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Dosimetry concepts and ionometry

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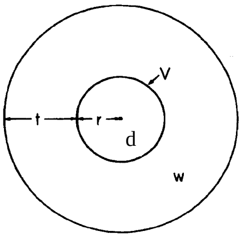
Dosimetry - recap

- *Dosimetry*: determination of absorbed dose
- Involves e.g. estimation of KERMA, fluence, radiation spectrum etc
- *Dosimeter*: device that provides a reading r ~ D
- Not interested in dose to dosimeter, but *dose to medium*

Dosimeter model

- Consider a dosimeter consisting of a wall and a sensitive volume:



- Wall: source of secondary electrons; shields V from electrons originating outside wall; mechanical protection of V; container (if V gas or liquid); may filter the beam.

Dosimetry - recap

- With cavity theory, the dosimeter energy response may be determined
- If photon irradiation + CPE:

$$D = K_c = \Psi\left(\frac{\mu_{en}}{\rho}\right)$$

- If charged particle irradiation:

$$D = \Phi\left(\frac{S}{\rho}\right)$$

- Theory of Burlin for intermediate-sized cavities

Dosimetry characteristics

- An *absolute* dosimeter directly provides a measure of absorbed dose without requiring calibration
- Examples: calorimetric dosimeters, ferrous sulfate dosimeters, *ionization chambers*
- A *relative* dosimeter provides a reading that is proportional to absorbed dose, and requires calibration
- Examples: thermoluminescence dosimeters, diodes, film dosimeters, EPR dosimeters

Precision

- Precision, or reproducibility, reflects fluctuations in in instrument, ambient conditions, stochastic nature of radiation fields
- Precision in single measurement can be estimated from a series of dosimeter readings $\{r_i\}$:

$$\sigma = \sqrt{\frac{1}{n-1}\left(\sum_{i=1}^{n}(r_i - \bar{r})^2\right)}$$

- Precision in mean estimate: $\sigma = \sqrt{\frac{1}{n(n-1)}\left(\sum_{i=1}^{n}(r_i - \bar{r})^2\right)}$

Accuracy

- Systematic errors reflect that the measured value contains an offset
- Accuracy reflects the proximity of the estimate to the true value - reflects all systematic error contributions that influence the reading
- Example: calibration error

High accuracy
Low precision

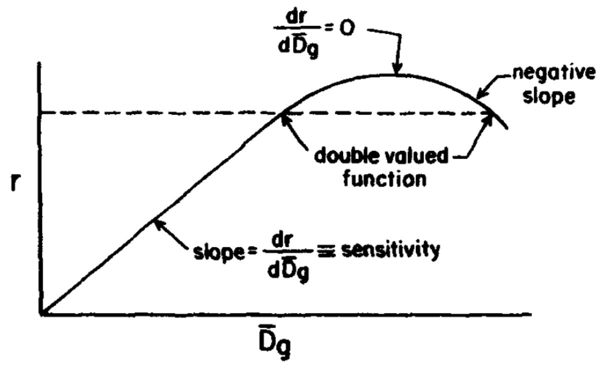
Low accuracy
High precision

Dosimeter limitations

- A sensitive dosimeter is characterized by a high dr/dD
- A constant sensitivity (dr/dD = const) means a linear dose response
- A dosimeter may give a background reading r_0
- If r_0 is small, a low detection limit may obtained by the dosimeter readout system
- The upper detection limit depends both on the readout system and the dosimeter material

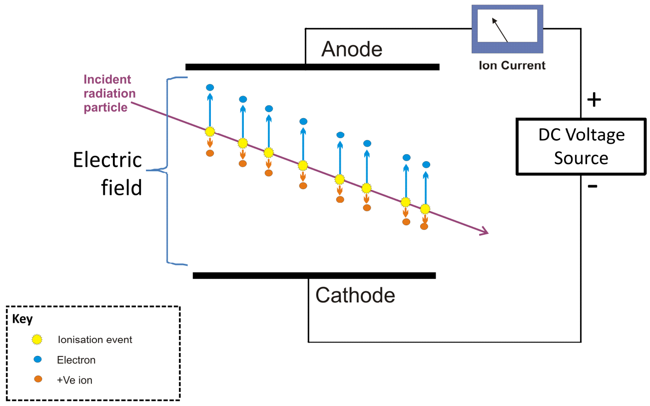
Dose response

- Example of dose-response characteristics



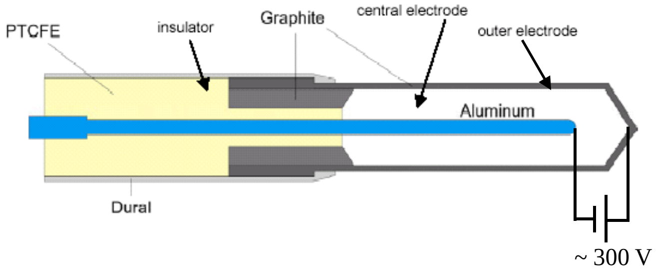
Ionometry

- Ionometry: the science of measuring ionizations
- Number of ionizations proportional to dose



Ionometry

- Air filled ionization chamber (”thimble”):



Ionometry

- High voltage over inner and outer electrode
- Air is ionized; electrons are liberated
- Electrons collected at the positive electrode
- Induced current
- The number of charges produced is counted by an electrometer, which also provides the voltage
- Number of charges proportional to dose to air

Exposure

- Exposure, X : number of charges Q (either positive or negative) prodused in a gass of mass m:

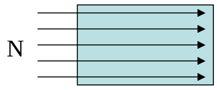
$$X = \frac{dQ}{dm}$$

- Number of charges per mass proportional to dose:

  $X \propto D_{air}$
- The quantity relating X to D_{air} is the mean energy per ion pair, $\overline{W}$

Mean energy per ion pair

- Determination of $\overline{W}$:
  - Charged particles with kinetic energy T_0 is completely stopped in a gas:



  - Total energy loss:

    $W = NT_0$
  - Mean energy loss per charge detected

$$\frac{\overline{W}}{e} = \frac{N\overline{T_0}}{Q}$$

Dose to air, D_{air}

- For air, $\overline{W/e}$ is 33.97 J/C
- The dose to air:

$$D_{air} = \frac{N\overline{T}_0}{m} = \frac{Q}{m}\left(\frac{W}{e}\right)_{air} = X\left(\frac{W}{e}\right)_{air}$$

- Thus, by measuring the number of charges produced per mass unit of air, D_{air} may be determined – indepedent of the radiation quality ($\overline{W/e}$ is close to being constant for all electron- and photon energies)

Dose to air, D_{air} 2

- If CPE is present in the ion chamber, the dose following photon irradiation is:

$$D_{air} \overset{CPE}{=} K_{c,\,air} = \Psi\left(\frac{\mu_{en}}{\rho}\right)_{air} = X\left(\frac{\overline{W}}{e}\right)_{air}$$

- The exposure is thus:

$$X \overset{CPE}{=} \Psi\left(\frac{\mu_{en}}{\rho}\right)_{air}\left(\frac{\overline{W}}{e}\right)_{air}^{-1}$$

(If the primary field is charged particles, Bragg-Gray theory may be used: $D_{air} = \Phi\left(\frac{dT}{\rho dx}\right)_{air}$)

Exposure, examples

- Electrometer and air filled ion chamber (volume = 0.65 cm^3) is used to measure Q=50 nC over 2 min – the radiation a 100 keV monoenergetic photons (CPE is assumed)
- Exposure:

$$X = \frac{Q}{m} = \frac{Q}{\rho V} = \frac{50 \times 10^{-9}\ \text{C}}{1.2 \times 10^{-3}\ \text{g/cm}^3 \times 0.65\ \text{cm}^3} = 0.064\ \text{C/kg}$$

- Energy fluence:

$$\Psi = X \left(\frac{\mu_{en}}{\rho}\right)_{air}^{-1} \left(\frac{\overline{W}}{e}\right)_{air}$$

$$= 0.064\ \text{C/kg} \times \frac{1}{0.0234\ \text{cm}^2/\text{g}} \times 33.97\ \text{J/C}$$

$$= \underline{\underline{0.093\ \text{J/cm}^2}}$$

Exposure, examples 2

- Dose to air and dose rate:

$$D_{air} = X \left(\frac{\overline{W}}{e}\right)_{air} = 0.064\ \text{C/kg} \times 33.97\ \text{J/C}$$

$$= 2.2\ \text{J/kg} = \underline{\underline{2.2\ \text{Gy}}}$$

$$\dot{D}_{air} = \frac{\Delta D_{air}}{\Delta t} = \frac{2.2\ \text{Gy}}{2\ \text{min}} = \underline{\underline{1.1\ \text{Gy/min}}}$$

- If the ion chamber is placed in water, the dose to water is

$$\frac{D_w}{D_{air}} = \left(\frac{\mu_{en}}{\rho}\right)_{air}^{w} = \frac{0.0256}{0.0234} = 1.094$$

$$D_w = 1.094\ D_{air} = 1.094 \times 2.2\ \text{Gy} = \underline{\underline{2.4\ \text{Gy}}}$$

Exposure, examples 3

- If the same exposure is resulting from 100 MeV protons, what is the corresponding energy fluence?
- For protons, Bragg-Gray theory is used:

$$D_{air} = \Phi \left(\frac{dT}{\rho dx} \right)_{air} = X \left(\frac{\overline{W}}{e} \right)_{air}$$

- The proton energy is virtually constant over the cavity:

$$\Rightarrow \Psi = \Phi T_0 \quad \Rightarrow \quad \frac{\Psi}{T_0} = X \left(\frac{\overline{W}}{e} \right)_{air} \left(\frac{dT}{\rho dx} \right)_{air}^{-1}$$

$$\Rightarrow \Psi = X T_0 \left(\frac{\overline{W}}{e} \right)_{air} \left(\frac{dT}{\rho dx} \right)_{air}^{-1}$$

$$= \frac{0.064 \text{ C/kg} \times 100 \text{ MeV} \times 33.97 \text{ J/C}}{6.43 \text{ MeV cm}^2 / g} = \underline{\underline{0.034 \text{ J/cm}^2}}$$

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Exposure, examples 4

- Dose til air:

$$D_{air} = X \left(\frac{\overline{W}}{e} \right)_{air} = 0.064 \text{ C/kg} \times 33.97 \text{ J/C} = \underline{\underline{2.2 \text{ Gy}}}$$

(must be equal to the dose from photons, since the exposure was the same)

- Dose to water:

$$\frac{D_w}{D_{air}} = \left(\frac{dT}{\rho dx} \right)_{air}^{w} = \frac{7.29}{6.43} = 1.13$$

$$\Rightarrow D_w = 1.13\, D_{air} = 1.13 \times 2.2 \text{ Gy} = \underline{\underline{2.5 \text{ Gy}}}$$

- Same exposure from photons and protons does *not* give the same dose to e.g. water!

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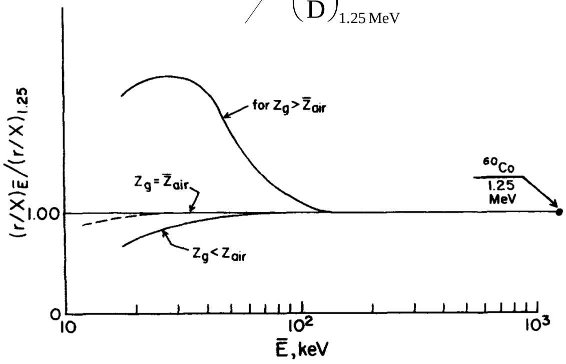
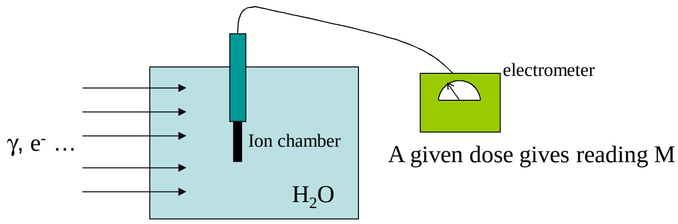
Energy response - photons

$$\frac{\left(\frac{r}{D}\right)_{\bar{E}}}{\left(\frac{r}{D}\right)_{1.25\,\mathrm{MeV}}}$$



Practical ion chamber dosimetry

- Problems with ion chambers is e.g. inacuracies in determining air volume
- In practice, the ion chamber is calibrated at a point where the dose is known – performed at a primary standards laboratory (PSDL)



Practical ion chamber dosimetry 2

- For a given dose to water, D_w, an ion chamber reading M is obtained. Thus:

$$D_w \propto M \quad \Leftrightarrow \quad D_w = MN_{D,w}$$

- The calibration factor is:

$$\boxed{N_{D,w} = \frac{D_w}{M}}$$

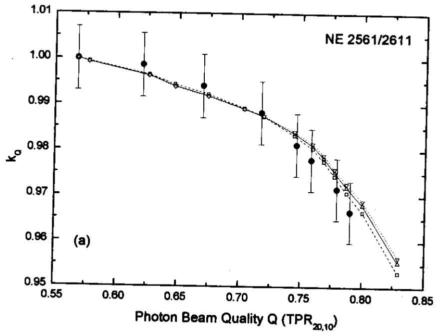
- Thus, the dose may be determined without using W/e, μ_{en}/ρ etc

Practical ion chamber dosimetry 3

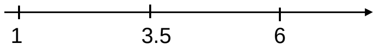
- However, the calibration factor is (weakly) dependent on the radiation type and energy, due to differences in absorption properties between water and air.
- Keep in mind (μ_{en}/ρ)- the (S/ρ)-ratios, and that M is proportional to D_{air}!
- Usually, the chamber is calibrated in a well defined field, e.g. ^{60}Co γ-rays (average energy 1.25 MeV)
- Corrections of the calibration factor, k_Q, is thus introduced for other energies (radiation ”qualities”, e.g. 15 MV X-rays)

Practical ion chamber dosimetry 4

- Absorbed dose to water:
- k_Q: beam quality correction factor



photons



~ Mean photon energy, MeV