\%$ reach patient.

$\mu = 0{,}03\ cm^{-1}$

$x = 20\ cm$

✓ Number of photons reach to the patient: $\eta_2 N_X (1 - e^{-\mu x}) = 3{,}4*10^{12}$

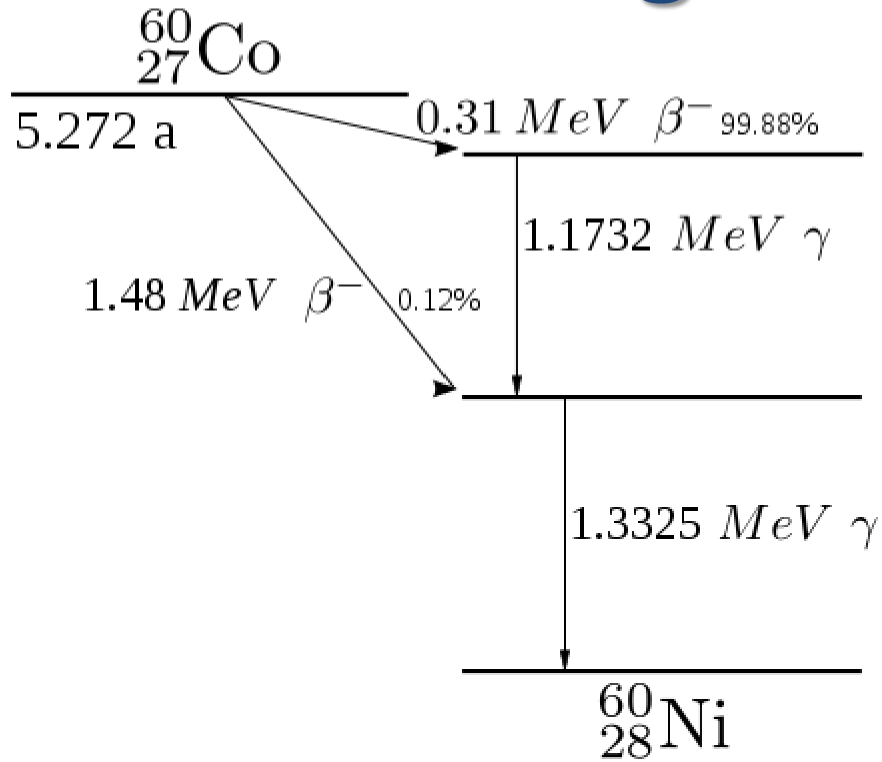
✓ Energy deposited: $E = 4{,}42*10^{17}\, eV = 0{,}0707\, J$ → **3,93 mGy**

$$\boxed{H_{eff} = \omega_{chest} * H_{chest} = 0{,}05*3{,}93 = 0{,}20\ \ mSv\ \langle\ H_{eff-\text{limit}} = 5\ mSv}$$

Public exposure (annual)

❖Example 2: ^{60}Co lost in Vung Tau

Source: from Internet



decay – scheme for ^{60}Co

- ✓Activity: 2,3 mCi
- ✓Source is unshielded
- ✓Compute the dose that a person at **3 m** distance from the source received?
- ✓ Compare this result to the one from natural environment in one year: 2,3 mSv? This value is correspond to D_0=6.3 μSv in 1 day.

❖Example 2: ^{60}Co

- ✓ Effect of Electron (E_γ =310 keV)
  - Range of Electron in the air: $R = (0.526\,E_\gamma - 0.095)/\rho_{air} \approx 53\,cm$

neglect

- ✓ Effect of photon $(\overline{E_\gamma} = 1.25\,MeV)$

Compton scattering

  - Fraction of photon is absorbed by student: (assume that tissue is composed by water)

$$\beta = 1 - e^{-\mu_w \rho_w x} = 1 - e^{-0.06\times1\times15} = 59.3\%$$

  - Solid angle : $\Omega' = \theta\varphi = 0.054\,sterad$
  - Energy-dose absorbed by student:

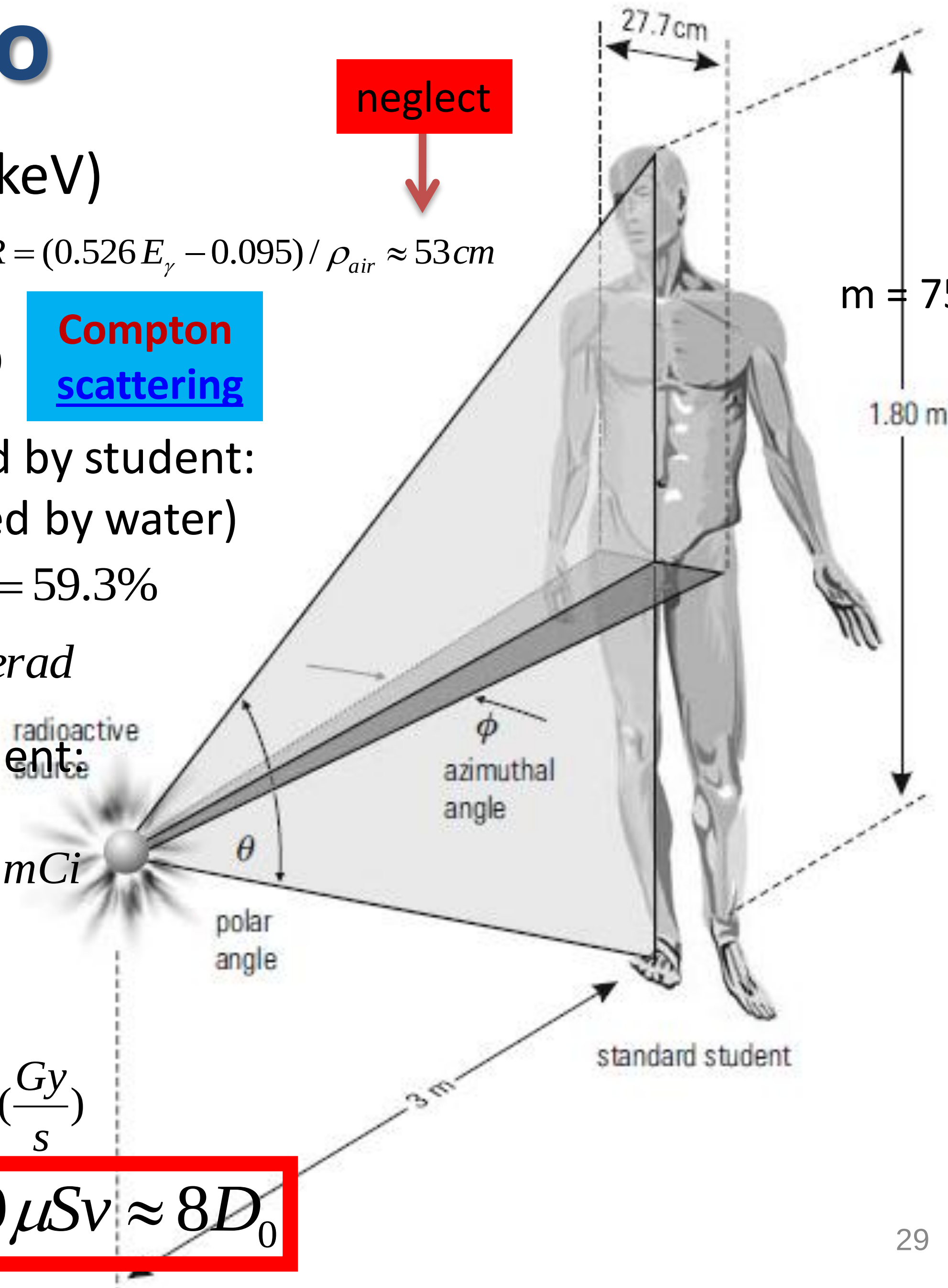
$$\overset{*}{E}_{ab} = \frac{1}{2} \times \frac{\Omega'}{\Omega} \times \frac{59.3}{100} \times \frac{98.9}{100} \times 2.5\,MeV \times 2.3\,mCi$$
$$= 4.2\times10^{-8}\,(J/s)$$

  - Dose rate:

$$\dot{D} = 4.2\times10^{-8}/75 = 5.727\times10^{-10}\left(\frac{Gy}{s}\right)$$

  - For 1 day of exposure: $\boxed{= 49\,\mu Sv \approx 8 D_0}$

m = 75 kg



QUESTIONS ?

Equivalent dose for different type of radiation

$$H_T = \sum_R \omega_R D_{T,R}$$

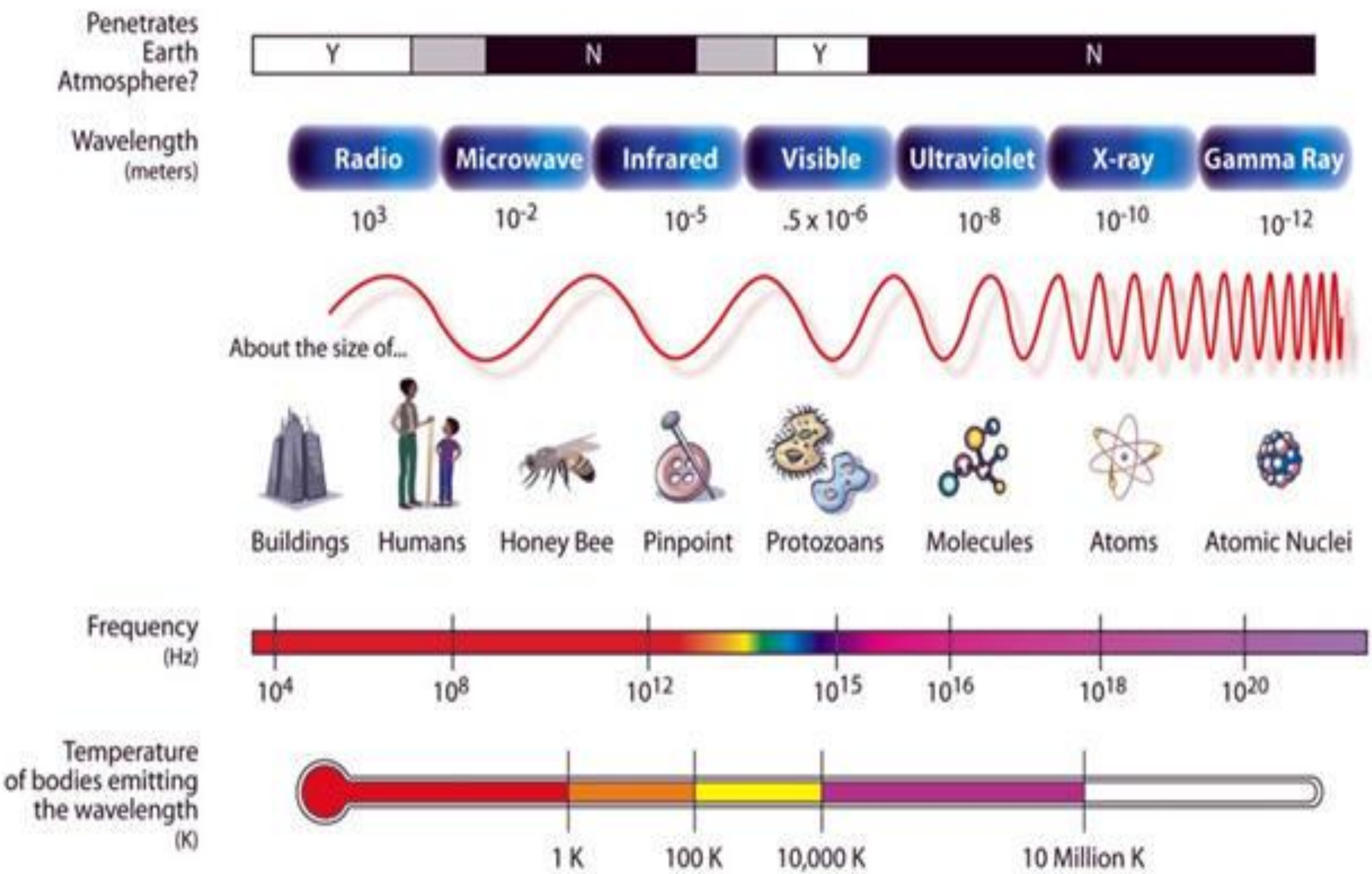
type of radiation and energy range	radiation weighting factor w_R
photons, all energies	1
electrons and muons[8], all energies	1
neutrons $E_n < 10\,\mathrm{keV}$	5
neutrons $10\,\mathrm{keV} \leq E_n \leq 100\,\mathrm{keV}$	10
neutrons $100\,\mathrm{keV} < E_n \leq 2\,\mathrm{MeV}$	20
neutrons $2\,\mathrm{MeV} < E_n \leq 20\,\mathrm{MeV}$	10
neutrons with $E_n > 20\,\mathrm{MeV}$	5
protons, except recoil protons, $E > 2\,\mathrm{MeV}$	5
α particles, fission fragments, heavy nuclei	20

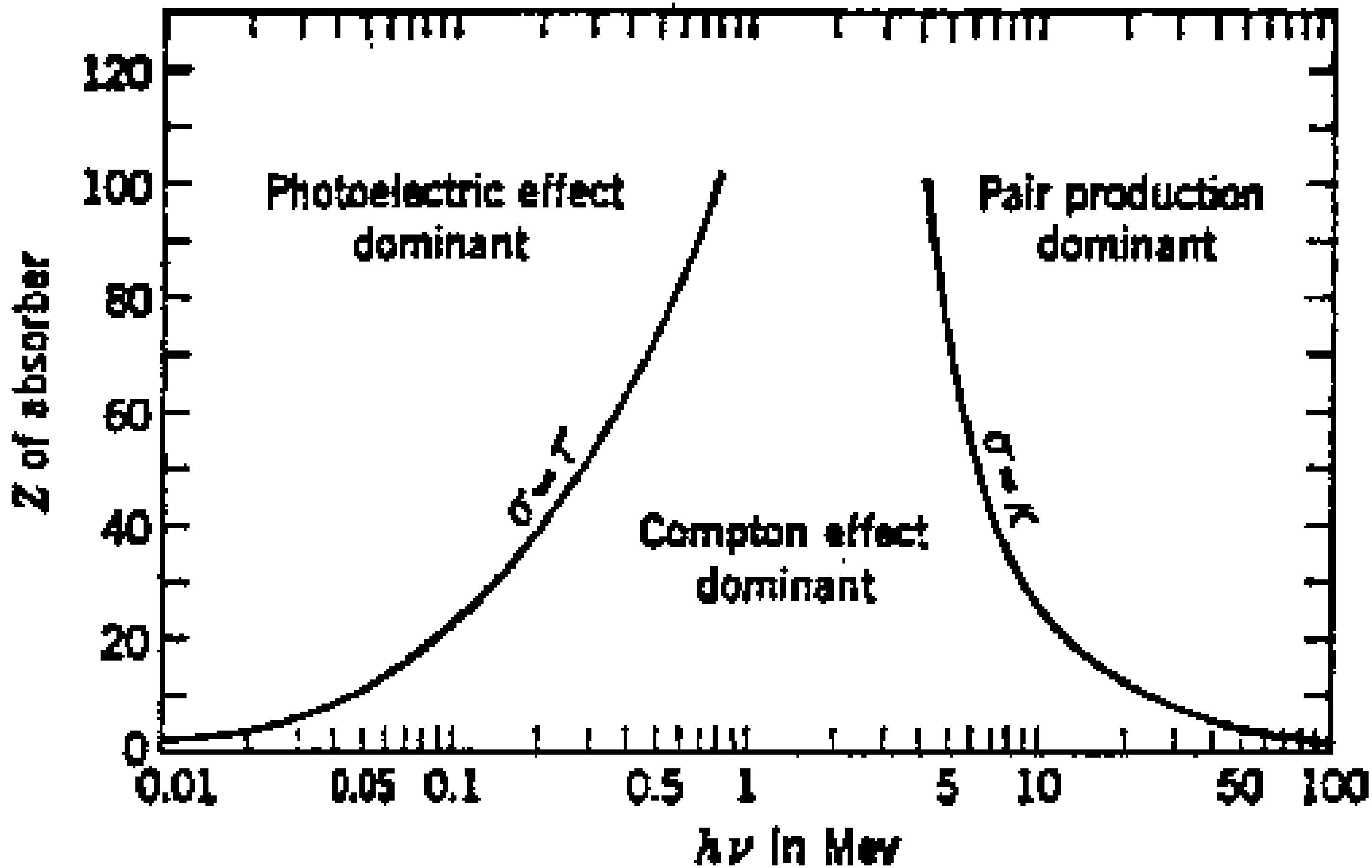
❖ Effective Dose

$$H_{eff} = \sum_{T=1}^{n} \omega_T H_T$$

organ or tissue	tissue weighting factor w_T
gonads	0.20
red bone marrow	0.12
colon	0.12
lung	0.12
stomach	0.12
bladder	0.05
chest	0.05
liver	0.05
esophagus	0.05
thyroid gland	0.05
skin	0.01
periosteum (bone surface)	0.01
other organs or tissue	0.05

THE ELECTROMAGNETIC SPECTRUM




Photoelectric effect dominant
Compton effect dominant
Pair production dominant
σ = τ
σ = κ
Z of absorber
120
100
80
60
40
20
0
0.01
0.05
0.1
0.5
1
5
10
50
100
hν in Mev