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# Department of Biomedical Engineering

## Course Name: 19BME301 – Medical Physics

## III Year : V Semester

## Unit V – BASIC RADIATION QUANTITIES

# Content

- Introduction
- Activity
- Kerma
- Exposure
- Absorbed dose
- Equivalent dose

- Effective dose
- DAC and ALI
- Collective effective dose
- Summery
- Reference

# Introduction

- What is a Quantity?
- Quantity means to characterise a physical phenomenon in terms of that are suitable for numerical expression.
- A physical quantity is a phenomenon capable of expression as the product of a number & unit.
- What is a Unit?
- A unit is a selected reference sample of a quantity.

# Radiation Units- Governing Bodies

- ICRP => INTERNATIONAL COMMISSION ON RADIATION PROTECTION.
- ICRU => INTERNATIONAL COMMISSION ON RADIATION UNITS
- ICRP is a private organisation consisting of 100 members from different countries.
- Motive- to prevent deterministic effect and reduce the risk of stochastic effect.

- ICRU was founded in 1925 comprises 19 committees.
- Objective- make assessments of radiation and their safe and effective use.
- In order to assess it gives some recommendations about definitions of the concepts, units and operations.
- Both ICRP & ICRU developed a hierarchy of quantities namely

  (i) Primary limiting dose quantities ( protection quantities)

  (ii) Operational dose quantities

- Primary Limiting Dose Quantity => relates the risk of exposure to ionising radiation ( both internal & external) to a single quantity( dose) taking man as a receptor with different radiation sensitivities of various organs & different radiation qualities/
- Operational Quantities => These are dose quantities defined for use in radiation protection measurements for external exposure.
- It usually provides an estimate of an upper limit for the value of limiting quantities.

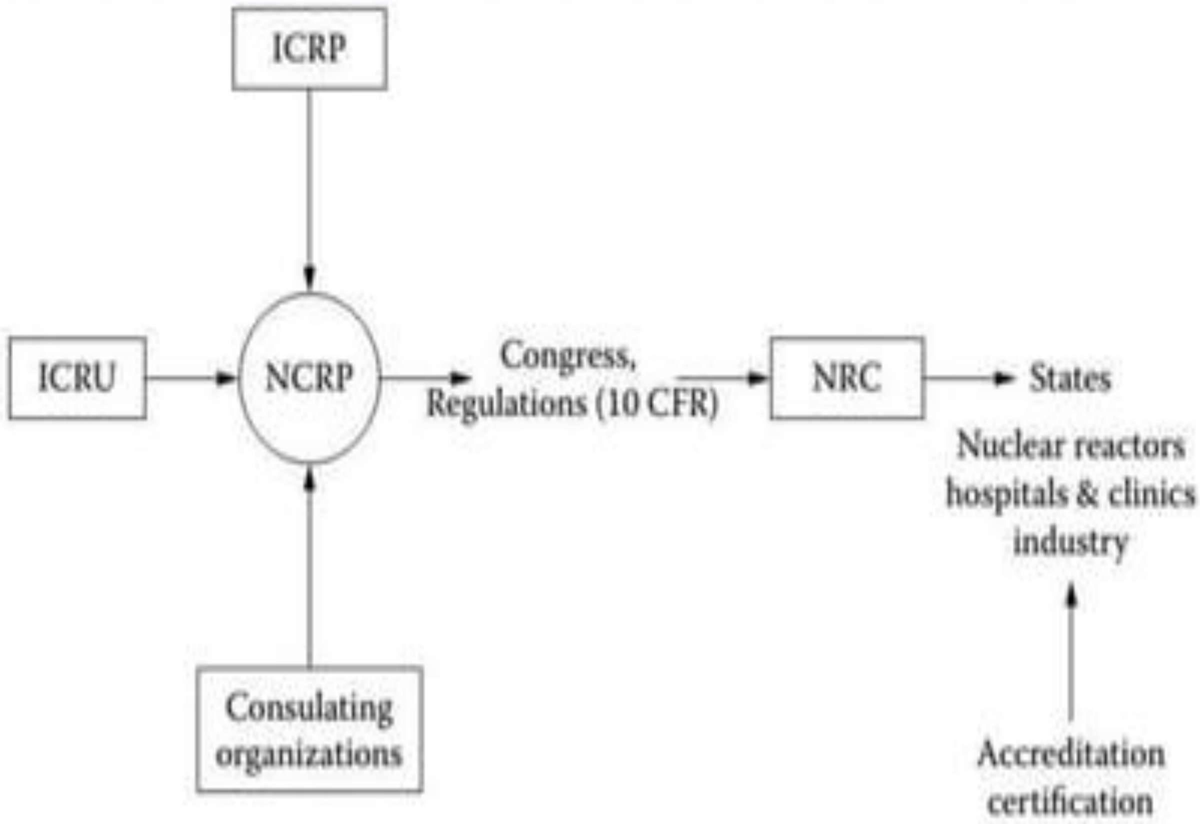



**FIGURE 3.1** The big picture: international and national organizations interact with each other in the process of studying and analyzing scientific data and formulating recommendations, standards, rules, and regulations for radiation safety.

# Quantities and Units

- **Activity :**

It is no of radioactive disintegration taking place per unit time.

**A= dN/dt**

dN => No. of nuclear transformation/ decay taking place in time dt.

**Unit : SI unit = Becquerel (bq)**

**old unit = Curie (Ci)**

# Becquerel and Curie

- How do we define 1 Becquerel??

  1 Becquerel is equal to 1 disintegration per second

  1 bq = 1dps

- How do we define 1 curie?

  1 Curie is roughly the time taken for 1gm of $Ra^{226}$ to decay/ disintegrate

# Becquerel-Curie Relation

- 1Ci = 37GBq
- 1mCi = 37MBq
- 1μCi = 37KBq

# Decay Constant & Half Life

- What is decay constant?

  It is the probability that a nucleus decays in time interval

  It is denoted by $\lambda$

  $\lambda = dp/dt$

dp => probability that a nucleus decays in time interval dt.

Quantitiy related to decay  constant is "**Half life**".

- Half life is the time taken for a radionuclide to decay to half of its initial value.

- It is denoted by $t_{1/2}$

$$t_{1/2} = 0.693/\lambda$$

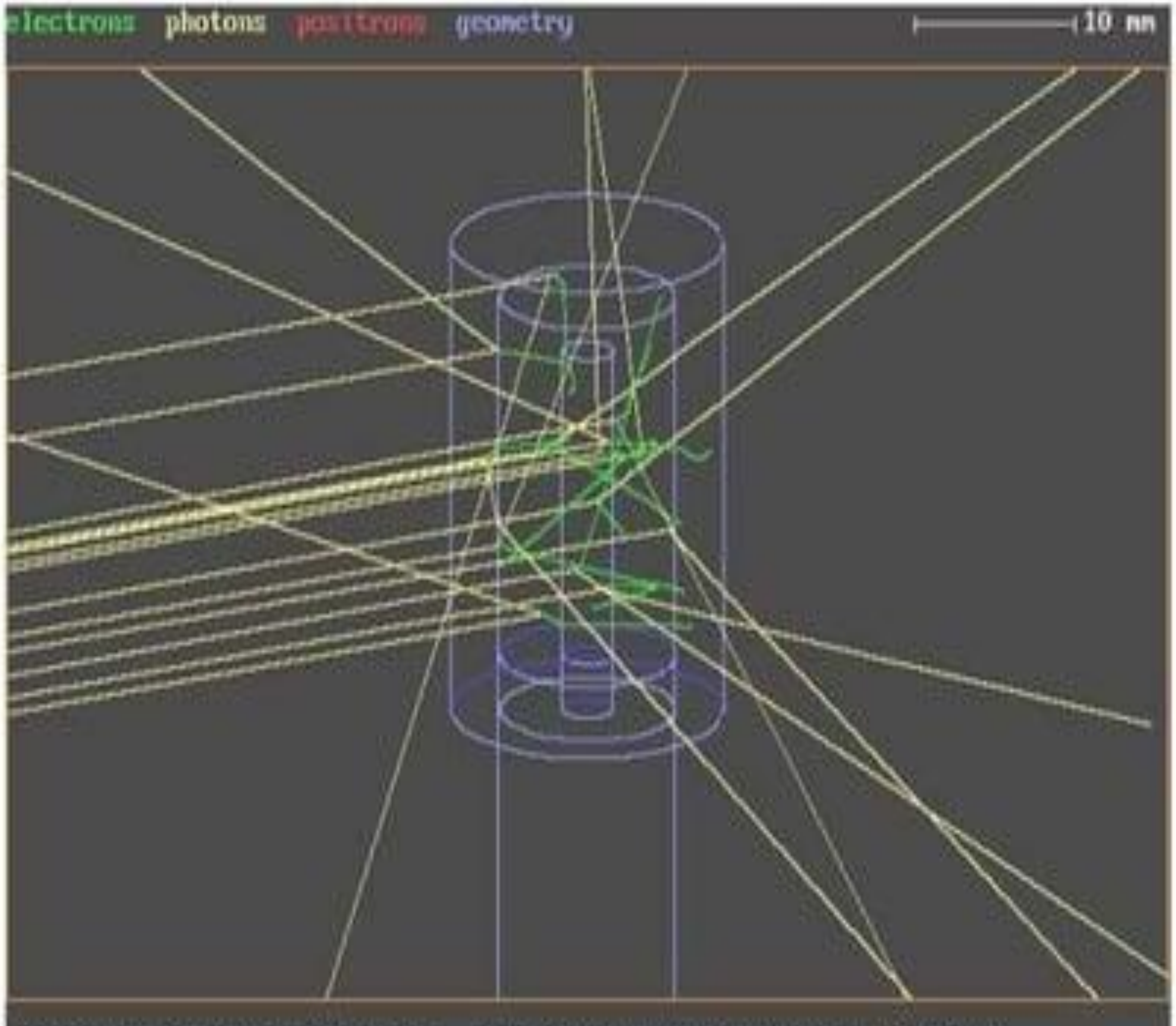
Unit : sec/min/hours

# ICRU SPHERE

- The operational quantites for all types of radiation are defined on the basis of a phantom namely **"ICRU SPHERE"**
- **ICRU SPHERE** is a sphere which is made up of tissue equivalent material.
- It has a diameter of 30cm and a density of $1 g/cm^3$
- Mass Composition : Oxygen = 76.2 %

  Carbon = 11.1 %

  Hydrogen = 10.1%



electrons
photons
positrons
geometry
10 mm

# Absorption of energy from x & γ rays

- **Fluence :**

No. of particles passing through a unit cross sectional area

$\varphi$ = photon/particles/ area

$\varphi = dN/da$

dN => no. of particles incident on a sphere of cross sectional area da

**Unit : $m^{-2}$ / $cm^{-2}$**

- **FLUX:**

the fluence rate ( rate at which the photon/ particles pass through an area per unit time ) is called flux.

**$\varphi$ = photons/ area*time**

**UNIT : $m^{-2}\ sec^{-1}$/ $cm^{-2}\ sec^{-1}$**

- **Energy Fluence** :

  It is the amount of energy passing through a unit cross sectional area.

$$\Psi = dR/da$$

dR => radiant energy incident on a sphere of cross sectional area da

**Unit : J/m$^2$**

For monoenergetic beam $\Psi = \varphi * E$

# KERMA

- It is the sum of initial kinetic energies of all charged particles liberated by photon in a mass of 1 kg.
- It is denoted by K

$$K = dE_{tr}/dm$$

$dE_{tr}$ = sum of initial kinetic energies of all charged particles liberated by charged particles in a mass dm

- The medium of interaction of the photons must be specified while measuring KERMA.
- When the interacting medium is air, then it is called " AIR KERMA".
- Total KERMA
  - collisional kerma ( $K_{coll}$)
  - radiative kerma ( $K_{rad}$)

- **Collisional Kerma ($K_{coll}$)** => leads to the production of electrons that dissipate energy as ionisation/ excitation near electron tracks in the medium.
- **Radiative Kerma ($K_{rad}$)** => leads to the production of bremsstrahlung as the charged particles are decelerated in the medium.
- **Unit** : J/Kg
- **Special Unit** : Gray

# Exposure

- It is amount of electrical charge ( $\Delta q$) produced by ionising electro magnetic radiation per mass ($\Delta m$) of air.
- It is denoted by X

$$X = \Delta q / \Delta m$$

Unit : SI Unit = C/kg

Special Unit = 1 R

- 1 R = 2.58 * $10^{-4}$ c/kg
- 1 Roentgen is defined as the no. of ion pairs produced by a gamma ray in a definite narrow area per cc. of air at STP which produces 1 esu of electricity
- 1 C/kg = 3876R

# Absorbed Dose

- Absorbed dose is the energy deposited by ionising radiation per unit mass of material at the point of interest.
- It is denoted by D

$$D = \Delta E/\Delta m$$

$\Delta E$ => mean energy imparted to matter of mass $\Delta m$.

Unit : SI Unit => GRAY(Gy)

Old Unit => RADS

100 rads = 1 Gy

1 Gy = 1 J/Kg

# Imparted Energy

- It is the total amount of energy deposited in matter.
- It is the product of dose & mass over which the energy is imparted.
- Unit : J

# Equivalent Dose

- Equivalent dose is the product of absorbed dose received by tissue (T) from radiation (R) and radiation weighting factor.
- It is denoted by $H_{T..R}$

$$H_{T..R} = D_{T..R} * w_R$$

$w_R$ = radiation weighting factor

Formerly called " Quality Factor" basically defines the quality of the radiation that is interacting with the matter.

Quality of a radaiton depends upon 2 parameters namely LET & RBE

# LET & RBE

- Linear Energy Transfer is the amount of energy transferred locally per unit length of the track.
- It is denoted by L.

$$L = dE/dl$$

dE => average energy locally imparted to the medium by a charged particle of a specified energy in traversing a distance dl.

Unit : keV/μm

- Relative Biological Effectiveness (RBE) is the ratio of biological effectiveness one type of radiation relative to the other.
- Basically it is ratio of effectiveness of various types of radiation with that of X or $\gamma$ rays.

$$RBE = D_x/D_R$$

$D_x$ => absorbed dose of a radiation from a standard radiation

$D_R$ => abosorbed dose of radiation of type R that causes the same amount of biological damage.

- Standard => absorbed dose from X-rays generated with a potential of 200 keV.
- RBE is an unit less quantity and it is more for high LET radiation.
- So equivalent dose greatly depends on the LET & RBE
- UNIT : SI Unit: SIEVERT (Sv) 100rem = 1 Sv

  Old Unit : REM ( Roentgen Equivalent Men)

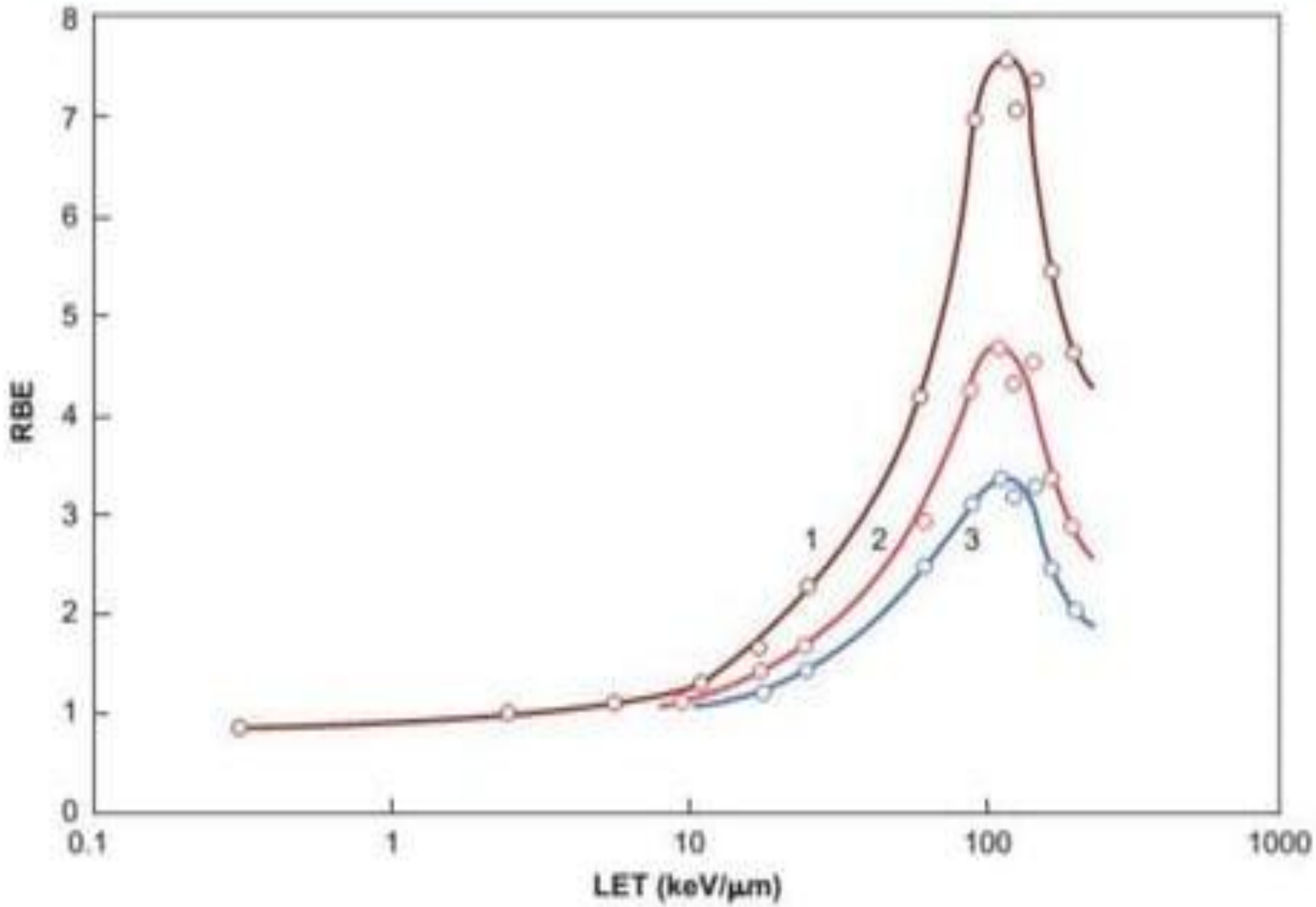



**FIGURE 7.5** Variation of relative biologic effectiveness (RBE) with linear energy transfer (LET) for survival of mammalian cells of human origin. The RBE rises to a maximum at an LET of about 100 keV/μm and subsequently falls for higher values of LET. Curves 1, 2, and 3 refer to cell survival levels of 0.8, 0.1, and 0.01, respectively, illustrating that the absolute value of the RBE is not unique

- REM = Roentgen Equivalent Men
- REM is defined as that amount of ionising radiation such that the dose delivered per gram of living tissue per 1 rad has the same effectiveness as delivered by 200kV potential applied to the cathode tube.
- REM = RBE * rad.
- 1 rem = 10mSv.

# Radiation Weighting Factors

| Radiation | $w_R$ |
|---|---|
| Beta, gamma, x-rays | 1 |
| Neutrons, <10 keV | 5 |
| >10-100 keV | 10 |
| >100 keV-2 MeV | 20 |
| >2 MeV-20 MeV | 10 |
| >20 MeV | 5 |
| Protons, >2 MeV | 2 |
| Alpha, heavy ions | 20 |

# Effective Dose

- Effective dose is the product of Equivalent dose and Tissue Weighting Factor
- Since all tissues doesn't have the same sensitivity towards radiaton, so each tissue is given a factor based on the response to radiation.
- This factor is called Tissue Weighting Factor.
- It is denoted by E

$$E = \Sigma(H_{T,R} \times w_T)$$

- $w_T$ = tissue weighting factor.
- **Unit => SI unit = Sievert (Sv)**

**Tissue Weighting Factors**

| Tissue | $w_T$ |
|---|---|
| Gonads | 0.20 |
| Bone marrow | 0.12 |
| Colon | 0.12 |
| Lung | 0.12 |
| Stomach | 0.12 |
| Bladder | 0.05 |
| Breast | 0.05 |
| Liver | 0.05 |
| Esophagus | 0.05 |
| Thyroid | 0.05 |
| Skin | 0.01 |
| Bone surface | 0.01 |
| Remainder | 0.05 |
| **Total Body** | **1.00** |

| Tissue or organ | $w_T$ according to the ICRP 60 | $w_T$ according to the ICRP 103 |
|---|---|---|
| Gonads | 0.20 | 0.08 |
| Red bone marrow | 0.12 | 0.12 |
| Colon | 0.12 | 0.12 |
| Lungs | 0.12 | 0.12 |
| Stomach | 0.12 | 0.12 |
| Breast | 0.05 | 0.12 |
| Liver | 0.05 | 0.04 |
| Esophagus | 0.05 | 0.04 |
| Thyroid | 0.05 | 0.04 |
| Skin | 0.01 | 0.01 |
| Bone surface | 0.01 | 0.01 |
| Salivary glands | – | 0.01 |
| Brain | – | 0.01 |
| [illegible] | [illegible] | [illegible] |
| $\sum w_T$ | **1.00** | **1.00** |

Weighting coefficients ($w_T$) according to the International Commission of Radiological Protection *

# Annual Limit Intake

- Annual Limit of Intake (ALI) means the greatest values of annual intake of the specified radionuclide in a committed dose equivalent not exceeding the dose equivalent limit, prescribed by the competent authority, even if the intake occurred every year for 50 years.
- Ex

| | |
|---|---|
| Iodine -131 | 1 MBq |
| Tc-99m | 2000 MBq |
| Iodine -123 | 200 MBq |

# Derived Air Concentration

- Derived Air Concentration (DAC) means the maximum concentration of a radionuclide in the ambient air by a person for 2000 hours in a year at a breathing rate of 1.2 $m^3$/hr will not result in a annual effective dose equivalent in excess of the limits prescribed by the competent authority
- DAC = ALI/ 2.4*1000
- Unit of DAC : $Bq/m^3$

# Collective effective dose

- This quantity is related to exposed group or population.
- It takes account of the number of people exposed to a source multiplying the average dose to the exposed group from the source by the number of individual in the group.
- Unit – Person sievert

# Conversion of Exposure to Absorbed Dose

- When a biological system is placed in a X or γ ray field and if the exposure rate is known then the energy absorbed by the system depends upon the energy of the photons and nature of the systems.
- The energy absorbed by the system can be determined by the f-value.
- F-values gives the conversion from exposure to absorbed dose.
- F-value gives the information regarding the rads per roentgen.

# Specific Gamma Ray Constant

- F-value is replaced by specific gamma ray constant which gives the exposure rate at 1cm from a source of 1mci which is expressed in R/hr/mci.

- SI UNIT is μGy/hr/Gbq

- It is also called air kerma rate constant.

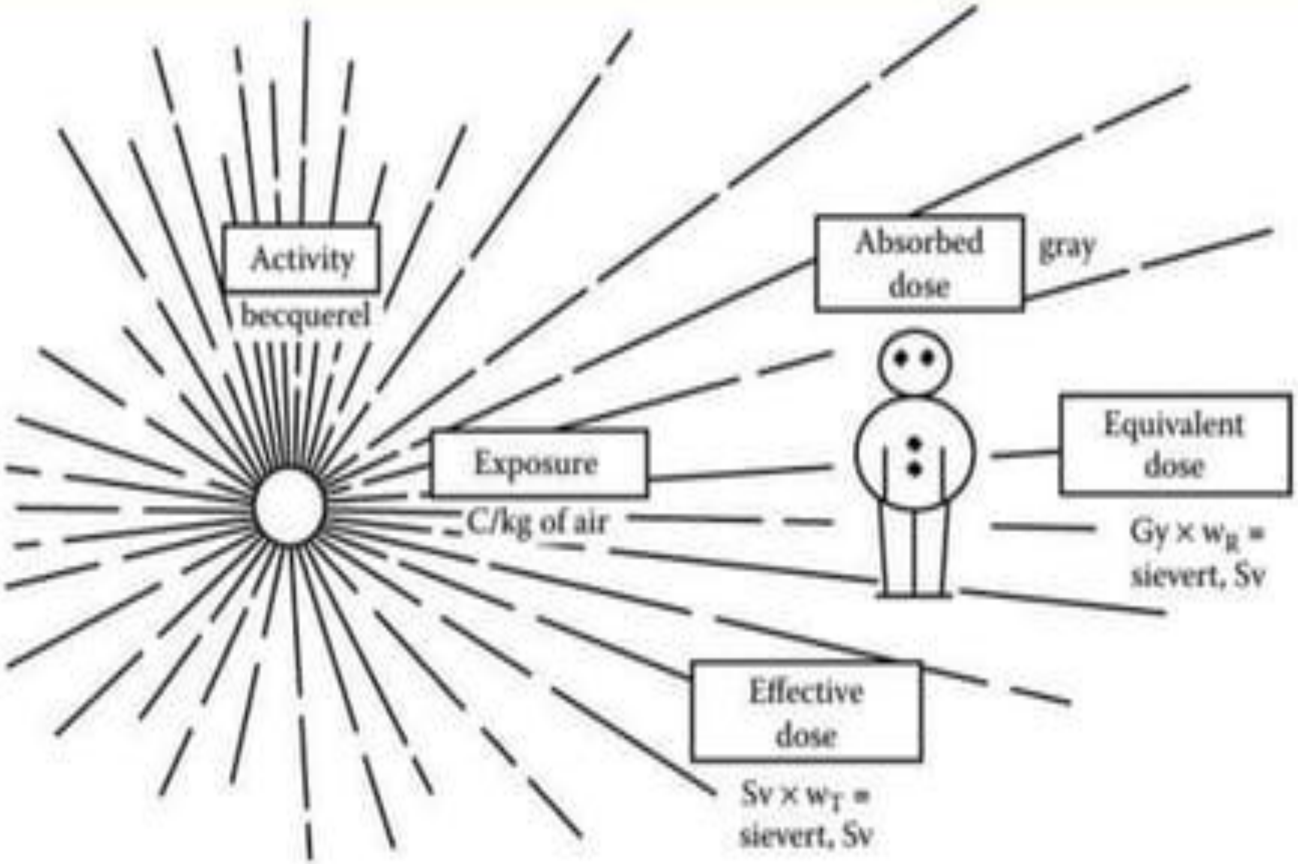



**FIGURE 2.1** The five concepts that relate a radiation worker to a radioactive source: Activity, measured in becquerels; Exposure, measured in C/kg of air; Absorbed dose, measured in grays; Equivalent dose, measured in sieverts; and Effective dose, also measured in sieverts.

# Summary

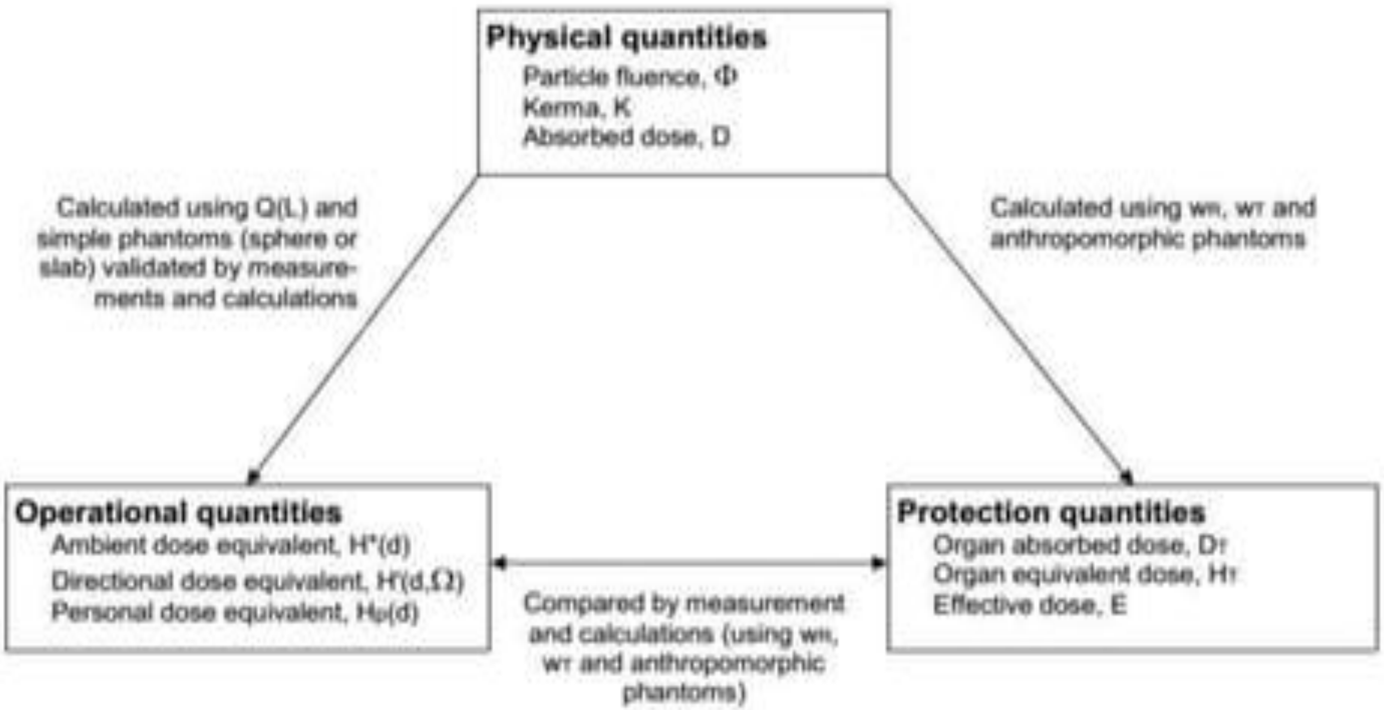



***Figure 2**: Relationship between the basic physical quantities, the operational quantities and the protection quantities [8].*

5.1 Basic physical quantities

| Quantity | Unit | Application |
| --- | --- | --- |
| Air kerma, $K_a$ | Gray (Gy) | Traceable reference quantity for photon radiation |
| Fluence, $\Phi$ | $cm^{-2}$ | Traceable reference quantity for neutron radiation |
| Absorbed dose, D | Gray (Gy) | Traceable reference quantity for electron radiation |

## 5.2 Operational quantities

| Quantity | Unit | Application |
| --- | --- | --- |
| Personal dose equivalent, $H_p(d)$ | Sievert (Sv) | Individual monitoring |
| Ambient dose equivalent, $H^*(d)$ | Sievert (Sv) | Area monitoring for penetrating radiation |
| Directional dose equivalent, $H'(d, \Omega)$ | Sievert (Sv) | Area monitoring for low-penetrating radiation |

## 5.3 Primary limiting or protection quantities

| Quantity | Unit | Application |
| --- | --- | --- |
| Organ absorbed dose, $D_T$ | Gray (Gy) | Dose limitation |
| Organ equivalent dose, $H_T$ | Sievert (Sv) | Dose limitation |
| Effective dose, E | Sievert (Sv) | Dose limitation |
| *Collective effective dose, S* | *man sievert* | *Optimisation* |

# References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# Thank You