Dosimetry for directly ionizing radiation

Lesson FYSKJM4710

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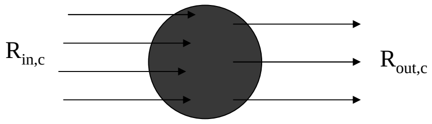
Indirectly ionizing radiation

- Directly ionizing radiation: charged particles experiencing small and frequent energy losses – continous slowing down approximation
- Limited range
- The energy loss of charged particles is described by the stopping power
- Electrons give rise to new electrons and photons – *coupled* radiation transport with mixed fields

Dose from charged particles

- Radiation field of charged particles impinges volume:

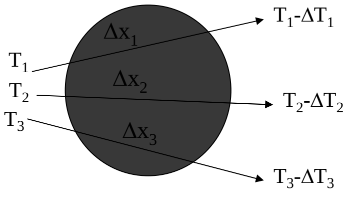


- Absorbed energy and dose:

$$\begin{aligned}
\varepsilon &= R_{in,u} + R_{in,c} - R_{out,u} - R_{out,c} + \Sigma Q \\
&= R_{in,c} - R_{out,c} \quad \boxed{, \Sigma Q = 0} \\
&= \Delta R_c \\
\Rightarrow D &= \frac{\Delta R_c}{m}
\end{aligned}$$

Dose from charged particles 2

- Problem: determining ΔR_c

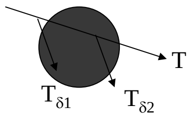


- Collision stopping power $(dT/dx)_{col}$ provides relevant energy loss:

$$\Delta R_c = \sum_{i=1}^{n} \Delta T_i = \sum_{i=1}^{N} \left(\frac{dT}{dx} \right)_{col,i} \Delta x_i$$

Dose from charged particles 2

- New problem: what about secondary electrons, both bringing and removing energy
- Such secondary electrons are called δ-electrons (remember LET_Δ)
- Energy imparted from charged particles:



$$\varepsilon = \Delta R_c + \Delta R_\delta$$

- However: δ-electrons are relatively few – remember that the cross section for energy transfer ~$1/E^2$

δ-particle equilibrium

- If the energy brought into the volume by δ-particles is the same as is taken out, $\Delta R_\delta=0$ and:'

$$\varepsilon = \Delta R_c$$

$$\Rightarrow D = \frac{\varepsilon}{m} = \frac{\Delta R_c}{m} \overset{\delta-\text{likevekt}}{=} \frac{1}{m}\sum_{i=1}^{N}\left(\frac{dT}{dx}\right)_{\text{col},i} \Delta x_i$$

- Remember that the maximum energy transfer from heavy charged particles to electrons is:

$$E_{\max} = 2m_e c^2 \frac{\beta^2}{1-\beta^2}$$

δ-particles

- Since β is low (in the MeV-region), E_{max} is low
- $\beta=0.1$ (e.g. 38 MeV α-particles) gives $E_{max}=10$ keV
- Range of 10 keV electrons in water: 2.5 μm

→ δ-electrons deposit their energy locally, and δ-equilibrium may often be present

- Range of 1 MeV electrons: 0.5 cm

→ δ-equilibrium may not obtained for high energy electron beam

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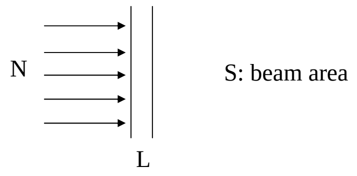
Dose from heavy charged particles

- A parallell beam of N heavy charged particles impinge a thin foil:



- Fluence: $\Phi=N/S$
- Little brehmsstrahlung from heavy charged particles:

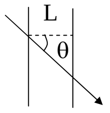
$$\left(\frac{dT}{dx}\right) \cong \left(\frac{dT}{dx}\right)_{col}$$

Dose from heavy charged particles 2

- Dose: $$D = \frac{1}{m}\sum_{i=1}^{N}\left(\frac{dT}{dx}\right)_i \Delta x_i \overset{\text{parallell}}{=} \frac{1}{m} N \left(\frac{dT}{dx}\right) L$$ $$= \frac{1}{\rho S L} N \left(\frac{dT}{dx}\right) L = \frac{N}{S}\left(\frac{dT}{\rho dx}\right)$$ $$\underline{\underline{= \Phi\left(\frac{dT}{\rho dx}\right)}}$$
- Dose prortional to beam intensity and energy loss per unit lenght
- Important assumption: (dT/dx) is constant over thin foil

Dose from heavy charged particles 3

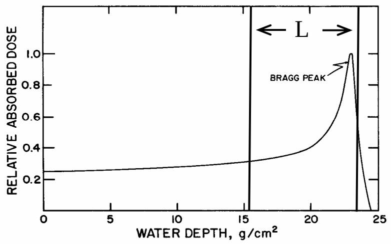
- If the beam direction is not normal to the foil plane →



$$D = \Phi\left(\frac{dT}{\rho dx}\right)\frac{1}{\cos\theta}$$

Δx=L/cosθ

- If the foil is thick or the angle high, dT/dx will vary:



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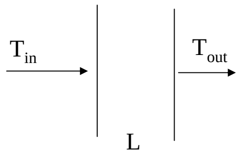
- Thick foil gives heterogenous dose distribution



- The average dose may be found by:
  - Calculating the residual range: $\Re_{res} = \Re_{in} - L$
  - Find the energy T_{out} corresponding to $\Re_{res}$
  - Imparted energy is: $\Delta T = T_{in} - T_{out}$
  - Dose: $D = \frac{N\Delta T}{m} = \Phi \frac{\Delta T}{\rho L}$

Dose from electrons

- Problems with electrons:
  - 1. Lot of scattering
  - 2. Radiative losses
  - 3. δ-elektrons
- For intermediate energy electrons in thin foils of absorbers with low Z, 1-3 is less important
- Analytic estimates for calculating the dose:
  - 1 Avarage scattering angle
  - 2 Radiation yield
  - 3. LET_{Δ}