

Principles of applied dosimetry - illustrated by ionometry

Lesson FYSKJM4710

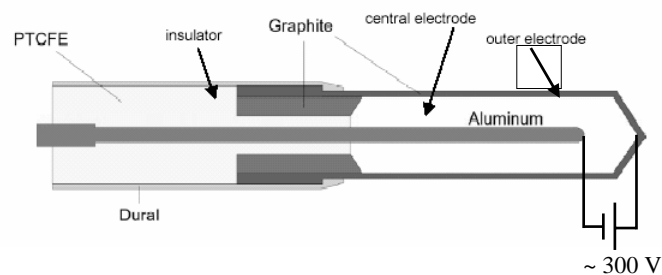
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Ionometry

- Ionometry: the art of measuring ionizations
- Number of ionizations proportional to dose
- Air filled ionization chamber ("thimble"):



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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) produced in a mass of mass m :

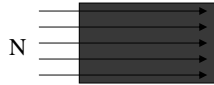
$$X = \frac{dQ}{dm}$$

- Number of charges per mass proportional to dose:
 $X \propto D_{\text{air}}$
- The quantity relating X to D_{air} is the mean energy per ion pair, \bar{W}



Mean energy per ion pair

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



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

$$\frac{\overline{W}}{e} = \frac{NT_0}{Q}$$

Dose to air, D_{air}

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

$$D_{\text{air}} = \frac{NT_0}{m} = \frac{Q}{m} \left(\frac{W}{e} \right)_{\text{air}} = X \left(\frac{W}{e} \right)_{\text{air}}$$

- Thus, by measuring the number of charges produced per mass unit of air, D_{air} may be determined – independent 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:

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

- The exposure is thus:

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

- Hvis primærefeltet er ladde partikler, anvendes Bragg-Gray teori:



Dose to air, D_{air} 3

- If the primary field is charged particles, Bragg-Gray theory may be used:

$$D_{\text{air}} = \Phi \left(\frac{dT}{\rho dx} \right)_{\text{air}}$$



Exposure, examples

- Electrometer and air filled ion chamber (volume = 0.65 cm^3) is used to measure $Q=50 \text{ nC}$ 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:

$$\begin{aligned} \Psi &= X \left(\frac{\mu_{\text{en}}}{\rho} \right)_{\text{air}}^{-1} \left(\frac{W}{e} \right)_{\text{air}} \\ &= 0.064 \text{ C/kg} \times \frac{1}{0.0234 \text{ cm}^2/\text{g}} \times 33.97 \text{ J/C} \\ &= \underline{\underline{0.093 \text{ J/cm}^2}} \end{aligned}$$

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Exposure, examples 2

- Dose to air and dose rate:

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

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

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

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

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

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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:

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

- The proton energy is virtually constant over the cavity:

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

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

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

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Exposure, examples 4

- Dose til air:

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

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

- Dose til water:

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

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

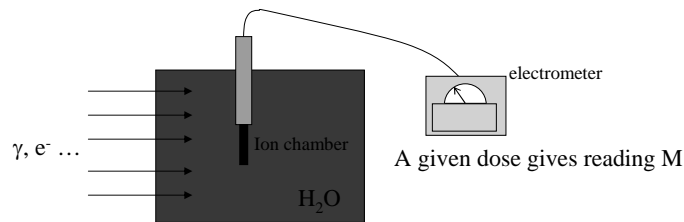
- Same exposure from photons and protons does *not* give the same dose to e.g. water!

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Practical ion chamber dosimetry

- Problems with ion chambers is e.g. inaccuracies 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)



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Practical ion chamber dosimetry 2

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

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

- The calibration factor is:

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

- Thus, the dose may be determined without using $W/e, \mu_{en}/\rho$ etc

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Practical ion chamber dosimetry 3

- However, the calibration factor is dependent on the radiation type and energy, due to differences in absorption properties between water and air.
- Keep in mind (μ_{en}/ρ) - the $(dT/\rho dx)$ -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)



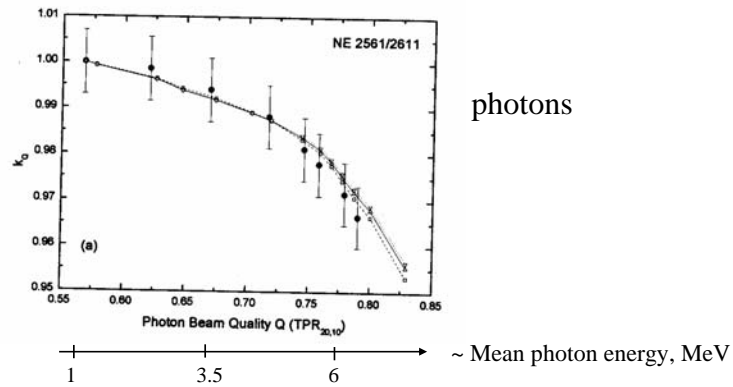
Practical ion chamber dosimetry 4

- 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 $(dT/\rho dx)$ -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 5

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



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