PAM1014
Introduction to Radiation Physics

"Radiation Units & Detection"

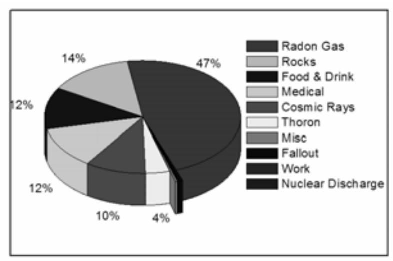
In this lecture

- ★Ionizing radiation doses in the UK
- ★Effects of Ionizing Radiation
- ★Units of Radiation
- ★Detecting Radiation

Units of Radiation

UK Average Dose

- We live in an environment where we are continuously bombarded by ionizing radiation
- UK average
  - 90% Natural
  - 10% Artificial



- All ionizing radiation is considered a hazard

Ionizing Radiation

- X-rays passing through air cause…
  1. Excitation
  2. Ionization
  3. Heating

Net Effects

1. Formation of electrical charge in air
2. Air absorbs energy as electric charges are slowed down by collisions with air molecules. Causes more ionizations
3. Heating via transfer of energy to air molecules

Traditional measure of exposure concerned only with 1.

Measure of amount of ionization in air

Exposure

Definition

"Exposure at a particular point in a beam is the ratio Q/M. Where Q is the total electric charge (of one sign) produced in a small volume of air of mass M"

- Units: $C . Kg^{-1}$

Exposure Rate

- Measure of the intensity of a beam of given quality
- Greater number of photons passing through unit area the greater the amount of ionization of air per unit time
- Units: $C . Kg^{-1} . s^{-1}$

Absorbed Dose

Definition

"Absorbed dose in a medium is the ratio E/M. Where E is the energy absorbed in a medium due to a beam of ionizing radiation directed at a small mass M."

Units: Gray
1 Gray = 1 Joule per Kilogram

Exposure & Absorbed Dose

Note:

- Exposure is defined in terms of X- or *γ-rays*
- Absorbed dose is defined in terms of any form of ionizing radiation

Detecting Radiation

Absolute Measurement of Absorbed Dose

- Requires highly specialised equipment
- Absolute Standards
  - Specialised dosemeters calibrated at the National Physics Laboratory (NPL)
- Secondary Standards
  - Used in hospitals & universities
  - Calibrated against absolute standard
- Substandard
  - Calibrated against Secondary Standard dosemeter

Absolute Measurement of Absorbed Dose

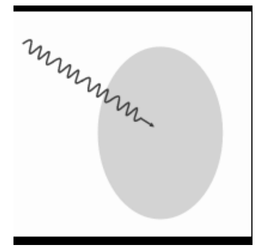
Three Techniques for Performing Absolute Measurement of Absorbed Dose

Standards against which other types of dosemeters are calibrated

1. Calorimetry
2. The Free-air Ionization Chamber
3. Chemical Methods

Calorimetry

- X-rays pass through medium: Attenuated
- Attenuation processes cause ionizations
- Kinetic Energy of ejected electrons is absorbed by atoms in medium
- Absorbed Kinetic Energy results in heating
- Temp rise prop to heat energy absorbed and therefore absorbed dose



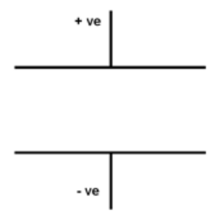
[Temperature rise: T_2 -> T_1]

Calorimetry

- However, temperature rise is VERY small
- 1 Gy produces temperature rise of ~2×10^{-4} °C
- Requires VERY sensitive measurement
- Controlled conditions
- Most appropriate for large doses

Free-air Ionization Chamber

- X-rays pass through medium: Attenuated
- Attenuation processes cause ionizations
- Ionizations can be collected at oppositely charged plates



- Charge Flow Through Chamber
- Proportional to Exposure (Coulombs per kilogram) & Absorbed Dose (Gy)

Free-air Ionization Chamber

- Total charge (Coulombs) is a direct measure of Exposure (C/Kg)
- Which is proportional to Absorbed Dose (J/Kg)
- Mass irradiated depends on temperature & pressure
- Requires precise calibration

Chemical Methods

- Ionizing radiation affects chemical bonds
- Transform Ferrous Sulphate - $FeSO_4$
- To Ferric Sulphate - $Fe_2(SO_4)_3$
- Number of $Fe_2(SO_4)_3$ ions produced is proportional to absorbed dose
- 100eV of absorbed dose produces ~15 ions

Chemical Methods

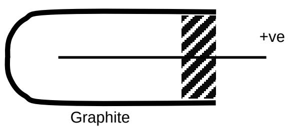
- Calibrated using either of previous methods
- Once conversion factor known: No further calibration required
- *Fricke Dosemeter*
- Large dose only (> 20Gy)
  - Due to insensitivity of measurement of Ferric Ion concentration

Detectors & Dosemeters

- Relative methods
- Used to estimate absorbed dose
- Calibrated against Absolute Methods
- Advantages & disadvantages

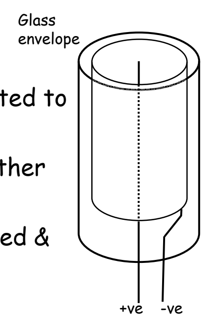
Thimble Ionization Chamber

- Condensed free-air ionization chamber
- Condenses air surrounding electrode into solid medium



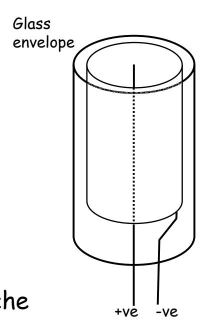
- Charge collected at electrode proportional to energy absorbed from x-ray beam

Geiger-Müller Tube



- *Gas multiplication*
- Primary Ionization: Ions accelerated to appropriate electrodes
- Sufficient energy to produce further ionizations
- Electrons produced are accelerated & produce more ionizations
- And so on …
- Excess of 1 million electrons per absorption event!

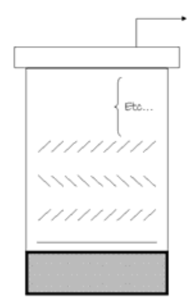
Geiger-Müller Tube



- Electron Avalanches produce electric pulses
- One pulse per primary ionization event
- Same magnitude of pulse per absorption event what ever the initial radiation energy
- Alcohol vapour 'quenches' avalanche to prevent continuous process (discrete pulses required)

Scintillation Detectors

- Scintillating Material
  - X- or γ-rays -> Light
- Photomultiplier
  - Photocathode
  - Dynodes
  - Anode
- Size of electric pulse proportional to energy deposited in material



Thermoluminescent Dosimetry

- Estimate dose using lithium fluoride powder, chips or impregnated PTFE discs
- Average atomic number of lithium fluoride is 8.2 (close to soft tissue 7.5)
- Both have similar absorption spectra

Mechanism of Thermoluminescence

- X-ray photon -> photoelectric interaction
- Photoelectrons get 'stuck' in traps caused by impurities in the lithium fluoride
- Remain in traps until heated
- Some of the escaping electrons find luminescent centres & emit light photons
- Intensity of light emitted is proportional to absorbed dose

Thermoluminescent Dosimetry

- Similar radiolucency to tissue allows dose measurement without interfering with procedure
- Small diameter ~1mm
- May be used to estimate dose to different body parts during a procedure

Photographic Film

- Film produces an increase in optical density when it is irradiated
- NOT proportional to Absorbed Dose
- Calibration required for specific processing
- Film has higher Z than tissue (AgBr: Z = 41)
- Much higher photoelectric absorption at low eV
- Requires correction for photon energy to allow estimation of absorbed dose

Semiconductor Detectors

- Absorption of X-ray energy raises energy of electrons in a semiconductor in to conduction band
- These electrons conduct electricity
- If potential difference is applied, electrons collect at anode before recombination with holes
- Produces current pulse proportional to number of electrons & therefore absorbed dose

Semiconductor Detectors

- Similar to current through ionization chamber
- *Solid-state ionisation chamber*
- Produces 10 times as many electrons for given dose;
  - Ion-pair production requires
    - 3 eV in semi-conductor
    - 33 eV in air
- Far more sensitive than thimble chamber

Summary

★Ionizing radiation doses in the UK

★Effects of Ionizing Radiation

★Units of Radiation

★Detecting Radiation