- EXAM DISCUSSION

- COMPTON SUPPRESSION ?

POST EXAM DISCUSSION

- RADIATION GENERATION + SOURCES
  - NATURAL + ACCELERATORS
- ↙
  RADIOACTIVE DECAY + GOVERNING LAWS
- FUNDAMENTAL INTERACTIONS OF RADIATION WITH MATTER
- DETECTION + ENERGY DETERMINATION

DOSIMETRY

Q: WHAT IS DOSIMETRY ?

↪ QUANTIFICATION OF DOSE

Q: WHAT IS DOSE?

Q: WHY DO WE CARE ?

↪

Q: WHAT ARE UNITS OF DOSE?

AS WE HAVE LEARNED, AS RADIATION IS EMITTED IT UNDERGOES VARIOUS REACTIONS IN WHICH ENERGY IS DEPOSITED INTO SURROUNDING MATTER ?

Q: IS THIS DESIRABLE OR NOT ?

WELL DEPENDING ON TYPE OF RADIATION, ITS ENERGY + PROPERTIES OF THE ABSORBING MEDIUM, THE AMONT OF ENERGY RANGES FROM SMALL TO SIGNIFICANT

WE CHARACTERIZE THE ENERGY DEPOSITION ~~BY~~ AS ABSORBED DOSE, ENERGY/UNIT MASS $[J/kg]$

$$DOSE = \frac{ENERGY}{MASS} = \frac{J}{kg}$$

CONVENTIONAL SYSTEM: UNIT FOR ABSORBERD DOSE IS THE RAD (RADIATION ABSORBED DOSE)

$$1\ RAD = \frac{100\ ergs}{gram\ of\ MATERIAL} \qquad 1\ erg = 1 \times 10^{-7}\ J$$

IN THE INTOLERABLE SI SYSTEM DOSE IS IN UNITS OF GRAY (Gy)

$$1\ Gy = 100\ RAD = 1\ J/kg$$

THE RATE OF ABSORBED DOSE IS EXPRESSED AS RAD/HR Gy/s RAD/PULSE

EXPOSURE DEFINED AS AMOUNT OF IONIZATION PRODUCED WHEN GAMMA RAY (X-RAYS) INTERACT WITH AIR.

ABSORBED DOSE ISN'T JUST DEPENDANT ON THE RADIATION'S CHARACTERISTICS BUT ON THE PROPERTIES OF THE MATERIAL.

- IT IS USEFUL THEN TO HAVE A UNIT THAT DEPENDS SOLEY ON THE RADIATION TO WHICH A SAMPLE IS BEING "EXPOSED TO"

ROENTGEN [R] [mR]

DEF

1 R LIBERATES $\frac{2.58 \times 10^{-4}\ C}{kg}$ (JUST ONE SIGN +/-) IN AIR (WHEN ALL PHOTONS ARE STOPPED IN THE AIR)

Q: MEAN X + γ-RAY ENERGY REQUIRED TO PRODUCE 1-ION PAIR IS ?

A: 33.7 eV

SO 1-cm^3 OF AIR IS GIVEN 1-R (OF X, γ-RAY) RADIATION, THE ENERGY TRANSFERED FROM THE PHOTON BEAM TO THE MEDIUM IS

$2.08 \times 10^9 \times 33.7\ eV/_{ion\ pair}$ ← ENERGY DEPOSITED

ABSORBED DOSE

$$\frac{(2.08 \times 10^9\ \text{ion pairs})(33.7\ eV/\text{ion pair})}{0.00129\ g}$$

(NOTE: 1 RAD = 6.24×10^{13} eV/g)

1 R = 0.87 rad

Q: WHAT IF YOU HAVE LESS THAN 1 kg ?

CONSIDER 1 cm^3 OF AIR @ 0°C, 760 Torr

0.00129 g/cm^3

IS EXPOSED TO A BURST OF X-RAYS, γ-RAYS

SECONDARY e^- ARE PRODUCED HAVING RANGE OF SEVERAL cm IN AIR + CAUSES IONIZATION ALONG THE WAY, ~~AS~~ CREATING TOTAL CHARGE OF 3.33×10^{-10} C, EXPOSURE IS 1 R

$$\left(2.58 \times 10^{-7} \frac{C}{g}\right)\left(1.29 \times 10^{-3} g\right) = 3.33 \times 10^{-10} C$$

SINCE e^- CHARGE IS 1.6×10^{-19} C

$$\frac{3.33 \times 10^{-10} C}{1.6 \times 10^{-19} C/e^-} = 2.08 \times 10^{9} \text{ ION-PAIRS}$$

↑ REMBER JUST 1-SIGN(±)

EXAMPLE

Q: IN 1 mR/hr gamma field, at what rate IN cm^3/s ARE IONS BEING PRODUCED IN air ?

air :

$$\frac{\text{CHARGE}}{\text{ION}} \Rightarrow \frac{2.58 \times 10^{-4}\ C/\overset{R}{kg}}{1.6 \times 10^{-19}\ C/\text{ion}} = 1.61 \times 10^{15}\ \frac{\text{ions}}{kg}\ \text{PER } R$$

FOR 1 mR

$$1.61 \times 10^{12}\ \frac{\frac{\text{IONS}}{kg}}{mR} = 1.61 \times 10^{9}\ \frac{\text{ION}/g}{mR}$$

IONS IN 1-cm^3 CAN BE DETERMINED USING DENSITY OF AIR $1.29\ mg/cm^3$

$$\left(1.29 \times 10^{-3}\ \frac{g}{cm^3}\right)\left(1.61 \times 10^{9}\ \frac{\text{ions}/g}{mR}\right) = 2.08 \times 10^{6}\ \frac{\text{ions}/mR}{cm^3}$$

EXPOSURE RATE OF 1 mR/hr

$$2.08 \times 10^{6}\ \frac{\text{ions}/mR}{cm^3/hr} \cdot \frac{1\ hr}{3600\ s} = 578\ \frac{\text{ions}}{cm^3}/\text{sec.}$$

DOSE CALCULATIONS

- TO CALCULATE DOSE, WE NEED TO KNOW AMOUNT OF INCIDENT RADIATION.

- TYPICALLY EXPRESSED AS FLUENCE [QUANTITY OF RADIATION/cm^2] OF FLUX RATE

  $[Q.O.R./cm^2 \cdot s]$

DEFINE FLUX

SOURCE STRENGTH, (ACTIVITY)

$$\varphi\left(\frac{\text{QUAN. OF RADIATION}}{cm^2\, s}\right) = \frac{Sf}{4\pi r^2}$$

FRACTIONAL YIELD

DISTANCE FROM THE SOURCE

$\propto 1/r^2$?

EXAMPLE

WHAT? IS PHOTON FLUX FROM A 1mCi POINT SOURCE OF ^{137}Cs AT 100 cm?

^{137}Cs $f = 0.85\ \gamma/\text{trans}$

$$S = (1\times10^{-3}\ Ci)\left(\frac{3.7\times10^{10}\ t/s}{Ci}\right) = 3.7\times10^{7}\ t/s$$

$$\varphi = \frac{(3.7\times10^{7}\ t/s)(0.85\ \gamma/t)}{4\pi\ (100\,cm)^2} = \cancel{8}\ 2500\ \frac{\gamma}{cm^2 s}$$

JUST A QUANTITY

DEF

ABSORBED DOSE RATE: (AT A GIVEN DISTANCE FROM LOCATION)

$$\dot{D} = \varphi\left(\frac{\mu}{\rho}\right)E$$

$\dot{D}$ = DOSE RATE $[Gy/s]$ OR $[J/kg\cdot s]$

φ = FLUX FROM SOURCE AT GIVEN LOCATION $[\#/cm^2 s]$

$\frac{\mu}{\rho}$ = MASS ABSORPTION COEFFICIENT FOR MATERIAL $[cm^2/kg]$

E = ENERGY OF RADIATION QUANTA $[J]$

EXAMPLE WHAT IS DOSE TO AIR 300 cm FROM 0.5 Ci OF ^{60}Co

→ USE LOOK UP TABLES TO FIND f & $\frac{\mu}{\rho}$

^{60}Co TWO γ-RAYS 1.173 (99.8) MeV
1.3325 (100%)

$$\frac{\mu}{\rho}\bigg|_{1.125\,MeV} = 0.0257\ cm^2/g$$

$$E = \left[\frac{(0.998 \times 1.173\,MeV) + (1 \times 1.3325\,MeV)}{2}\right] = 1.250\ \frac{MeV}{t}$$

$$\rho = \frac{\left(3.7 \times 10^{10}\,\frac{t}{s \cdot Ci}\right)(0.5\,Ci) \times 2\,\gamma/t}{4\pi(300\,cm)^2} = 6.17 \times 10^{7}\ \frac{t}{s \cdot cm^2}$$

$$\dot{D} = \left(6.17 \times 10^{7}\,\frac{\cancel{t}}{s \cdot \cancel{cm^2}}\right)\left(0.0257\,\frac{\cancel{cm^2}}{\cancel{g}} \cdot \frac{1000\,\cancel{g}}{kg}\right)\left(1.250\,\frac{\cancel{MeV}}{\cancel{t}} \cdot 1.6 \times 10^{-19}\,\frac{J}{\cancel{eV}} \cdot \frac{1 \times 10^{6}\,\cancel{eV}}{\cancel{MeV}}\right)$$

$$3.17 \times 10^{-4}\ \frac{J}{s \cdot kg} \quad \left[\frac{J}{kg \cdot s}\right] = [Gy/s]$$

3.17×10^{-4} Gy/s or

3.17×10^{-2} RAD/s = 30 mRad/s = [illegible]

BIOLOGICAL DOSIMETRY

$-dE/dx$ ≡ STOPPING POWER OF A MEDIUM

$\Rightarrow$ LET : LINEAR ENERGY TRANSFER OF THE PARTICLE

DOSE EQUIVALENT

ICRP INTRODUCED 'DOSE EQUIVALENT' FOR RADIATION PROTECTION PURPOSES.

$$\overset{\text{DOSE EQUIVALENT}}{H} = \overset{\text{QUALITY FACTOR, DEPENDS ON LET [keV/μm]}}{Q}\,D \leftarrow \text{ABSORBED DOSE}$$

- WHEN DOSE IS EXPRESSED IN Gy, THE SI UNIT OF DOSE IS THE SIEVERT Sv
- WHEN DOSE IS IN RAD UNIT OF DOSE EQUIVALENT IS THE REM, ROENTGEN EQUIV. MAN

SINCE $1\ \text{Gy} = 100\ \text{RAD}$

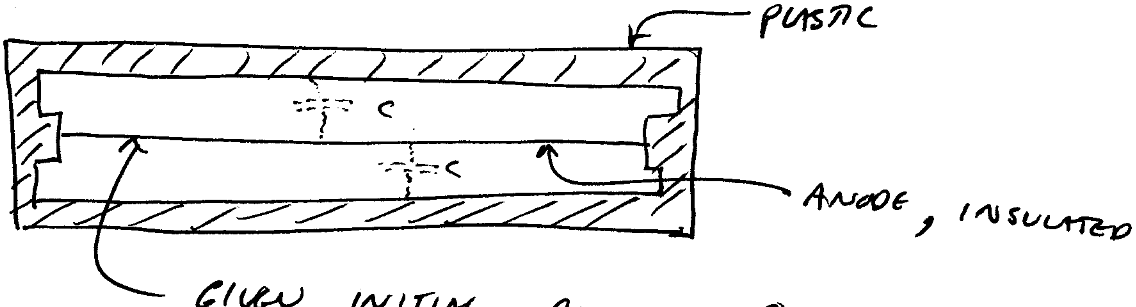
$1\ \text{Sv} = 100\ \text{REM}$

QUALITY FACTOR ON LET OF RADIATION

LET keV/μm in H_2O	Q
3.5 or less	1
3.5–7.0	1–2
7.0–23	2–5
23–53	5-10
53-175	10-20
γ & X-rays, e^- + e^+ of any LET	1

AIR- WALL CHAMBER

AIR-WALL POCKET CHAMBER, BUILT AS A CAPACITOR



GIVEN INITIAL CHARGE Q_0, A POTENTIAL DEVELOPS

$$Q = VC \, , \quad Q_0 = V_0 C$$

WHEN EXPOSED TO PHOTONS, THE SECONDARY e^- LIBERATED FROM THE WALLS + ENCLOSED AIR NEUTRALIZES THE CHARGE ON THE ANODE, + LOWERS THE POTENTIAL DIFFERENCE BETWEEN IT + WALLS,

TOTAL POTENTIAL DIFFERENCE IS PROPORTIONAL TO THE TOTAL IONIZATION + HENCE TOTAL EXPOSURE

AIR WALL EXAMPLE

P.I.C. HAS VOLUME OF 2.5 cm^3 & C = 7pF INITIALLY CHARGED TO 200 V, THE READER SHOWS A DIFFERENCE OF 170V AFTER EXPOSURE, WHAT IS EXPOSURE IN ROENTGENS?

$$\Delta Q = C\Delta V = 7\times10^{-12} \times (200-170) = 2.1\times10^{-10}\,C$$

MASS OF AIR (STP) $0.00129\,g/cm^3 \times 2.5\,cm^3 = 3.23\times10^{-3}\,g$

$$\frac{2.10\times10^{-10}\,C}{3.23\times10^{-3}\,g} \times \frac{1R}{2.58\times10^{-4}\,C/g} = 0.252\,R$$

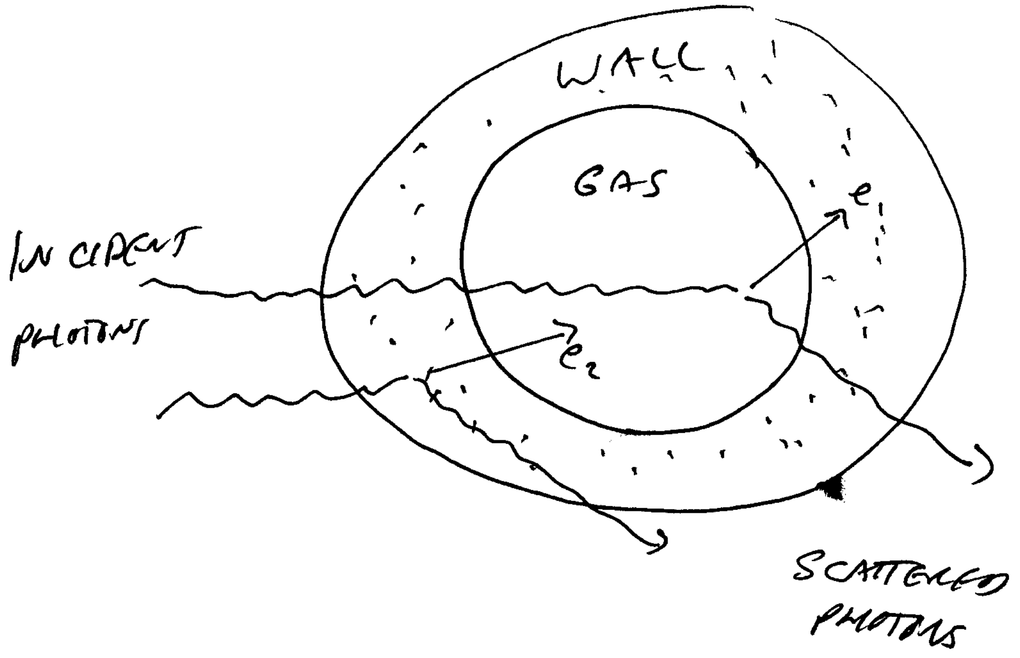
PRACTICAL CHAMBERS CAN HAVE ENERGY INDEPENDANT RESPONSE FROM A FEW HUNDRED KeV TO ~2MeV

~~[illegible] IS BEHIND THIS~~

BIOLOGICAL DOSIMETRY

- ONE OF THE PRIMARY GOALS OF DOSIMETRY IS THE DETERMINATION OF THE ABSORBED DOSE IN TISSUE EXPOSED TO RADIATION.

- THE BRAGG-GRAY PRINCIPLE PROVIDES A MEANS OF RELATING THE IONIZATION OF THE GAS TO ABSORBED DOSE IN SOME CONVENIENT MATERIAL, THAT CAN BE MANUFACTURED TO BE TISSUE EQUIVALENT. (OR AT LEAST EASILY SCALED TO T.E.)



REQUIREMENTS OF BRAGG-GRAY PRINCIPLE

- PHOTON LOSE ENERGY IN GAS BY PRODUCING SECCONDARY ELECTRONS.

  THE RATIO OF THE ENERGY DEPOSITED AND THE MASS OF THE GAS IS THE ABSORBED DOSE

- THIS ENERGY IS PROPORTIONAL TO THE AMOUNT OF IONIZATION IN THE GAS WHEN ELECTRONIC EQUILIBRIUM EXISTS BETWEEN THE WALL AND THE GAS.

  I.E. e_1 ENTERS THE WALL BEFORE LOSING ALL OF ITS ENERGY + e_2 PRODUCED IN THE WALL STOPS IN THE GAS.

- WHEN THE WALL + GAS HAVE SAME ATOMIC COMPOSITION, THEN e^- ENERGY SPECTRA WILL BE THE SAME, IRRESPECTIVE OF THEIR ORIGIN,

  SAME AS AIR-WALL CHAMBER

- ELECTRONIC EQUILIBRIUM REQUIRES WALL THICKNESS TO BE AT LEAST AS GREAT AS THE MAX RANGE OF SECONDARY PARTICLES

- BUT SHOULD NOT BE SO THICK AS TO ATTENUATE THE INCIDENT RADIATION.

BRAGG-GRAY STATE THAT, IF A GAS IS ENCLOSED BY WALL OF SAME ATOMIC COMPOSITION + IF ABOVE WALL THICKNESS REQUIREMENTS ARE MET, THEN THE ENERGY PER UNIT MASS IN THE GAS IS EQUAL TO THE NUMBER OF ION-PAIRS PRODUCED THERE X THE W VALUE / MASS OF THE GAS. ALSO THE DOSE ABSORBED IN THE WALL IS THE SAME AS IN THE GAS

\# ION PAIRS IN GAS

$$D_w = D_g = \frac{N_g W}{m}$$

ENERGY REQUIRED TO CREATE ION PAIR

MASS OF GAS

WHEN WALL + GAS ARE OF DIFFERENT COMPOSITIONS THE ABSORBED DOSE CAN STILL BE OBTAINED FROM IONIZATION IN THE GAS.

- CAVITY SIZE MUST BE SMALL
- LOW GAS PRESSURE

→ SO THAT SECONDARY e^- LOSE ONLY A SMALL FRACTION OF THEIR ENERGY IN THE GAS.

THE ABSORBED DOSE THEN SCALES AS THE RATIO

$$S_w / S_g$$ MASS STOPPING POWERS

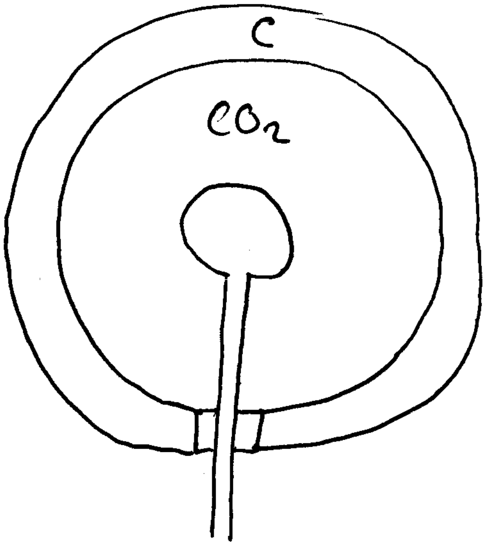
WALL GAS

$$D_w = \frac{D_g S_w}{S_g} = \frac{N_g W S_w}{m S_g}$$

IN THE CASE OF δn (AS OPPOSED TO γ)

TO SATISFY THE BRAGG-GRAY PRINCIPLE, THE WALL MUST BE AT LEAST AS THICK AS THE MAXIMUM RANGE OF ANY CHARGED RECOIL PARTICLE THAT THE δn PRODUCE IN IT.

MEASUREMENT OF X- + γ-RAY DOSE



SINCE CARBON IS THE MAJOR CONSTITUENT OF SOFT TISSUE, THE D_W APPROXIMATE $D_{\underset{\text{TISSUE}}{\uparrow t}}$

IN PRACTICAL APPLICATION, FOR PHOTON ENERGIES BETWEEN 0.2 MeV → 5 MeV $D_t = 1.1\, D_c$ WITHIN 5%

^1_0n DOSIMETRY

A PHOTON IONIZATION DEVICE WILL ALSO SHOW A RESPONSE WHEN EXPOSED TO ^1_0n, THIS IS FROM IONIZATION PRODUCED IN THE GAS BY THE CHARGED RECOIL NUCLEI STRUCK BY ^1_0n

IONIZATION CAN BE PROPORTIONAL TO ABSORBED DOSE

1. WALLS + GAS ARE TISSUE EQUIVALENT
2. B-G PRINCIPLE IS SATISFIED FOR ^1_0n

FOUR BASIC ELMENTS ~~AIR, WATER,~~ EARTH, AIR, FIRE, WATER

TISSUE PRINCIPLE ELEMENTS

ELEMENT	ATOMS/cm^3
H	5.98×10^{22}
O	2.45×10^{22}
C	9.03×10^{21}
N	1.29×10^{21}

SO CARBON WALL DETECTOR WOULD RESPOND QUITE DIFFERENTLY FROM TISSUE ~~FOR~~ TO A FIELD OF MIXED ENERGY ^1_0n, SINCE H, O, N ARE MISSING

- C-CO_2 CHAMBER CAN BE USED, IF RESPONSE IS PREVIOUSLY CALIBRATED TO PHOTONS & ^1_0n OF A GIVEN ENERGY FOR A FLUENCE THAT DELIVERS 7-RAD TO SOFT TISSUE, BY ~~[illegible]~~ SCALING AS A FUNCTION OF E:

ABSORBED DOSE IN CARBON (E_n)

$$\rho(E) = \frac{D_C^n(E)}{D_C^\gamma}$$

ABSORBED DOSE IN CARBON (E_γ)

RELATIVE RESPONSE OF C-CO_2 CHAMBER BETWEEN ~~[illegible]~~ n/γ

^1_0n E [MeV]	$\rho(E)$
0.1	0.109
0.5	0.149
1	0.149
2	0.145
3	0.151
4	0.247
5	0.168
10	0.341
20	0.487

EXAMPLE:

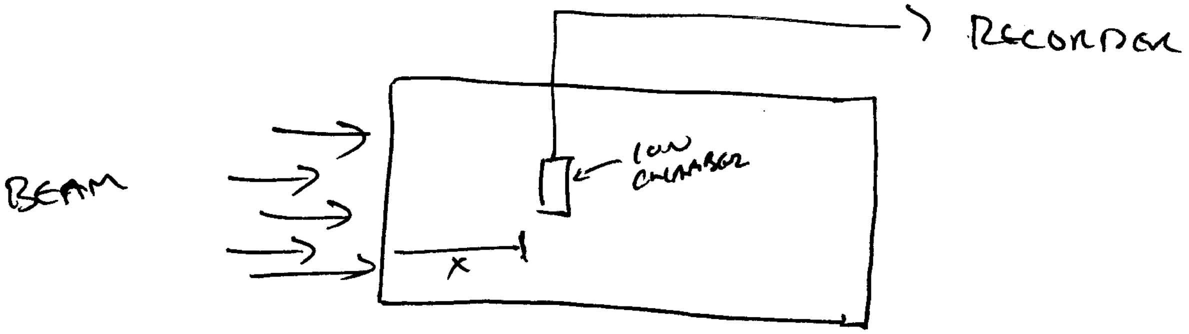
C-CO_2 CHAMBER EXPOSED TO 7-MeV ^1_0n GIVES SAME READING AS GAMMA RAYS THE DELIVER ABSORBED DOSE OF 2 mGy. WHAT IS ABSORBED DOSE ~~OF~~ FROM ^1_0n?

$$P(E)\,D_n = 0.149\,D_n = 2\,\text{mGy} \implies D_n = 13.4\,\text{mSv}$$ ✓

DOSE MEASUREMENT FOR CHARGED-PARTICLE BEAM

FOR EXPERIMENTS USING CHARGED PARTICLE BEAMS, ONE CAN MEASURE THE DOSE BY PLACEMENT OF SMALL IONIZATION CHAMBER DIFFERENT DEPTHS IN THE MATERIAL

- IN H.E.P. THIS IS CALLED A CALORIMETER
- IN MEDICAL FIELD THIS IS CALLED A PHANTOM



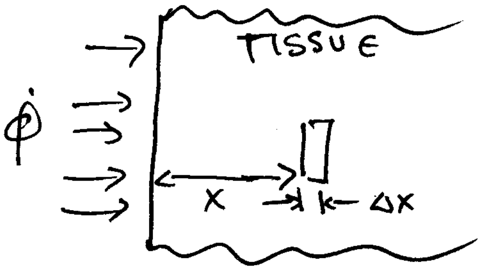
TO SPECIFY DOSE EQUIVALENT, ONE NEEDS, IN ADDITION TO THE ABSORBED DOSE, THE L.E.T. OF THE INCIDENT CHARGED PARTICLES OR THE L.E.T. OF THE CHARGED RECOIL PARTICLES PRODUCED BY INCIDENT NEUTRAL RADIATIONS (γ, n)

→ REFER TO LOOK-UP TABLES FOR QUALITY FACTOR

SO GEOMETRY FOR C.P.B. ASSUMES A MONO-ENERGETIC, PARALL~~AL~~EL, SINGLE SPECIES BEAM INCIDENT ON A SLAB OF THICK TISSUE

WITH A FLUENCE RATE

$\dot{\varphi}/\mathrm{cm}^2 \cdot \mathrm{s}$



CALCULATE DOSE RATE AT A GIVEN DEPTH IN x IN SLAB

CONSIDER THIN DISK OF THICKNESS ΔX & AREA A ⊥ TO BEAM. RATE OF ENERGY DEPOSITION IN THE VOLUME ELEMENT IS

$$\dot{\varphi} A \left(-\frac{dE}{dx}\right) \Delta x$$

← COLLISIONAL STOPPING POWER OF THE BEAM AS THE TRAVERSE THE SLAB @ X

DIVIDE BY MASS OF THE VOLUME ELEMENT

$$\dot{D} = \frac{\dot{\varphi} A (-dE/dx) \Delta x}{\rho A \Delta x} = \dot{\varphi}\left(-\frac{dE}{\rho\, dx}\right)$$

- CHEMICAL DOSIMETRY,
- THERMAL LUMINESCENCE DOSIMETRY
- CALORIMETRY
- ____________________