Principles of dosimetry – The ionization chamber

FYS-KJM 4710

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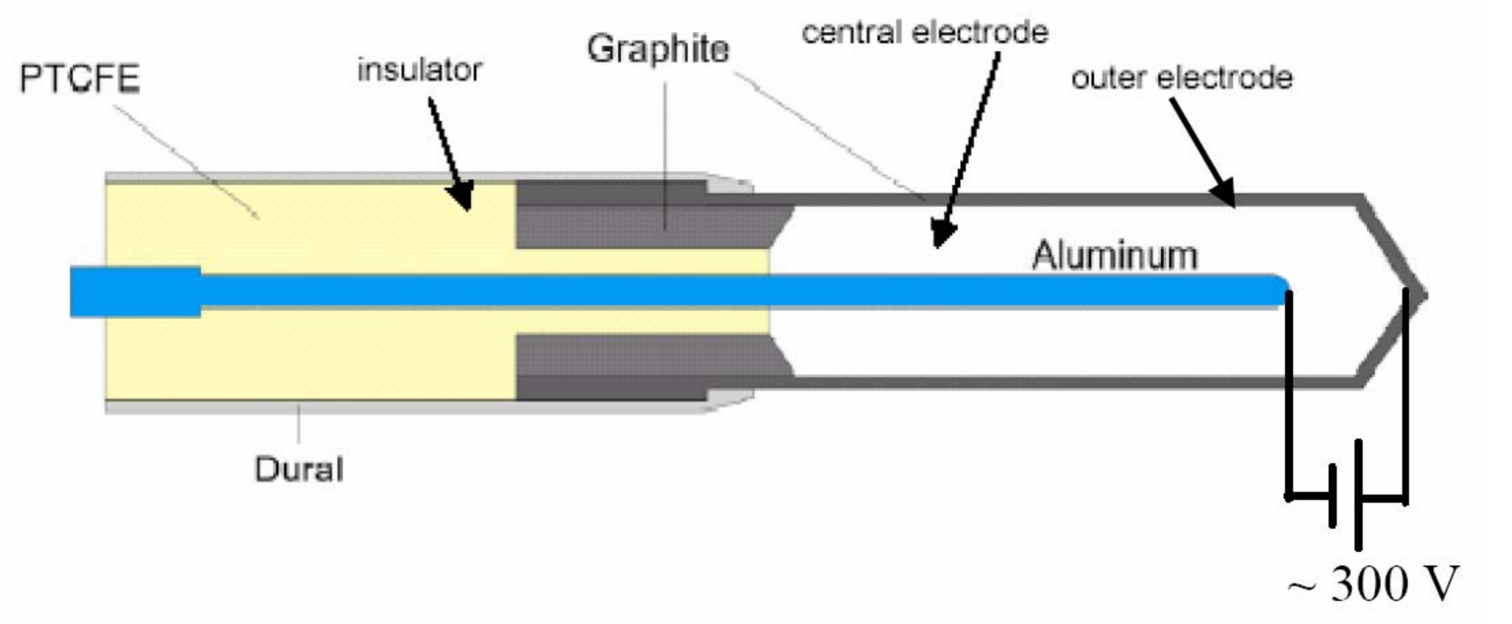
Ionometry 1)

- Ionometry: the measurement of the number of ionizations in substance
- The number of ionizations are used as a measure of the radiation dose
- Air filled ionizing chamber *(thimble)*:



Ionometry 2)

- High voltage between central and outer electrode
- Air ionized, electrons emitted from the atoms
- The electrons moves to the positive electrode
- Current induced
- An electrometer then count the number of total charges Q (of one type of charged +/–)
- Q is proportional with the dose to the air volume

Exposure

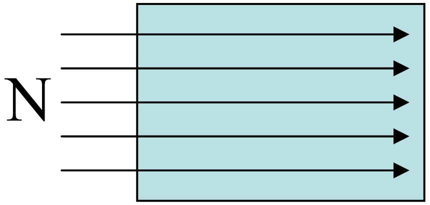
- *The exposure*, *X*: the number of charges *Q* (ether positive or negative) which is produced in the gas with mass m as a result of the radiation:

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

- The number of charges produced in the gas most be proportional with the dose; $X \propto D_{air}$
- The value connecting X and D_{air} is the mean energy expended in a gas per ion pair formed $\overline{W}$

The mean energy per ion pair, $\overline{W}$

- Definition of $\overline{W}$:
  - Charged particles with kinetic energy T_0 is stopped inside the gas:



  - Energy deposit per ion pair detected:
    $W=NT_0$ (the bremsstrahlung of electrons ought to be corrected for)
  - Mean energy per charge:

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

Dose to air, D_{air} 1)

- Air has $\overline{W}/e = 33.97$ J/C
- Then the dose to air becomes:

$$D_{air} = \frac{N\overline{T_0}}{m} = \frac{Q}{m}\left(\frac{\overline{W}}{e}\right)_{air} = X\left(\frac{\overline{W}}{e}\right)_{air}$$

- Thereby: when measuring the number of charges produced per unit of mass air, the D_{air} can be determent – independent of the type and energy of the ionizing radiation ($\overline{W}/e$ is close to constant for all electrons and photon energies)

Dose to air, D_{air} 2)

- When CPE is present inside the ionizing chamber, will the dose as a result of the photon exposure be given by:

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

- The exposure can thereby be expressed by:

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

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

$$X \overset{B\text{-}G}{=} \Phi\left(\frac{dT}{\rho dx}\right)_{air}\left(\frac{\overline{W}}{e}\right)_{air}^{-1}$$

Exposure, example 1)

- An electrometer and an air filled ionizing chamber (volume = 0.65cm^3) measure the number of charges *Q=50nC* in 2 minutes – the radiation source is 100 keV monoenergetic photons (CPE assumed)
- Exposure:

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

- What is the energy fluence of the photon field?

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

$$= 0.064\ \mathrm{C/kg}\times\frac{1}{0.0234\ \mathrm{cm^2/g}}\times 33.97\ \mathrm{J/C} = \underline{\underline{0.093\ \mathrm{J/cm^2}}}$$

Exposure, example 2)

- What is the dose to air and what is dose rate?

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

$$\dot{D}_{air} = \frac{\Delta D_{air}}{\Delta t} = \frac{2.2\ \text{Gy}}{2\ \text{min}} = 1.1\ \text{Gy/min} = \underline{\underline{18.3\ \text{mGy/s}}}$$

- If the ionizing chamber is placed in water what is the dose to water?

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

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

Exposure, example 3)

- If the same exposure is produced by 100 MeV protons, what is the energy fluence of that field?
- Bragg-Gray theory is used:

$$D_{air} = \Phi\left(\frac{dT}{\rho dx}\right)_{air} = X\left(\frac{\overline{W}}{e}\right)_{air} \qquad (\overline{W}/e \text{ assumed to be } 33.97\ \text{J/C})$$

- The proton energy is ~unchanged over the air cavity:

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

$$\Rightarrow \Psi = XT_0\left(\frac{\overline{W}}{e}\right)_{air}\left(\frac{dT}{\rho dx}\right)_{air}^{-1}$$

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

Exposure, example 4)

- Dose to air:

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

(has to be the same as of photon, because it gave the same exposure)

- Dose to water:

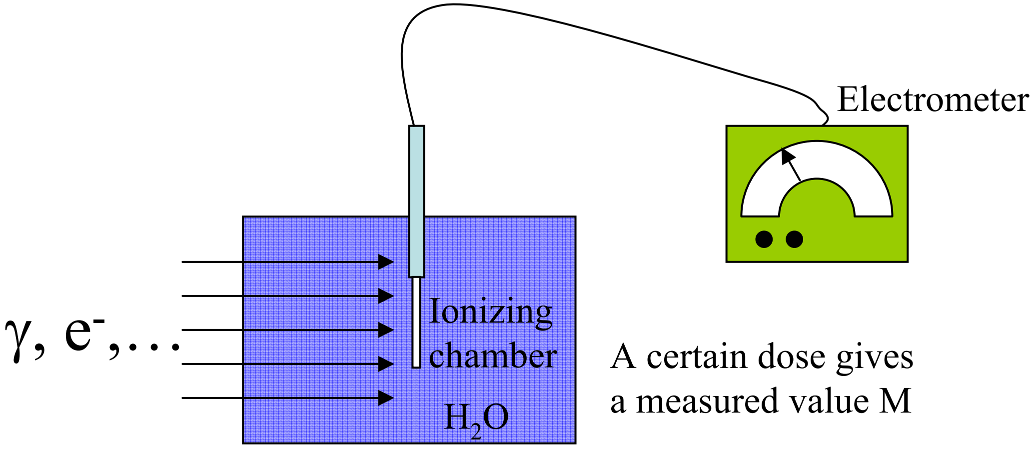
$$\frac{D_{water}}{D_{air}} = \left(\frac{dT}{\rho dx}\right)_{air}^{water} = \frac{7.29}{6.34} = 1.13$$

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

- The equal exposure of air by photons or protons give the equal doses to air but not to water!

Ionizing chamber, use 1)

- The problem with the ionizing chamber is among other difficulties to precise decide the size of the air volume – increase the uncertainty in dose
- In practice is the chamber calibrated in a point of the radiation field where the dose is known – done at a *primary standard laboratory* (PSDL)



A certain dose gives a measured value M

Ionizing chamber, use 2)

- A certain dose to water D_{water} gives a measured value M. Then:

$$D_{water} \propto M \;\Leftrightarrow\; D_{water} = M \cdot N_{D,water}$$

- The calibration factor of the chamber is then:

$$\boxed{N_{D,water} = \frac{D_{water}}{M}}$$

- The dose is then establish from the (measured) calibration factor – do not have to use W/e, μ_{en}/ρ or $dT/\rho dx$

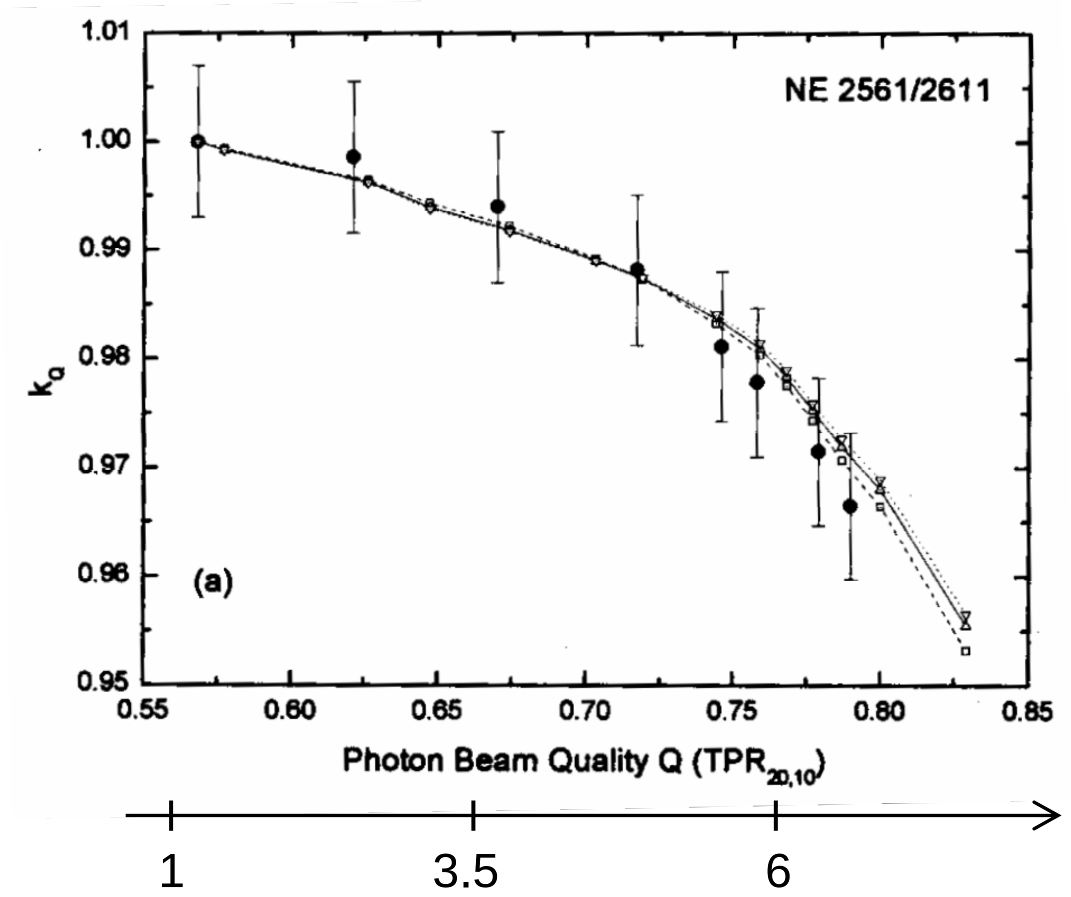
Ionizing chamber, use 3)

- But: the calibration factor is (weakly) dependent of radiation type and energy.
- Usually the calibration takes place in a well known radiation field as that of ^{60}Co γ-rays (mean energy 1.25 MeV)
- The corrections in the calibration factor, k_Q, is then introduced for other radiation qualities (*radiation qualities*, *Q*)
- The dose is then given by:

$$\boxed{D_{water,Q} = M_Q \cdot N_{D,water} \cdot k_Q}$$

Ionizing chamber, use 4)

- k_Q is named the energy correction factor; shown below in the case of high energy photons:



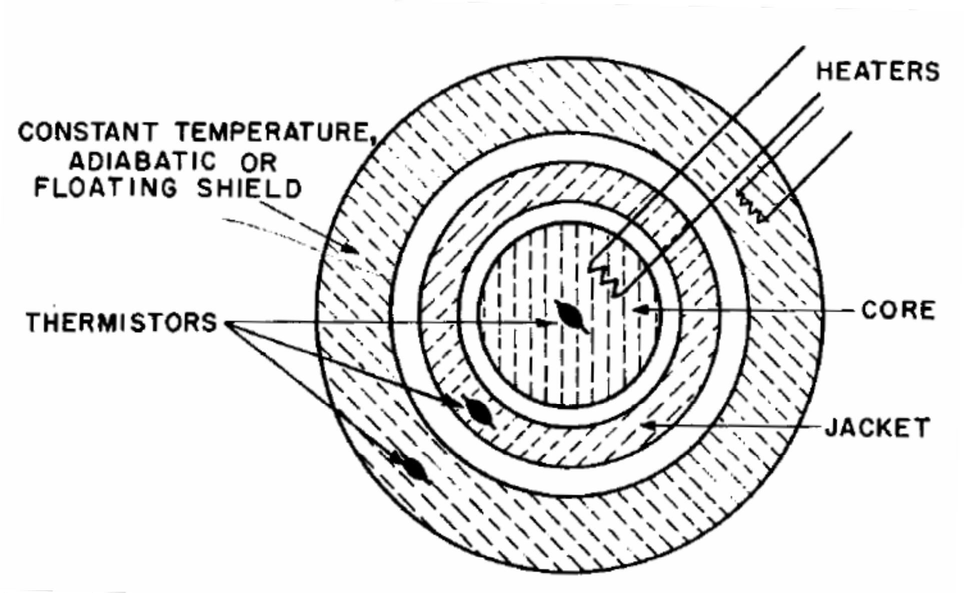
~mean photon energy, MeV

Other methods 1)

- The method and theory explained is basically the same also in other measuring methods – the measurable unit *M* is transferred into dose by a calibration factor
- Example: *EPR dosimetry*. To calibrate are dosimeters radiated in a known radiation field (^{60}Co-γ) to a known dose. The EPR-intensity of the dosimeters (*M*) is then proportional with the dose. The calibration factor of the dosimeters will then be determent as described above. k_Q most then be found if other *radiation qualities* if these are to be used.

Other methods 2)

- Calorimetric: measure the temperature in detector – very good method in absolute dosimetry:



$$\Delta\text{Temp} = \frac{\varepsilon(1\text{-}\delta)}{\text{hm}} = \frac{\text{D}(1\text{-}\delta)}{\text{h}}$$

$$\Rightarrow \quad \text{D} = \frac{\text{h}\Delta\text{temp}}{(1\text{-}\delta)}$$

δ: thermal defect

h: heat capacity

Other methods 3)

- Semiconductor dosimetry: current induced by the radiation over the depletion layer. Current proportional with the dose rate.