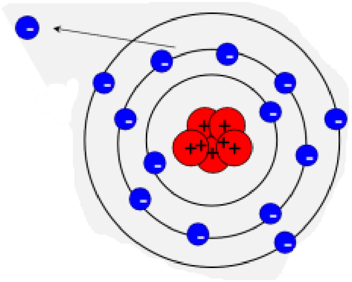
INTRODUCTION

- Ionization process
- Radiation Dose
    - Exposure
    - Air KERMA
    - Absorbed Dose
    - Equivalent Dose
    - Effective Dose
    - Collective Effective Dose
- Flux
- Operational quantities

ABSORPTION OF ENERGY

- Energy from a heat source can be absorbed by matter and increase its temperature.
- Nuclear radiation can transfer energy from a radiation source to an absorbing medium.
- The body can detect harmful levels of heat, but it cannot detect absorbed energy from nuclear radiation – even in lethal quantities
- Nuclear radiation differs from heat and other types of radiation in that it has sufficiently high energy to cause ionization

IONIZATION



- Removal of an orbital electron from an atom gives
    - an electron
    - remainder of atom (an ion) positively charged
- This is an ion pair
- The energy needed to remove the electron is the ionization energy

IONIZATION

- Ionization energy is supplied by the absorption of radiation energy in the medium
- The radiation loses its energy to the medium in the process
- Alpha, beta, gamma, and X-ray radiation is termed ionizing radiation
- Ionization in a gas provides a means of detecting radiation

EXPOSURE

The quantity of electronic charge in coulombs (C) produced by ionization per kilogram (kg) of AIR

(Either the positive or negative charge – not both)

SI units are C / kg

1 Roentgen = 2.58 x 10 - 4 C / kg

KERMA

- Kinetic Energy Released per unit Mass
- Units are: Joules per kilogram (J kg^{-1})
- Energy deposited (NOT absorbed) in unit mass of a material (e.g. air) by exposure to radiation
- Only different to Absorbed Dose at high keVs (more than 200 keV) due to:
  - Long range of secondary electrons
  - Bremsstrahlung
- Air KERMA is replacing exposure as standard

ABSORBED DOSE (D)

$$\frac{\text{Energy imparted to matter in a small volume (J)}}{\text{Mass of the small volume (kg)}}$$

- SI unit is the gray (Gy)
- 1 Gy = 1 Joule of energy absorbed in 1 kg of matter = 1 J/kg

Conversion factor: 1 gray ≈ 100 rads

ORGAN OR TISSUE DOSE

$$D_T = \frac{\text{Energy imparted to organ or tissue}}{\text{Mass of the organ or tissue}}$$

More useful for radiation protection purposes

Units: Gray (Gy)

CONVERTING DOSE IN AIR TO DOSE IN ANY OTHER TISSUE

$$\frac{\text{Dose in Tissue}}{\text{Dose in Air}} = \text{Ratio of mass absorption coefficients}$$

Values for mass absorption coefficients can be found in reference books

LINEAR ENERGY TRANSFER (LET)

- Rate at which energy transferred from radiation beam to the medium
- Density of ionization along the track of radiation
- High LET radiations are more easily stopped

Radiation	LET (keV per µm)
1 MeV gamma rays	0.5
100 keV x-rays	6
20 keV betas	10
5 MeV alphas	50

RELATIVE BIOLOGICAL EFFECTIVENESS (RBE)

- Different types of radiation can be more or less damaging

$$RBE = \frac{\text{Dose of 220 kV x} - \text{rays}}{\text{Dose of radiation under test}}$$

- Both doses cause same biological end point e.g., 10% cell survival
- RBE increases with LET

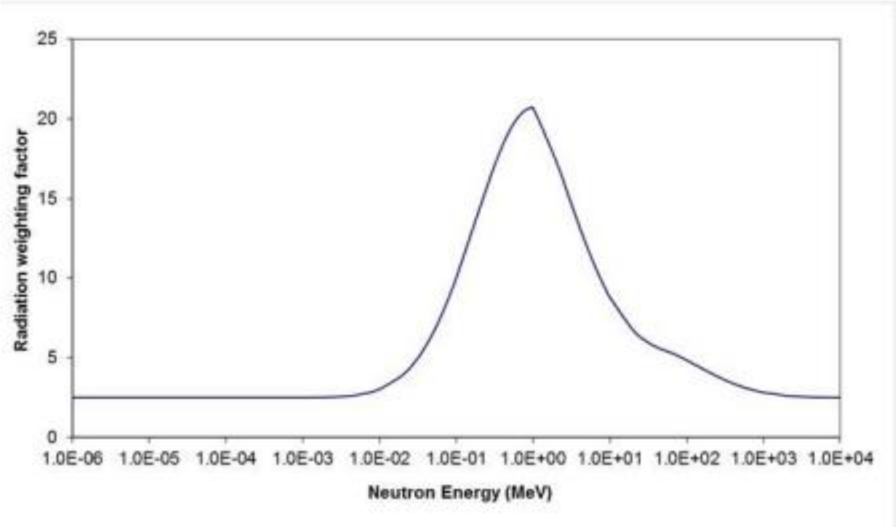
RADIATIONWEIGHTING FACTORS

Type of radiation	wR
X-rays, y-rays and electrons	1
Protons	5
Thermal neutrons	2.5
Fast neutrons	2.5 to 20*
Alpha particles, fission fragments	20

* Depending on energy

Set from a study of RBE and using organ dose concept

NEUTRON RADIATION WEIGHTING FACTORS (FROM ICRP103)



EQUIVALENT DOSE (H)

$$H = \text{Absorbed Dose (in Grays)} \times \text{Radiation WeightingFactor (wR)}$$

Strictly speaking this is the absorbed dose averaged over the organ or tissue

Dimensionless quantity

$$\text{Total } H_T = \sum W_R \times D_{T,R}$$

where DT,R is the average absorbed dose to the organ for a particular radiation type

EQUIVALENT DOSE (H)

Unit: Sievert (Sv) Still dimensionally J / kg as wR is just a number

Conversion factor: 1 Sv ≈ 100 rem

EXAMPLE NO. 1

- What is the total equivalent dose to the organ (HT) if the absorbed dose to the lungs is 0.2 mGy from x-rays?

$$H_T = \text{Absorbed Dose} \times \text{ radiation weighting factor}$$

Radiation weighting factor for x-rays (wR) = 1 (for any energy)

$$H_T = 0.2 \text{ x wR } = 0.2 \text{ x } 1 = 0.2 \text{ mSv}$$

Note that the units change from mGy to mSv

EXAMPLE NO. 2

- What is the total equivalent dose to the organ (HT) if the absorbed dose to the lungs is 0.2 mGy from x-rays and 0.01 mGy from alpha radiation?

$$H_T = \sum \text{Absorbed Dose x radiation weighting factor}$$

Radiation weighting factor for x-rays (WR) = 1 (for any energy)
Radiation weighting factor for alpha (WR) = 20 (for any energy)

$$H_T = 0.2 \text{ x } 1 + 0.01 \text{ x } 20 = 0.4 \text{ mSv}$$

Note that the units change from mGy to mSv

EFFECTIVE DOSE (E)

- Accounts for uneven irradiation of the body and represents overall risk from whole body exposure

$$E = \sum_T W_T \times H_T$$

H_T = Equivalent dose to tissue or organ ‘T’

W_T = tissue weighting factor

- Tissue weighting factors represent risks of detrimental radiation effects to different organs or tissue

TISSUE WEIGHTING FACTORS

Organ	W_T for organ
Gonads	0.08
Red bone marrow, colon, lung, stomach, breast	0.12
Bladder, liver, esophagus, thyroid	0.04
Skin, bone surface, brain, salivary glands	0.01
Remainder (in total)	0.12

EXAMPLE NO. 3

- A patient receives the following equivalent (organ) doses as a result of a chest PA x-radiograph:

Bone Marrow0.01 mSv	(WT=0.12)	
Thyroid	0.02 mSv	(WT=0.04)
Lungs	0.17 mSv	(WT=0.12)
Breast	0.09 mSv	(WT=0.08)

- What is the effective dose resulting from this examination?

$$E = \sum W_T \times H_T$$

E_T = 0.01 x 0.12 + 0.05 x 0.04 + 0.17 x 0.12 + 0.09 x 0.08 = 0.0308 mSv or 30.8 µSv

DOSE RATE

- The Gray and Sievert are units expressing an amount of radiation received over some period of time
- In controlling hazards, it is usually necessary to know the rate at which the radiation is being received – the DOSE RATE

$$\text{Dose} = \text{Dose Rate x Time}$$

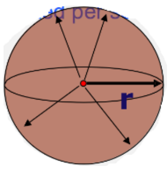
- For example: if someone works in an area for 2 hours and receives a dose of 4 mSv, then the dose rate in that areas will be 2 mSv/h

FLUX

- The number of particles or photons crossing an area of 1 square metre in 1 second
- This is strictly 'fluence rate', but is commonly referred to as FLUX (denoted by Φ)

A point source emits neutrons at the rate of Q per second Neutrons are being emitted uniformly in all directions

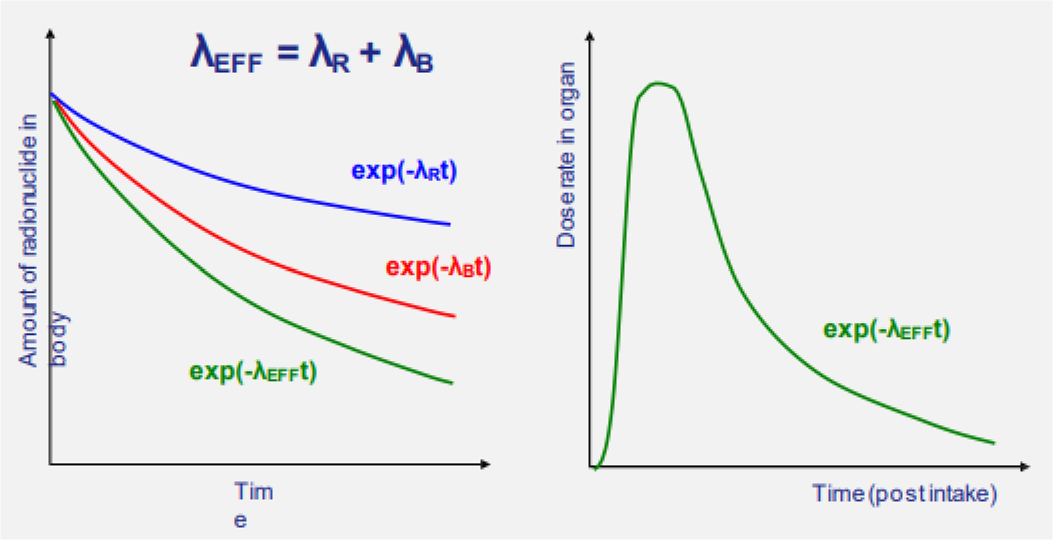
So the flux at distance r is the number of neutrons emitted per second divided by the surface area of the sphere of radius r



This area is $4\pi r^2$ and so the flux Φ is:

$\Phi = Q/4\pi r^2$ neutrons per m2 per second

INTERNAL RADIATION



COMMITTED EQUIVALENT DOSE

$H_T(50)$ = Equivalent dose summed over a 50 year period

Note: 70 year period for children

Also: Committed Effective Dose

ANNUAL LIMIT OF INTAKE (ALI)

The amount of radionuclide (in Bq) which when taken into the body will result in:

Committed Effective Dose = Dose Limit (20mSv)

Radionuclide	ALI (MBq)	
	Inhalation	Ingestion
Sodium-22	10	7
Iodine-131	1	0.8

Also depends on chemical compound

Annual Occupational Effective Dose in UK

COLLECTIVE DOSE

- If a group of the population is exposed to radiation, then the collective effective dose is:

$$S = E_m \times N$$

where:

E_m = mean effective dose to individual in group

N = number of individuals in the group

Units: man Sieverts (man Sv) or person Sieverts (person Sv)

OPERATIONAL QUANTITIES

For individual monitoring (ICRP 103):

- Individual Dose Equivalent, Penetrating – Hp(d)
  The dose equivalent in soft tissue below a specified point on the body at depth, d (mm), that is appropriate for strongly penetrating radiation
- Individual Dose Equivalent, Superficial – Hs(d)
  The dose equivalent in soft tissue below a specified point on the body at depth, d (mm), that is appropriate for weakly penetrating radiation

Personal Dose Equivalent – Hp(d)

where	d = 10mm for	strongly penetrating
	d = 0.07mm for	weakly penetrating

SUMMARY 1

- Absorbed dose (D): energy absorbed in a medium by any type of ionizing radiation. Unit: Gray 1 Gy = 1 J/kg
- Equivalent dose (H): obtained by multiplying the 'D' by the radiation weighting factor for the particular type of radiation. Unit: Sievert (Sv)
- Radiation weighting factor, W_R: measure of the ability of a particular type of radiation to cause biological damage $W_R = 1$ for β, X and γ, 5 for protons and 20 for α particles
- Effective dose (E): obtained by multiplying the 'H' to each exposed organ by its tissue weighting factor and then summing over all of the organs
- Tissue weighting factor, W_T: reflects the radio-sensitivity of a particular tissue or organ

SUMMARY 2

- Dose = dose rate × time
- Flux: from point source = $Q/4\pi r^2$
- Committed effective dose: effective dose for internal irradiation
- Annual Limit of Intake (ALI): amount of radionuclide (in Bq) which when taken into the body will result in 20 mSv committed effective dose
- Collective Dose: dose to a particular cohort of persons. Unit: man Sv