Radiation Quantities and Units

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Lecture_0

Objective

- To explain the ways that ionizing radiation interacts with matter.

- To familiarize the student with the basic principles of the quantities used in dosimetry for ionizing radiation.

Outline

Part I:

- Types of radiation
- Radiation effects
- Photon interaction with matter
- Electron interaction with matter

Part II:

- Inverse square law
- Exposure
- Kerma and absorbed dose
- Air kerma
- Equivalent dose
- Effective dose

Part I

Interaction of Radiation with Matter

Types of Radiation

There are two types of Radiation

- Non ionizing Radiation (visible light)
- Ionizing Radiation
  - Directly ionizing (Charged Particles like Electrons, Protons, Alpha, etc.)
  - Indirectly ionizing (Neutral Particles like Photons (X-rays, gamma) and Neutrons)

Physical and Chemical Effects of Ionising Radiation

- Incident ionising radiation can cause the following effects on matter (which can, therefore conversely be used to measure the amount of radiation imparted):
  - Ionisation (i.e., electrons removed from atoms)
  - Excitation (atoms/molecules raised to excited states)
  - Chemical effects (changes in the structure of molecules which can lead to molecular disassociation resulting in biological changes).
  - Radiation damage to the crystalline structure in solids.
  - Thermal effects (radiation causes increase in temperature)
  - Nuclear excitations and/or transmutations.

Radiation Effects

- **Stochastic effects**
  - Where the severity of the result is the same but the probability of occurrence increases with radiation dose, e.g., development of cancer
  - There is no threshold for stochastic effects
  - Examples: Cancer
- **Deterministic effects**
  - Where the severity depends upon the radiation dose, e.g., skin burns
  - The higher the dose, the greater the effect
  - There is a threshold for deterministic effects
  - Examples: Skin burns

Photon interactions

- Based on their origin, ionizing photon radiation is classified into four categories:
  - Characteristic x ray

    Results from electronic transitions between atomic shells
  - Bremsstrahlung

    Results mainly from electron-nucleus Coulomb interactions
  - Gamma ray

    Results from nuclear transitions
  - Annihilation quantum (annihilation radiation)

    Results from positron-electron annihilation

Interaction of Photons with matter

- In medical physics, photon interactions fall into three groups:

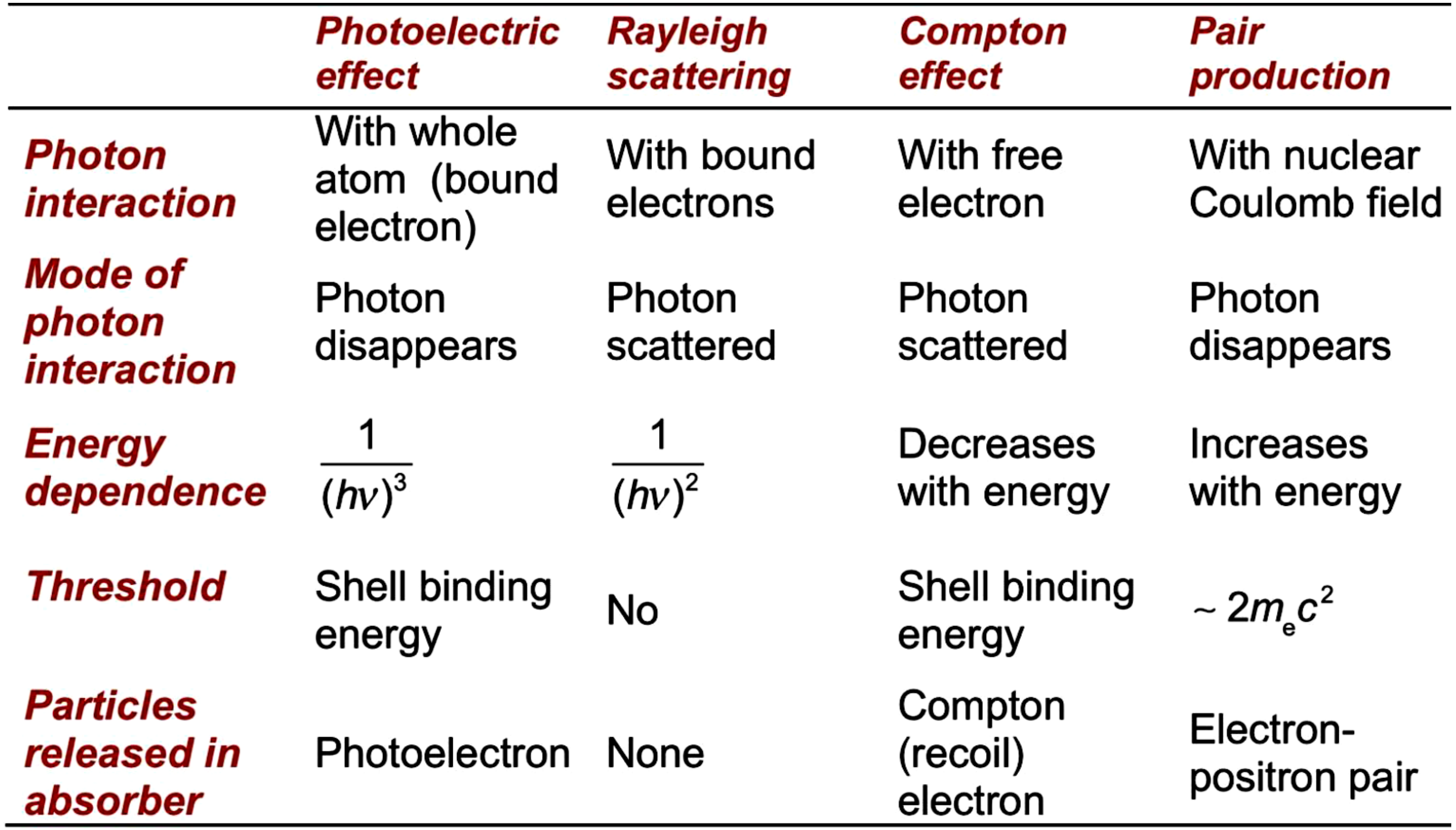
1) Interactions of major importance:
   - Photoelectric effect (Bound electrons) (C)
   - Compton scattering (Free electron) (P)
   - Pair production (Coulomb field of nucleus) (C)

2) Interactions of moderate importance:
   - Rayleigh scattering (or low energy limit of Compton scattering) (Bound electrons) (N)

3) Interactions of minor importance:
   - Photonuclear reactions or Nuclear photoelectric effect (Nucleus) (C)

(N) No photons absorbed (P): Photon Partially absorbed (C) Photon Completely absorbed

Photon interactions (Recap)



	Photoelectric effect	***Rayleigh scattering***	***Compton effect***	***Pair production***
Photon interaction	With whole atom (bound electron)	With bound electrons	With free electron	With nuclear Coulomb field
Mode of photon interaction	Photon disappears	Photon scattered	Photon scattered	Photon disappears
Energy dependence	$\frac{1}{(h\nu)^3}$	$\frac{1}{(h\nu)^2}$	Decreases with energy	Increases with energy
Threshold	Shell binding energy	No	Shell binding energy	$\sim 2m_e c^2$
Particles released in absorber	Photoelectron	None	Compton (recoil) electron	Electron-positron pair

Electron interactions with matter

- As an energetic electron traverses matter, it undergoes Coulomb interactions with:
  - Atomic electrons
  - Nucleus
- Through these collisions the electrons may:
  - Lose their kinetic energy (collision and radiation loss).
  - Change direction of motion (scattering).

Electron interactions with matter

- Energy losses are described by stopping power.
- Scattering is described by angular scattering power.

- Collision between incident electron and absorber atom may be:
  - Elastic
  - Inelastic

Electron interactions with matter

- In an elastic collision the incident electron is deflected from its original path but no energy loss occurs.
- In an inelastic collision with orbital electron the incident electron is deflected from its original path and loses part of its kinetic energy.
- In an inelastic collision with nucleus the incident electron is deflected from its original path and loses part of its kinetic energy in the form of bremsstrahlung.

Any Questions ?

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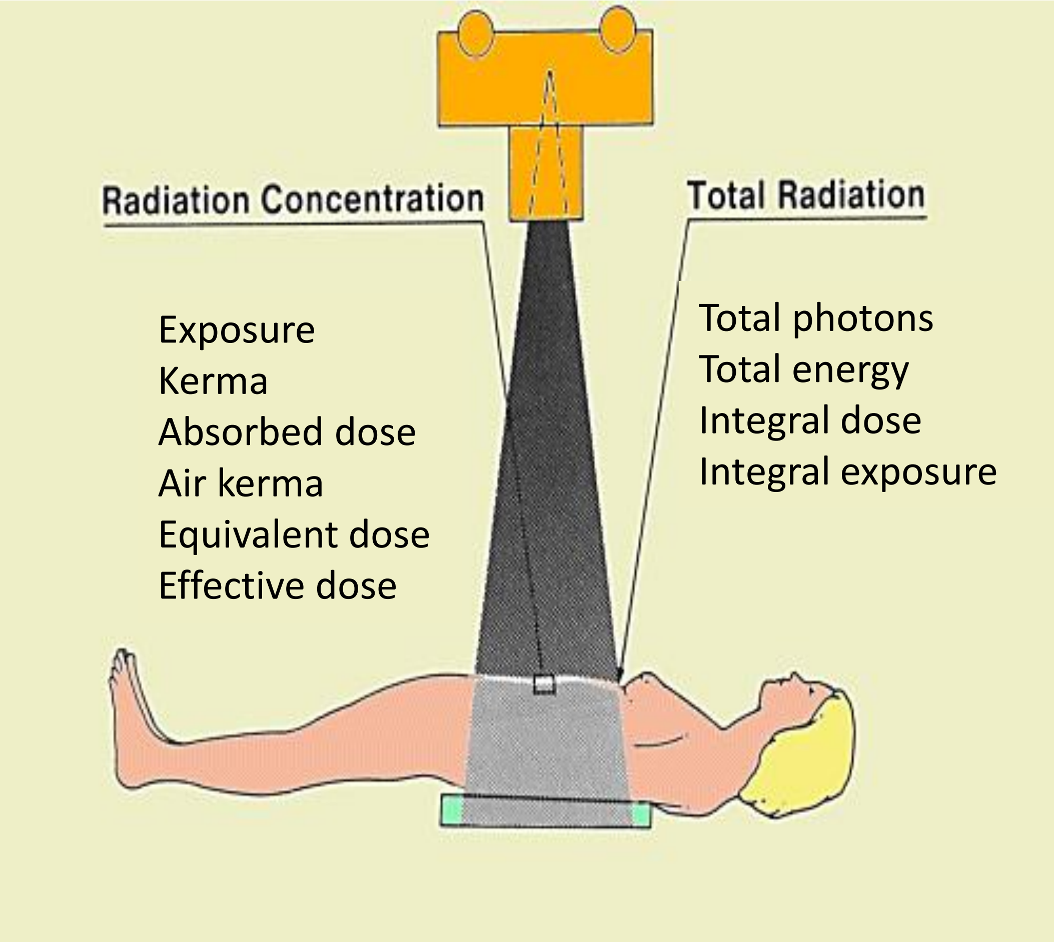
Part II

Dosemetric Quantities and Units

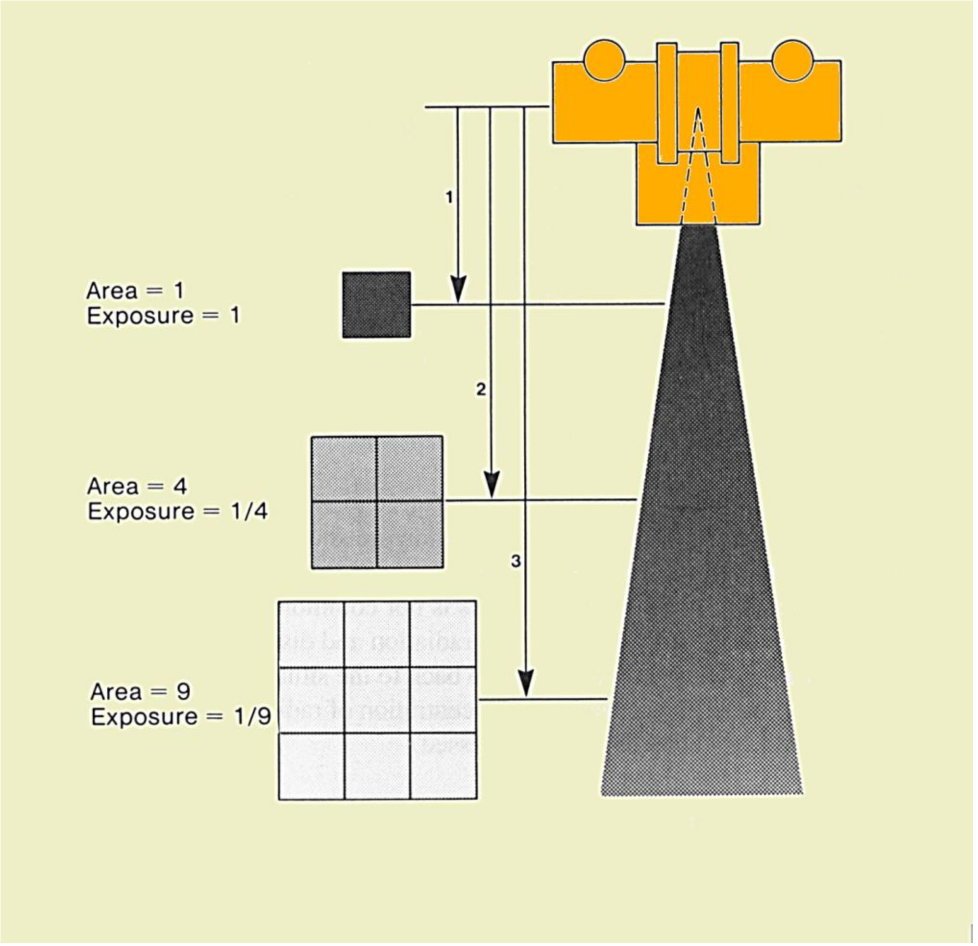
Radiation Quantities

- Radiation quantities fall into two general categories:
  - The quantities that express the total amount of radiation.
  - The quantities that express radiation concentration at a specific point.



Inverse square law

- The concentration of radiation is inversely related to the square of the distance from the source.
- This is commonly known as the inverse-square law.



Exposure

- Exposure is the amount of ionization produced within a small volume of air when a all the electrons liberated by the incident photons in air are stopped in the volume of air.

- Units of Exposure

1 Roentgen (R) = 2.58 x 10^-4 C/kg

1 C/kg = 3876 R

Limitation of Exposure

- Occurs only in air.
- Not used in Radiation Oncology
- Defined only for x-rays and gamma rays.

Kerma and Absorbed dose

- Photons interact with matter leading to secondary electrons. These electrons deposit their energy as they are slowed.
  - KERMA is the energy given by the photons to the electrons.

    (KERMA = Kinetic Energy Released per unit MAss)
  - Absorbed dose is the energy given to the matter by the electrons. Electrons will not deposit all their energy in one place.
- Therefore KERMA will be greatest when the number of photons is greatest (i.e. at the surface) while absorbed dose will be greatest when the number of electrons is greatest
- Kerma unit: 1 Gray (Gy or G) = 1 joule/kg
- Absorbed dose units: 1 rad = 100 erg/g = 0.01 J/kg = 0.01 Gy (1Gy = 100 rad)

Air kerma

- It is the measure of the amount of radiation energy, in the unit of joules (J), actually deposited in or absorbed in a unit mass (kg) of air. Therefore, the quantity, kerma, is expressed in the units of J/kg which is also the radiation unit, the gray (G) .

(Kinetic Energy Released per unit Mass of air)

- Air kerma can be calculated from exposure:

Air Kerma determination

Air kerma corresponding to 1 R :

I. Measure exposure

II. Convert C to IP

III. Multiply by the energy transferred to the medium per ionization

IV. Arrange the units

$$1\text{R} = 2.58\times10^{-4}\frac{\text{C}}{\text{kg}}\times1.6\times10^{19}\frac{\text{IP}}{\text{C}}$$

$$= 4.128\times10^{15}\frac{\text{IP}}{\text{kg}}$$

$$1\text{R} = 4.128\times10^{15}\frac{\text{IP}}{\text{kg}}\times33.7\frac{\text{eV}}{\text{IP}}$$

$$= 139.1\times10^{15}\frac{\text{eV}}{\text{kg}}$$

$$1\text{R} = 139.1\times10^{15}\frac{\text{eV}}{\text{kg}}\times\frac{1}{1.6\times10^{19}}\frac{\text{J}}{\text{eV}}$$

$$= 86.9\times10^{-4}\frac{\text{J}}{\text{kg}}$$

$$= 0.869\ \text{cGy}$$ air kerma

Equivalent Dose (H_T)

- **H_T** measures the biological damage to human due to exposure to a particular type of radiation.

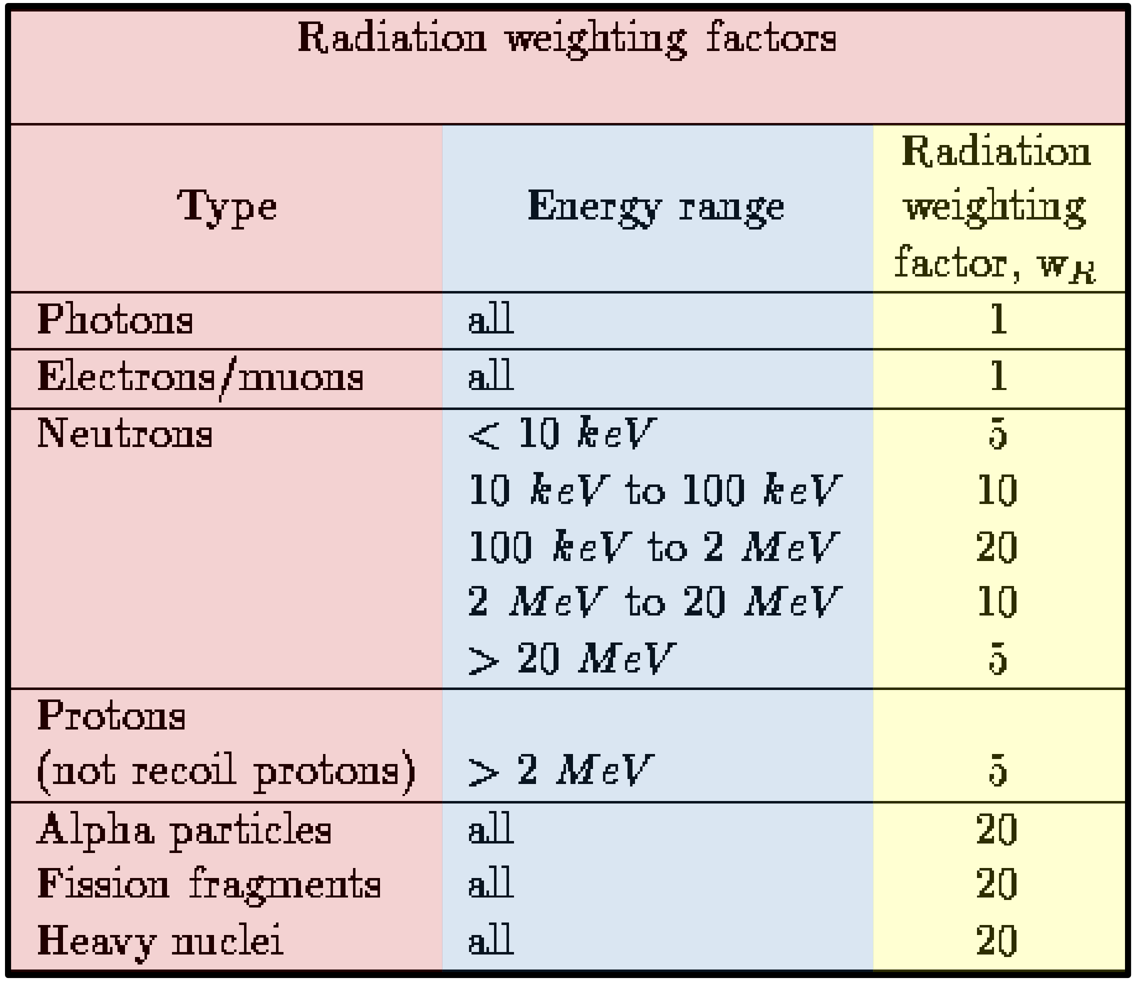
$$H_T = W_R\, D_T$$

- **D_T** is absorbed dose to a specific organ or a part of body and **W_R** is radiation weighting factor.
- The SI unit for human-equivalent dose is the Sievert (Sv).

$$1\ \text{Sv} = 1\ \text{Gray} \times W_R$$

Equivalent Dose (H_T)

- Table of radiation weighting factors.



Radiation weighting factors

Type	Energy range	Radiation weighting factor, w_R
Photons	all	1
Electrons/muons	all	1
Neutrons	$< 10\ keV$	5
	$10\ keV$ to $100\ keV$	10
	$100\ keV$ to $2\ MeV$	20
	$2\ MeV$ to $20\ MeV$	10
	$> 20\ MeV$	5
Protons (not recoil protons)	$> 2\ MeV$	5
Alpha particles	all	20
Fission fragments	all	20
Heavy nuclei	all	20

Effective dose (H_E)

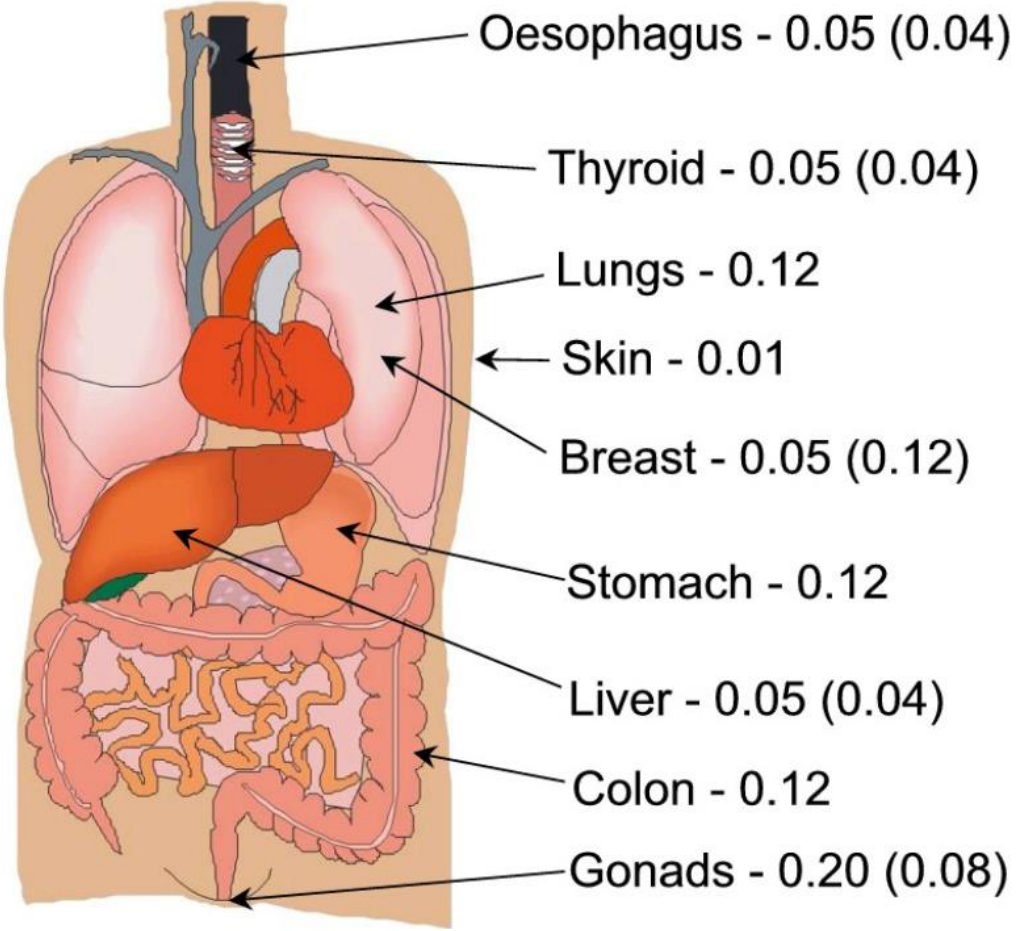
- The same size of dose can cause different degrees of biological damage depending on which part/organ of the body is exposed.
- So, different tissues respond differently to the same dose of radiation
- The Effective Dose (H_E) is a way of determining the whole-body biological damage due to radiation exposure of different types to different types of the body.

$$H_E = \sum W_T \, H_T$$

- Note that $\mathbf{H_E}$ and $\mathbf{H_T}$ both have SI units of Sieverts (Sv).

Effective dose

- Weighting factors for individual organs [ICRP] 1991 (and 2007 in brackets) .



Thank You
Any Questions ?