PAM2001
Detectors & Dosemeters

In this lecture

★Absolute measurement of absorbed dose

★Measuring absolute absorbed dose

★Relative methods of assessing absorbed dose

Absolute Measurement of Absorbed Dose

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

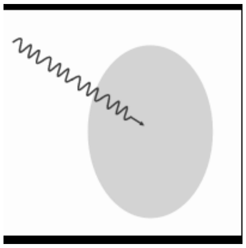
Absolute Measurement of Absorbed Dose

<u>Three Techniques for Performing Absolute Measurement of Absorbed Dose</u>

Standards against which other types of dosemeters are calibrated

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

Calorimetry



[Temperature rise: T_2 -> T_1]

- 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

Calorimetry

- Absorbed Dose can be calculated from temperature rise (T_2-T_1)
- If we know the specific heat capacity

$$D = c\,(T_2 - T_1)$$

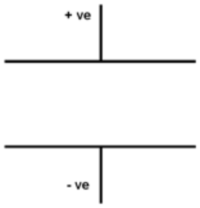
- c is the heat capacity of medium

Heat Energy Revision: Cloke, Pages 63 - 64

Calorimetry

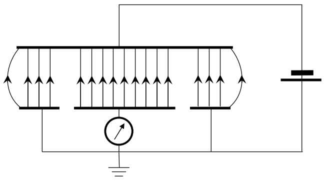
- However, temperature rise is VERY small
- 1 Gy produces temperature rise of ~2 X 10^{-4} ^{o}C
- Requires VERY sensitive measurement
- Controlled conditions
- Most appropriate for large doses

Free-air Ionization Chamber



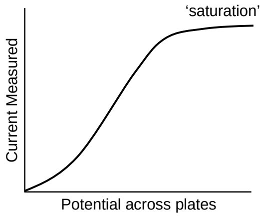
- X-rays pass through medium: Attenuated
- Attenuation processes cause ionizations
- Ionizations can be collected at oppositely charged plates
- Charge Flow Through Chamber
- Proportional to Exposure (Coulombs per kilogram) & Absorbed Dose (Gy)

Free-air Ionization Chamber



- Disc surrounded by annulus
  (Earth Potential)
- Enables accurate estimation of volume where ions are produced
- Ensures parallel field lines
- Potential across plates must be sufficient to collect all ion-pairs in measurement volume

Free-air Ionization Chamber



- Steady beam of radiation: measured current will vary with applied potential
- Below saturation some ion-pairs are able to recombine
- Above saturation: ion-pairs permanently separated
- Typically several hundred volts

Free-air Ionization Chamber

Plate Separation

- Must be sufficient to allow all secondary ionizations in air
  - I.E. No electron must reach plate before it produces all ions pairs which it is capable of
- If separation is too small, measure current will be too low
- Optimal separation depends on photon energy
- High energy photon produce high energy e^-s which travel further
- Varies from 20 cm (for <250keV) to several metres (<1MeV)
- High energy devices are LARGE!

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

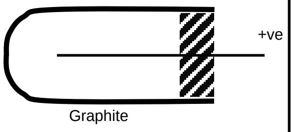
Chemical Methods

- 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

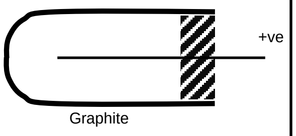
- Relative methods
- Used to estimate absorbed dose
- Calibrated against Absolute Methods
- Advantages & disadvantages

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

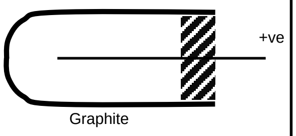
Thimble Ionization Chamber



<u>Cap Material</u>

- Air equivalent
- Same atomic number as air
- Same absorption as the *same mass of air*
- Electrons used to measure change in charge are produced in cap NOT air

Thimble Ionization Chamber

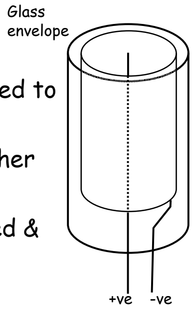


- Calibrated for several photon energies
- Correction Factor
- Must correct for temperature
- Factor to convert exposure to dose for specific radiation

<u>Cap Thickness</u>

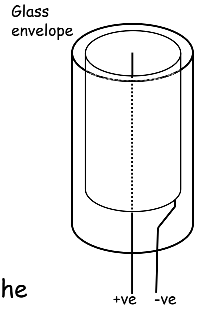
- Too thin: Insufficient electrons enter chamber
- Too thick: Too much radiation absorbed

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

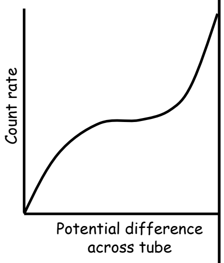


- Electron Avalanches produce electric pulses
- One pulse per primary ionization event
- Same magnitude of pulse per absorption event what ever the initial radiation energy
- Alcohol vapour ‘quenches’ avalanche to prevent continuous process (discrete pulses required)

Geiger-Müller Tube

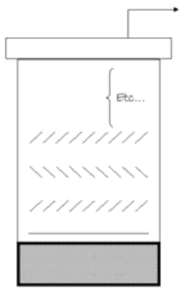
- *Dead Time* after each pulse where another absorption event is not recorded
- Typically 5μs
- Only effect high count rates
- Observed count rate of 1,000Hz is really 1005Hz
- Observed count rate of 100,000Hz is really 200,000Hz

Geiger-Müller Tube



- Must apply correct potential
- *Proportional region*: some gas multiplication, size of pulses proportional to radiation energy
- *Plateaux region:* maxium gas amplification, all pulse has same magnitude
- *Continuous discharge region:* Field ionizes gas – continuous unwanted gas multiplication
- Usually 100 to 1500V – depending on size

Scintillation Detectors



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

Scintillation Detectors

- Plastics – atomic number Z close to air
  - Termed air equivalent
  - Used to estimate absorbed dose in air
- Sodium Iodide: Cloke Appendix B
- Scintillation Detectors are very Sensitive

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 Revision: Cloke, Section 18.3

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

- Absolute measurement of absorbed dose
    - Calorimetry
    - Free-air Ionization Chamber
    - Chemical Methods
- Dosemters
    - Thimble
    - GM Tube
    - Scintillation Detectors
    - Thermoluminescence
    - Photographic Film
    - Semiconductors

Directed Reading

Cloke

- Section 18.3
- Appendix B