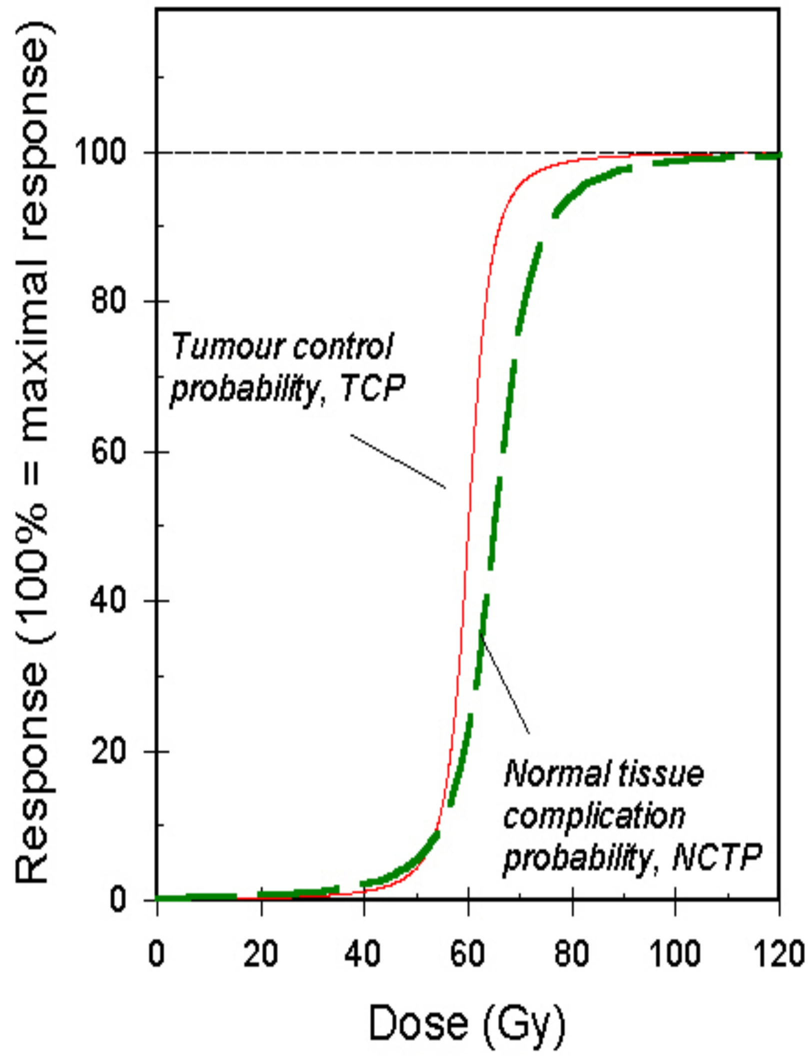
Dosimetry

Aims:

- to understand the basic concepts of dosimetry and dosimetric measurement

Syllabus:

- Fluence, Exposure, Absorbed dose, Kerma, equivalent dose, effective dose, relationships between each.
- Charged particle equilibrium, Bragg-Gray theory.
- Dosimeters – free air chamber, ion chamber, TLD


Response (100% = maximal response)
100
80
60
40
20
0
Tumour control probability, TCP
Normal tissue complication probability, NCTP
0
20
40
60
80
100
120
Dose (Gy)

Fluence

Fluence Φ

$$\Phi = \frac{dN}{da}$$ (m^{-2} or cm^{-2})

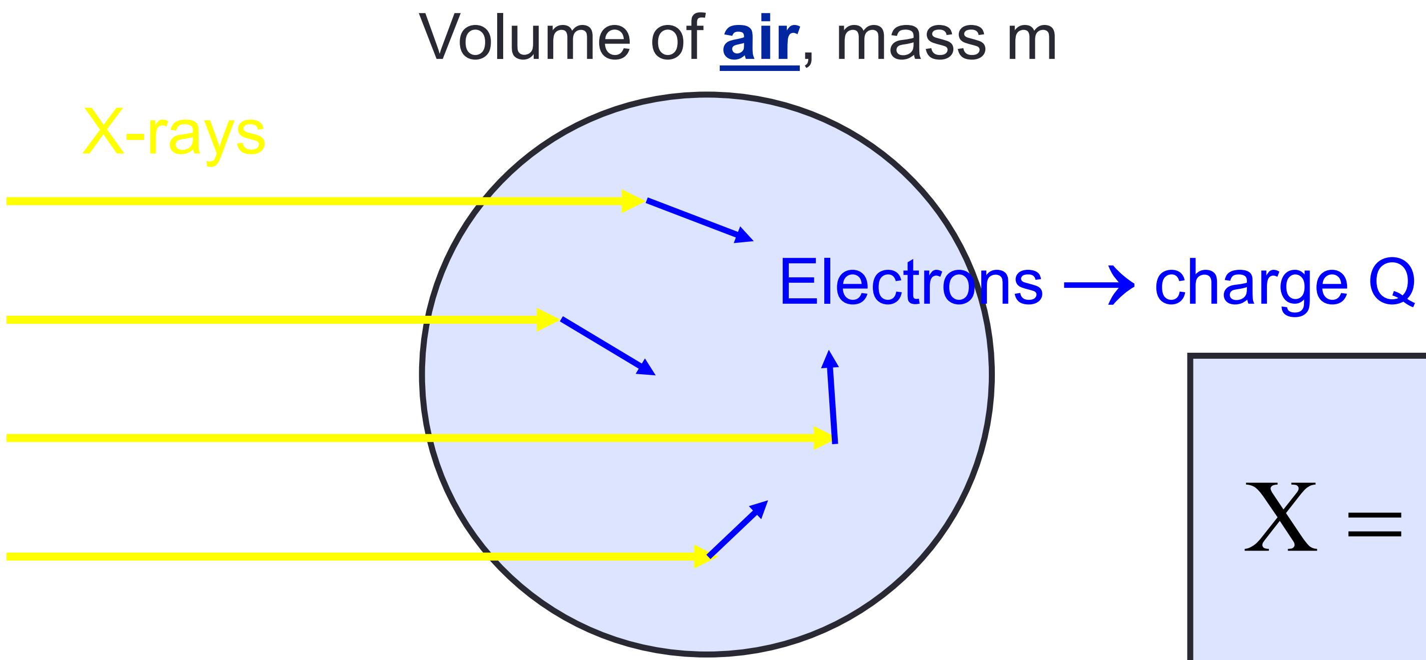
N is number of rays/particles,
a is cross sectional area

Energy fluence Ψ

$$\Psi = \frac{dR}{da}$$ (Jm^{-2})

R is total energy (summed energy of each ray/particle)

Exposure, X



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

$C\ kg^{-1}$

- by convention only applied to x- and γ-rays in air

→ a measure of photon flux at point of interest

Relationship with energy fluence

Consider the following;

Charged particle energy released per unit mass of air is

$$\Psi\left(\frac{\mu_{en}}{\rho}\right)_{air}$$

So number of ion pairs per unit mass is

$$\Psi\left(\frac{\mu_{en}}{\rho}\right)_{air}\cdot\frac{1}{W_{air}}$$

and so charge Q produced per unit mass (i.e. X) will be

$$X=\Psi\left(\frac{\mu_{en}}{\rho}\right)_{air}\cdot\frac{e}{W_{air}}$$

Worked example

A radionuclide produces 3 x 10^{10} photons cm^{-2} at the surface of the patient with an energy of 140 keV. Calculate the exposure at that point.

$W_{air}/e = 33.97\ JC^{-1}$; $(\mu_{en}/\rho)_{air} = 0.0247\ cm^2\ g^{-1}$;
1 eV = 1.602 x 10^{-19} J

Use formula $$X = \Psi \left(\frac{\mu_{en}}{\rho}\right)_{air} \frac{e}{W_{air}}$$

where Ψ = 3 x 10^{10} x 140 x 10^3 x 1.602 x 10^{-19}

= 6.73 x 10^{-4} J cm^{-2}

substituting to find X

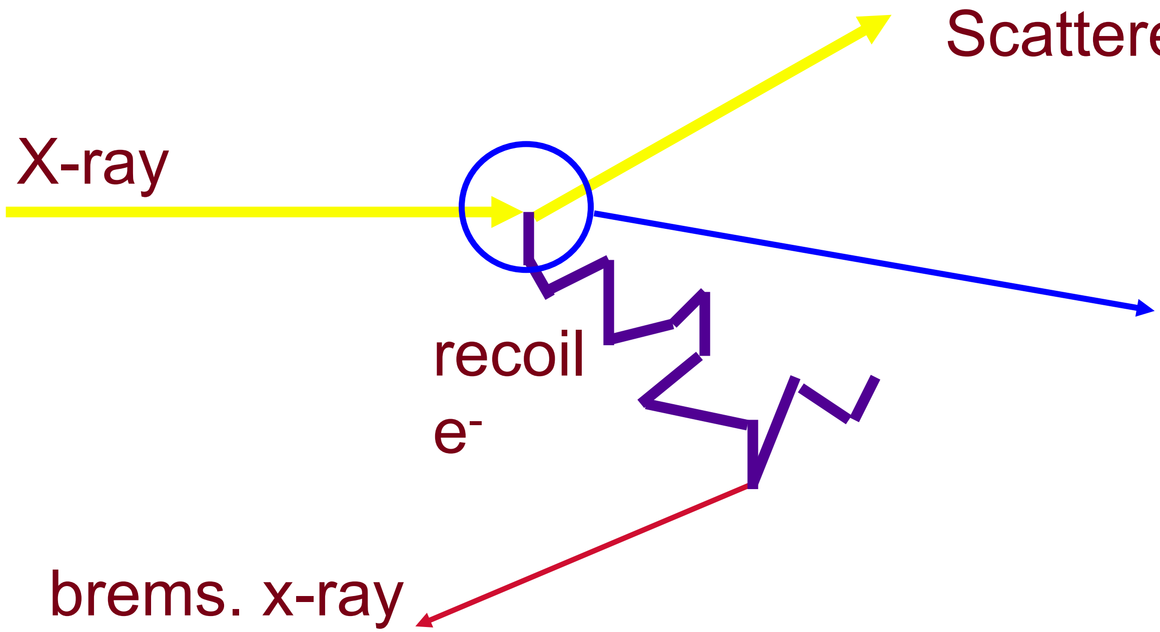
= 6.73 x 10^{-4} x 0.0247 x 1/33.97 = 4.91 x 10^{-7} C g^{-1}

= 4.91 x 10^{-4} C kg^{-1}

KERMA

KERMA - Kinetic Energy Released per unit MAss

Indirectly ionising radiation transfers energy to matter by 2 stage process



$$K = \frac{dE_{tr}}{dm}$$

(J kg^{-1} or Gy)

Components of Kerma

Total kerma = $K_c + K_r$

Collision kerma

$$K_c = \frac{dE_{tr}^{n}}{dm}$$

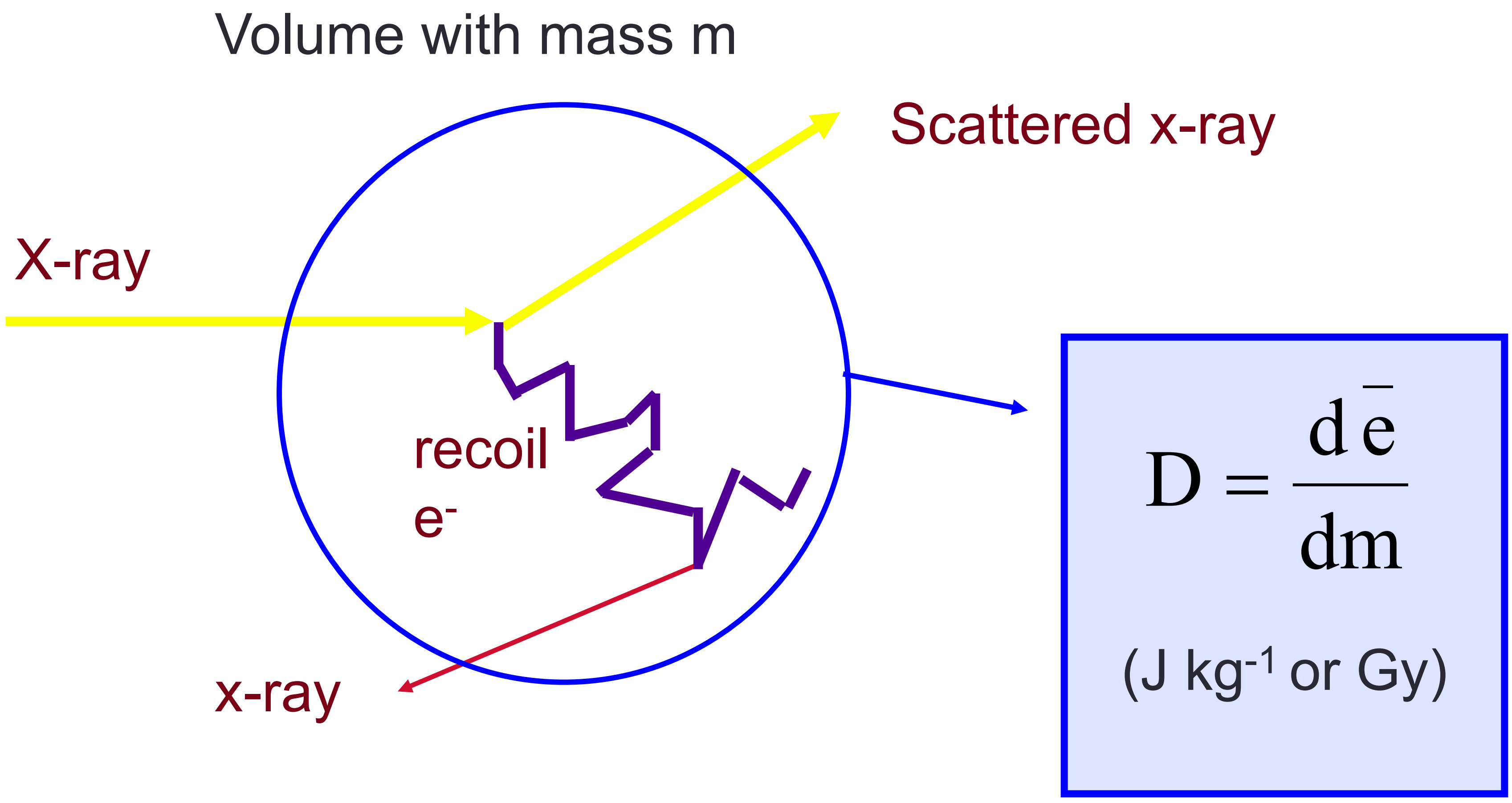
E_{tr}^{n} is the net energy transferred

- equivalent to energy transferred minus the radiative energy.

So,

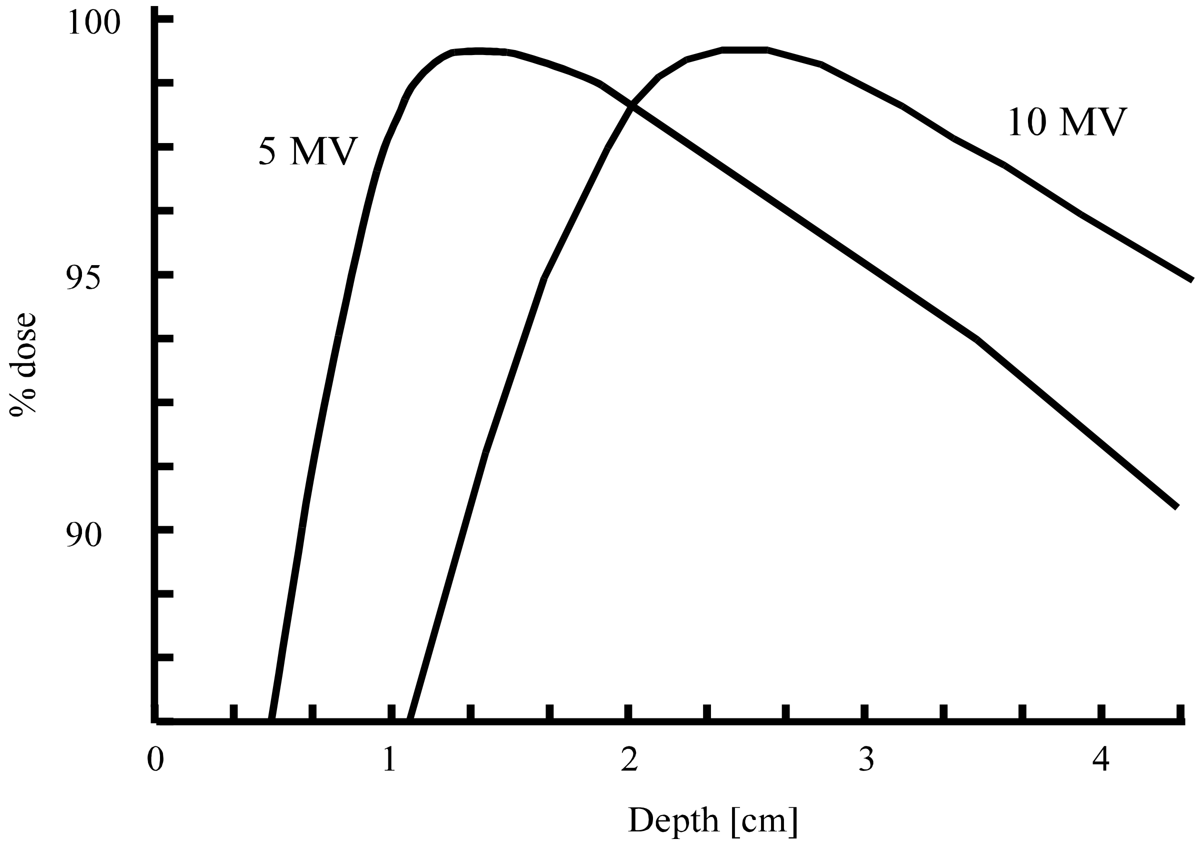
$$K_c = \Psi\left(\frac{\mu_{en}}{\rho}\right)$$

Absorbed Dose, D

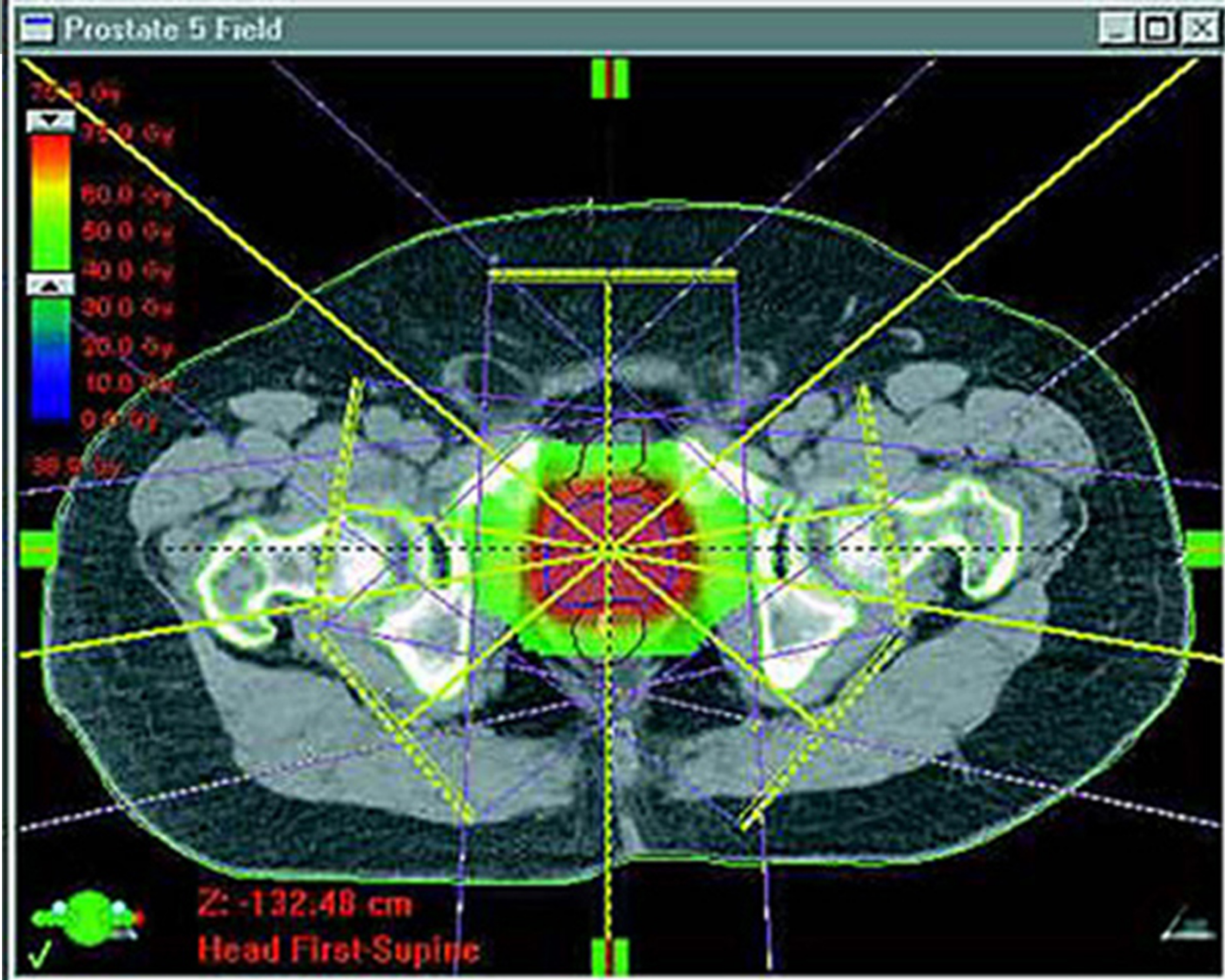


$d\bar{e}$ = total energy in - total energy out

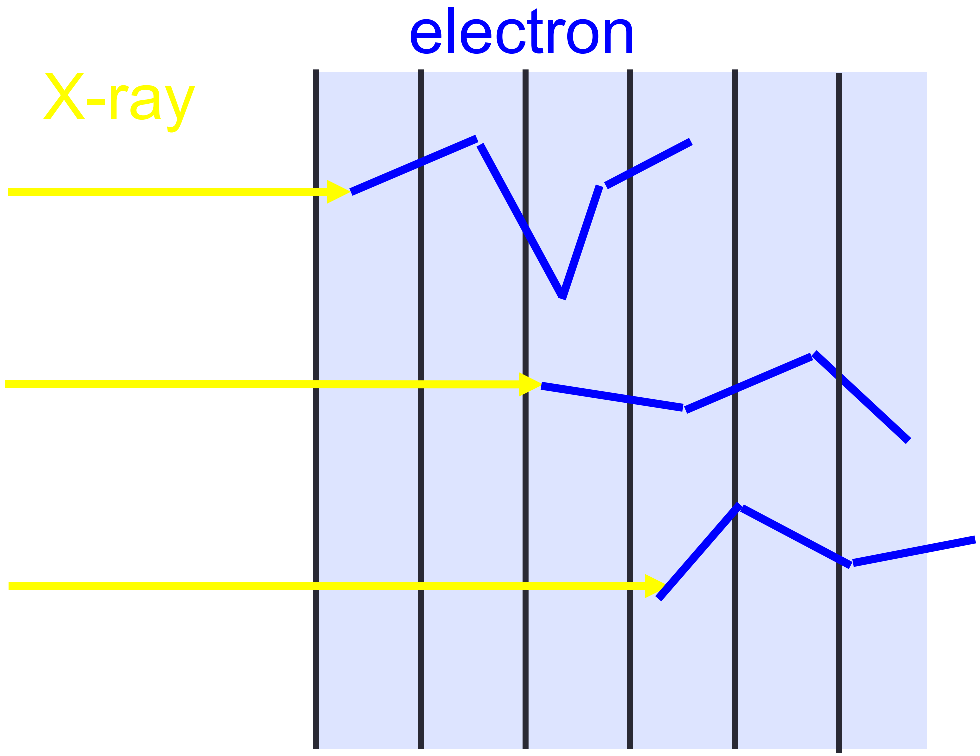
Depth Dose



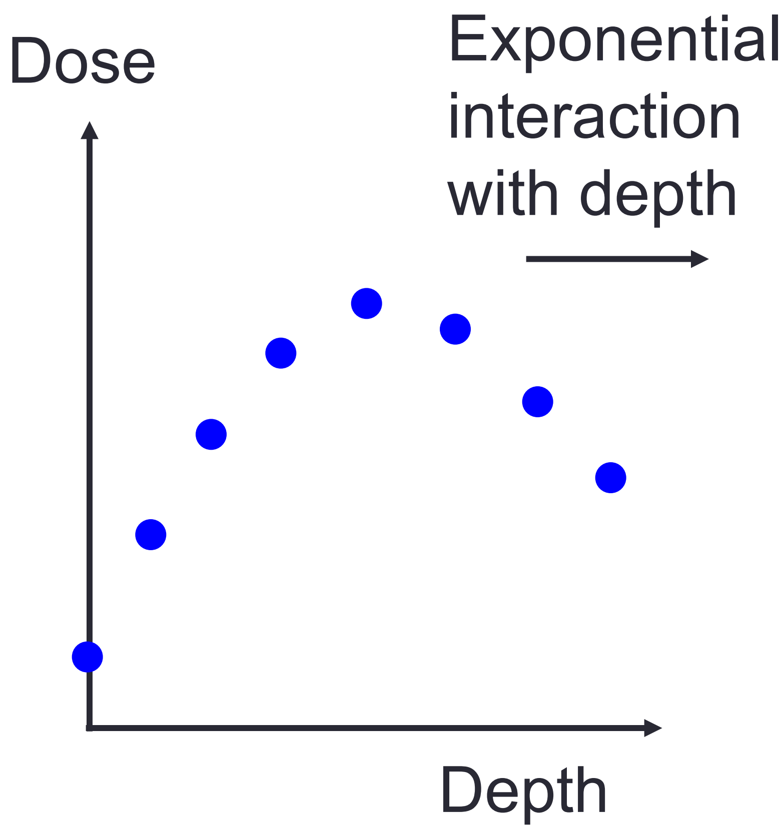
Skin tumours ~ 50 – 100 kV x-rays,
deep tumours ~ 2 – 10 MV x-rays typically.


Prostate 5 Field
60.0 Gy
50.0 Gy
40.0 Gy
30.0 Gy
20.0 Gy
Z: -132.48 cm
Head First-Supine

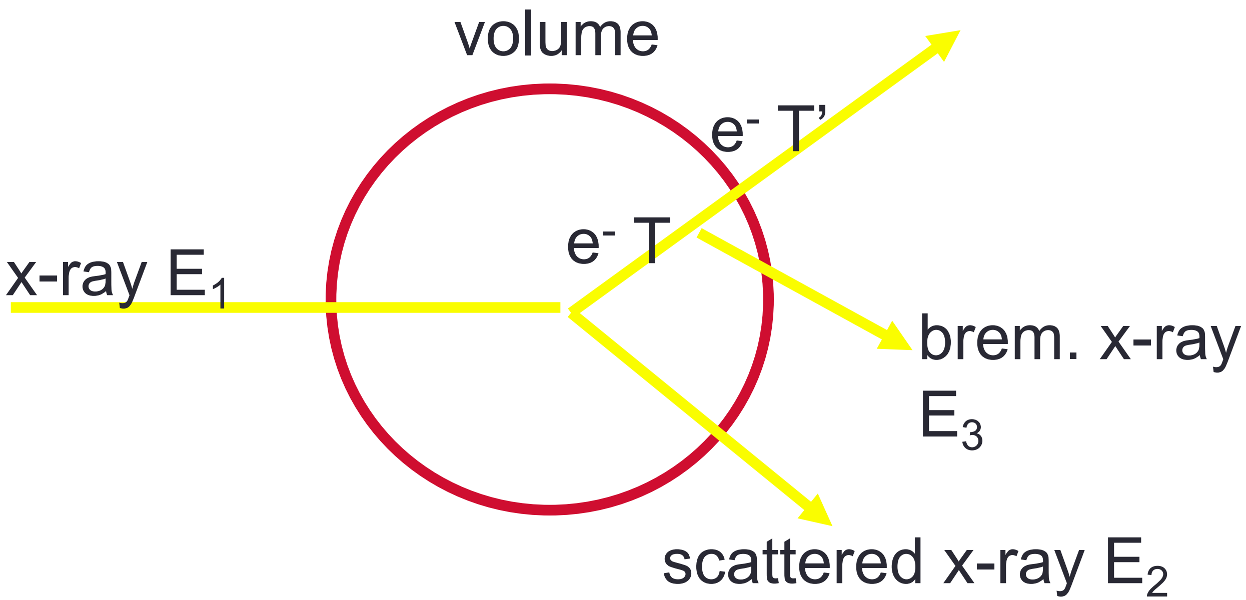
Explanation of Depth Dose



Layers in a material



Comparison between Kerma and absorbed dose



- Kerma $K = (E_1 - E_2) / m$
- Collision Kerma $K_c = (E_1 - E_2 - E_3) / m$
- Absorbed dose $D = (E_1 - E_2 - E_3 - T') / m$

Relationship between K_c and X

We know that

$$X = \Psi \left(\frac{\mu_{en}}{\rho} \right)_{air} \frac{e}{W_{air}}$$

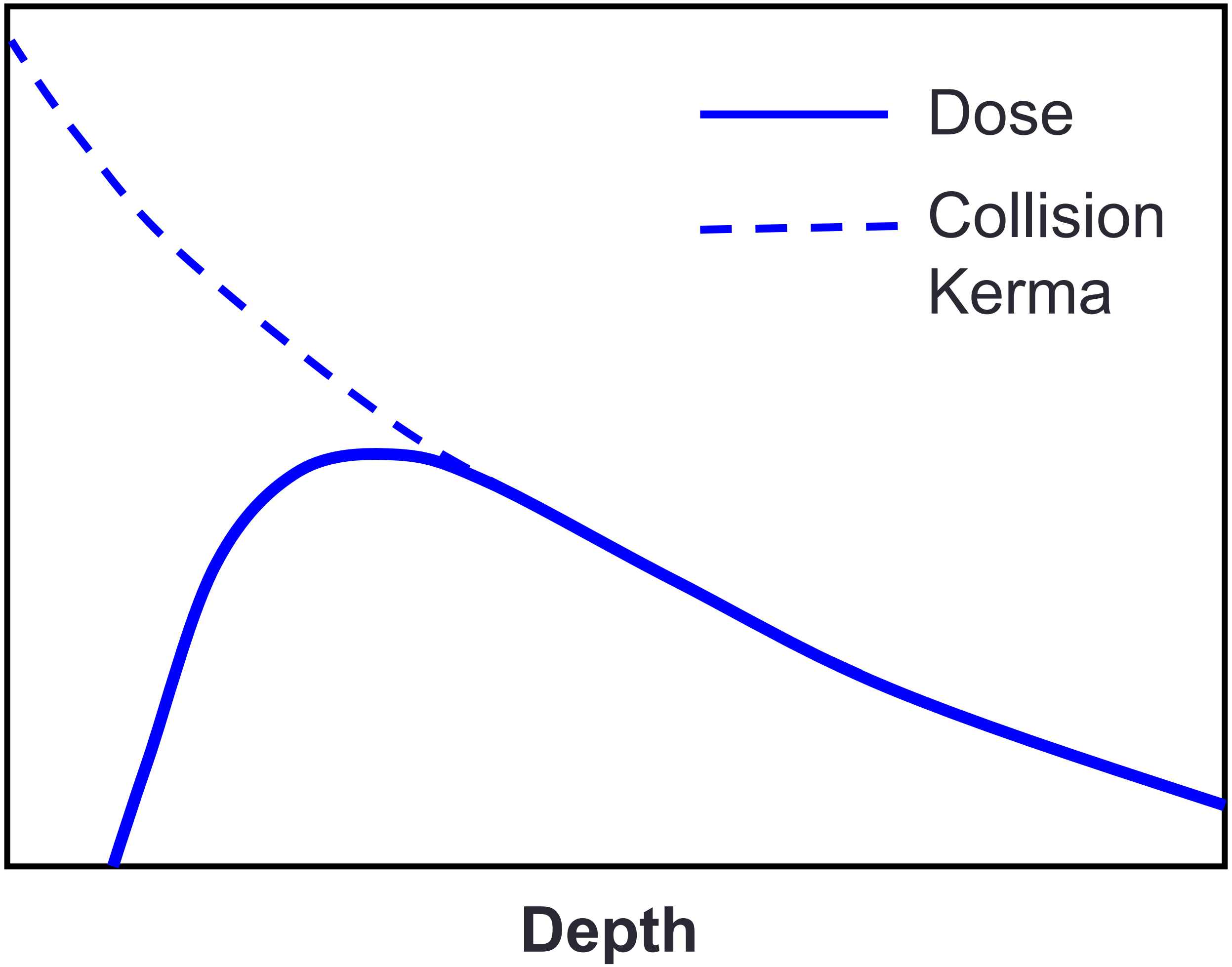
and

$$K_{c_{air}} = \Psi \left(\frac{\mu_{en}}{\rho} \right)_{air}$$

therefore, substituting for Ψ

$$K_{c_{air}} = X \frac{W_{air}}{e}$$

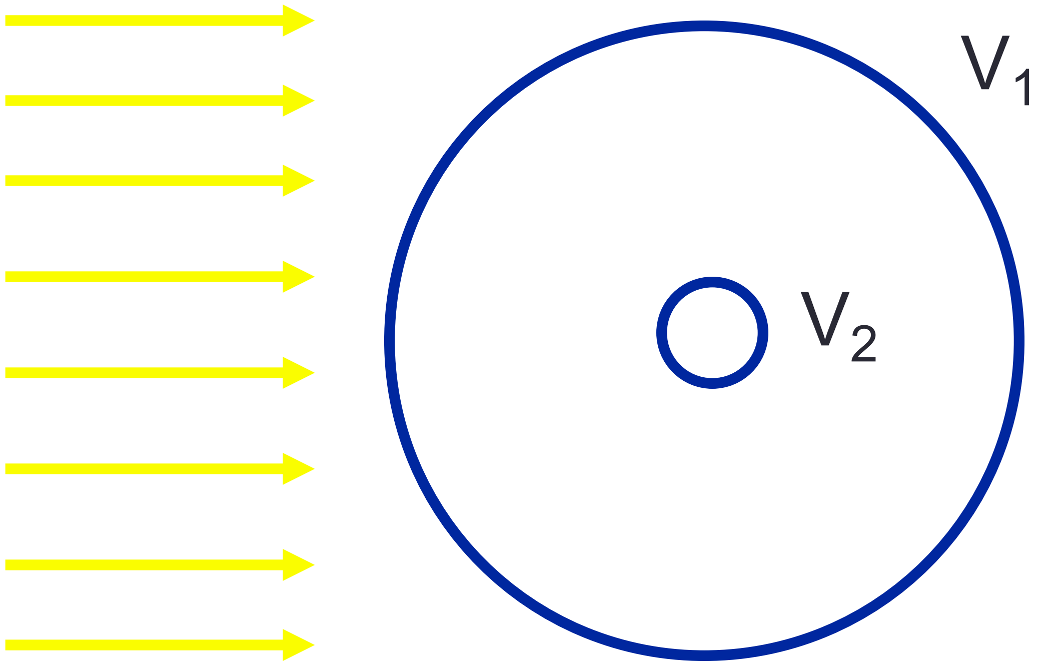
Relationship between K and D

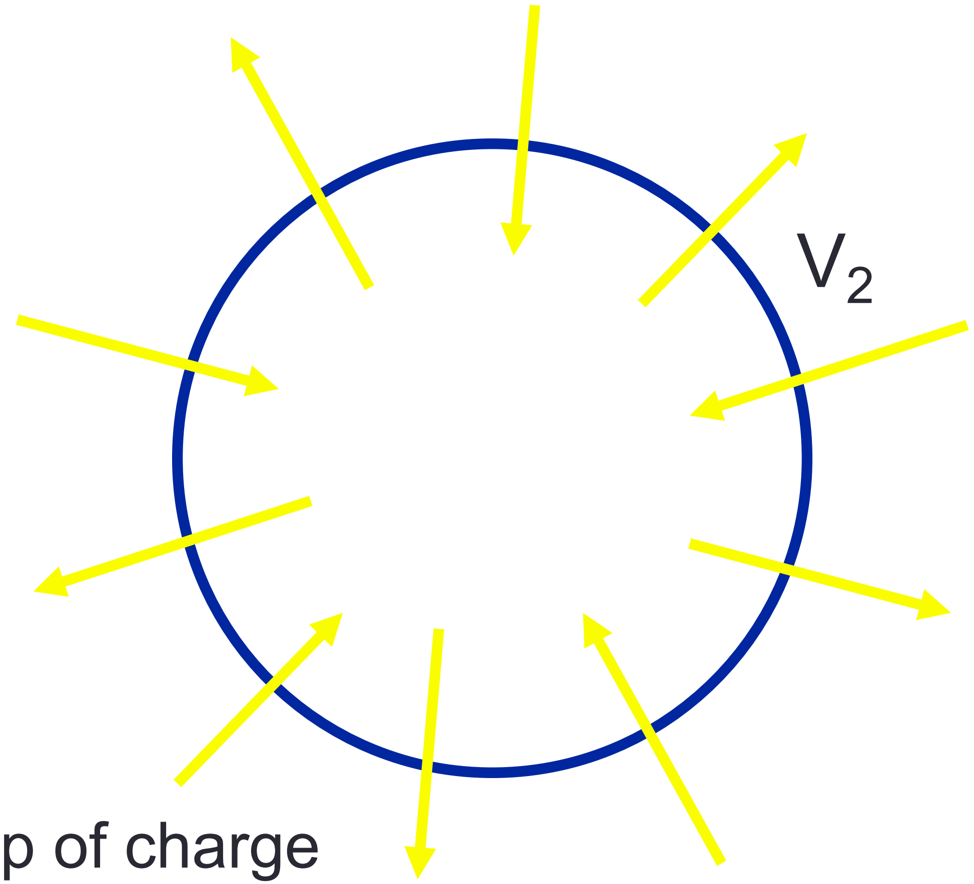


Complex relationship!

Charged particle equilibrium

Consider a large volume V_1 uniformly irradiated by photons



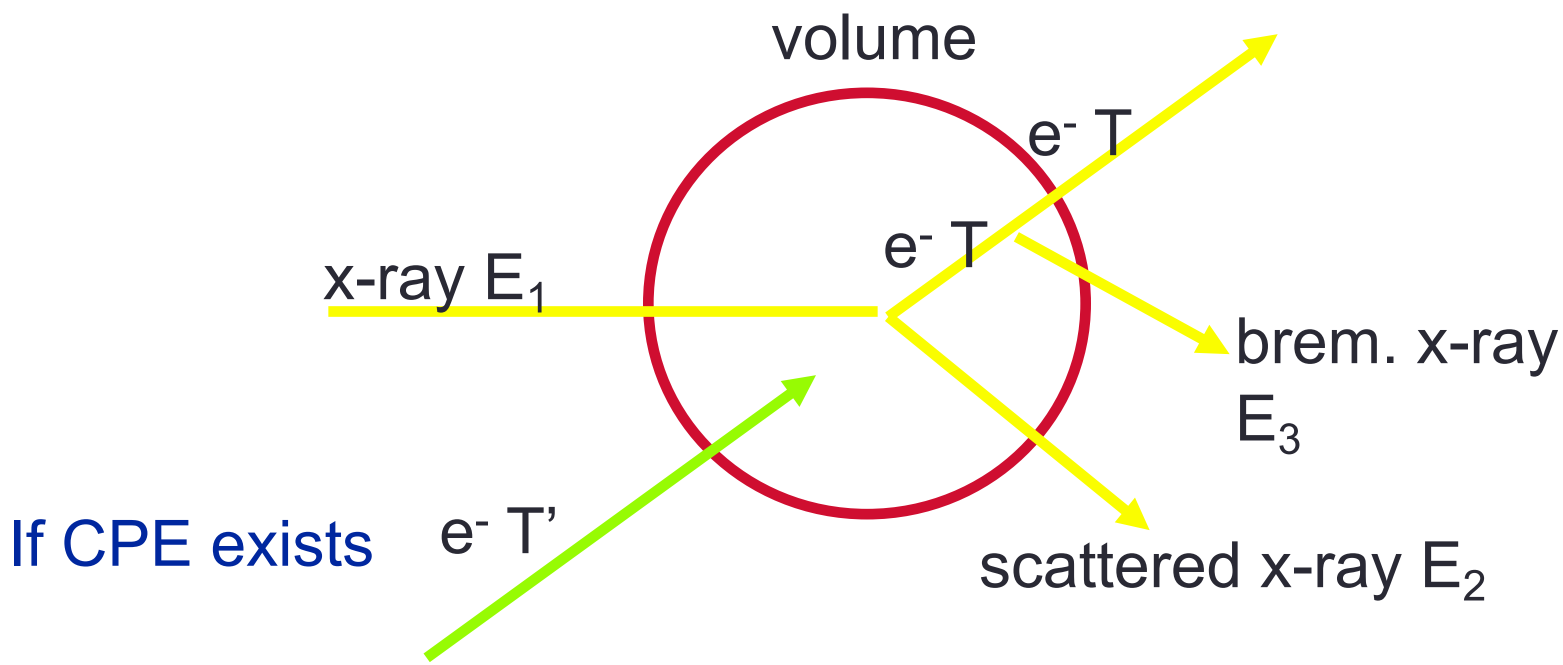


No build up of charge

- same number, energy & directions of electrons enter and leave

Charged particle equilibrium

Collision kerma and dose under CPE



- Collision kerma = $(E_1 - E_2 - E_3) / m$
- Absorbed dose = $(E_1 - E_2 - E_3 - T + T) / m$

Relationship between D, X and K

Under charged particle equilibrium,

energy imparted = net energy transferred

Therefore, $D = K_c$ for CPE

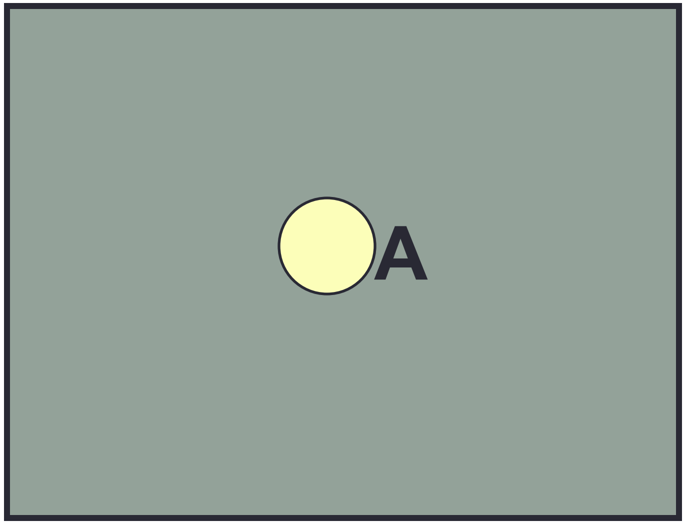
so, $$D_{air} = X\left(\frac{W_{air}}{e}\right)$$ etc.

Measurement of dose in a patient

- Say we want to know the dose at point A in a medium

- To measure D we must introduce a radiation sensitive device into it.

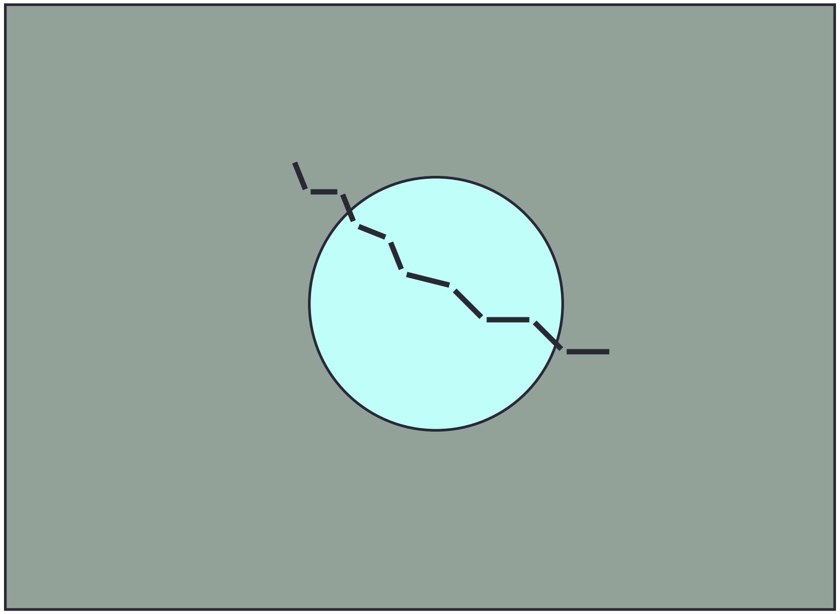
- But, the device usually not the same material - usually a gas-filled cavity



How do we relate the dose in the cavity to the dose in the material surrounding the cavity?

Bragg-Gray cavity theory

Consider a small cavity in a medium



Assume

- cavity is so small that it does not disturb the CP fluence
- absorbed dose in cavity is deposited entirely by charged particles crossing it

Fano's theorem

effectively states

electron fluence in a medium is independent of density variations

Implications

- introduction of a cavity into a material has no effect providing it has the same elemental composition

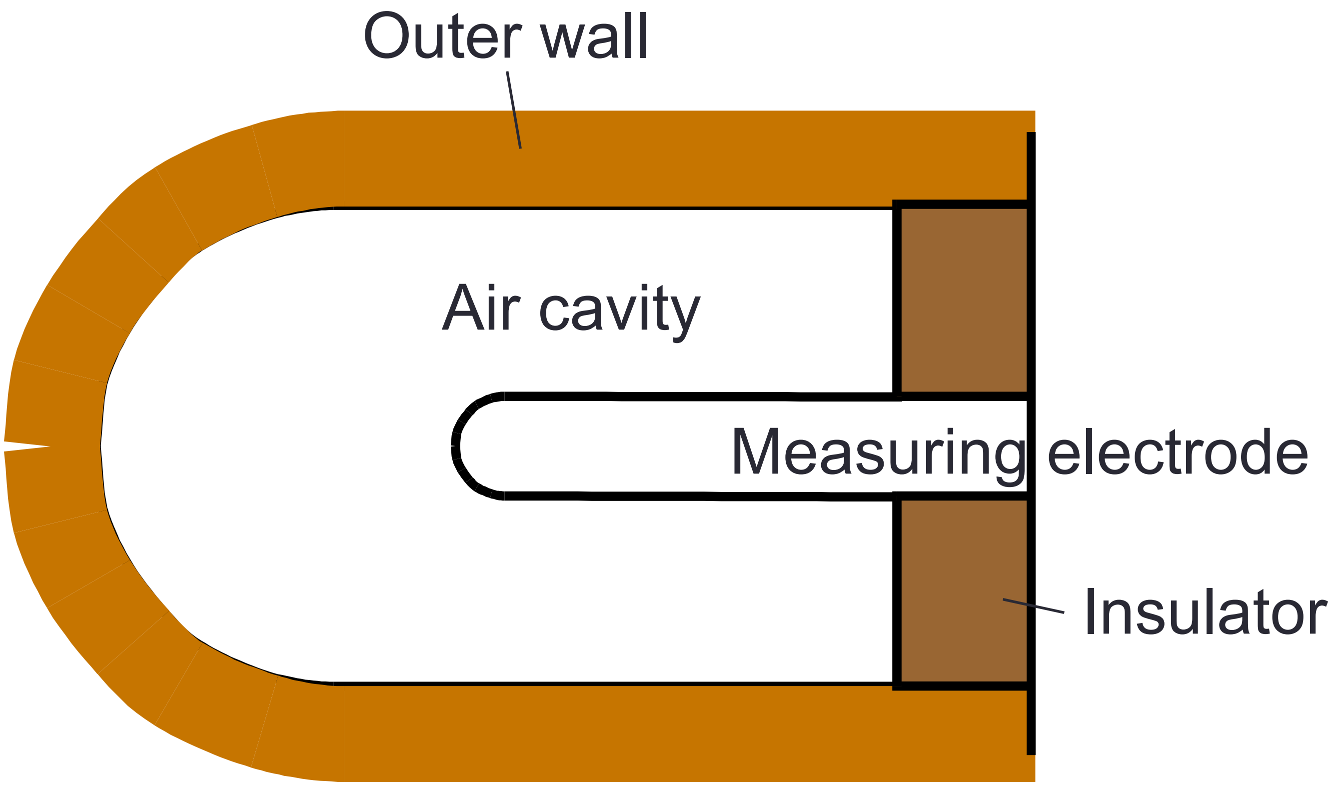
- Therefore, if the elemental composition is the same, the cavity does not need to be so small

Absorbed dose in other materials

Using Bragg-Gray theory and under conditions of CPE

$$D_m = D_{air} \frac{\left(\frac{\mu_{en}}{\rho}\right)_m}{\left(\frac{\mu_{en}}{\rho}\right)_{air}}$$

Practical cavity ion chamber



- Electrode gives the charge Q
- if volume of cavity is known then we can calculate air mass
- therefore we can find exposure