

Dosimetry Fundamentals

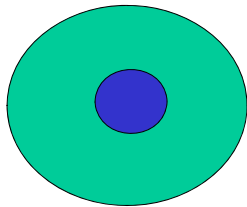
What is radiation dosimetry?

- Measurement of absorbed dose or dose rate
- Determination of radiologically relevant quantities: exposure, kerma, fluence, dose equivalent, energy imparted, and so on.
- One often measures one quantity and derive another.

What is a dosimeter?

- Any device that can provide a reading that is a measure of the absorbed dose deposited in its sensitive volume V .
- If the dose is not homogeneous inside V , then it provides a mean absorbed dose.
- Often we measure in some device because a direct measurement on the material is not possible. Transfer of absorbed dose from one material to another is often necessary.
- In some cases, the dosimeter can be directly calibrated in terms of the desired quantity, but such a calibration is generally energy-dependent unless the dosimeter simulates the reference material.

Simple dosimeter model



- being a source of secondary charged particles that contribute to the dose in V , and provide charged-particle equilibrium (CPE) or transient charged-particle equilibrium (TCPE) in some cases,
- shielding V from charged particles that originate outside the wall,
- protecting V from "hostile" influences such as mechanical damage, dirt, humidity, light, electrostatic or RF fields, etc., that may alter the reading,
- serving as a container for a medium g that is a gas, liquid, or powder, and
- containing radiation filters to modify the energy dependence of the dosimeter.

General guidelines on the interpretation of dosimeter measurements FOR PHOTONS AND NEUTRONS

- Importance of CPE and TCPE

Photons $D = K_c \overset{\text{CPE}}{=} \Psi \left(\frac{\mu_{\text{en}}}{\rho} \right)$

$D = K_c(1 + \mu'\bar{x}) \overset{\text{TCPE}}{=} K_c\beta = \Psi \left(\frac{\mu_{\text{en}}}{\rho} \right) \beta$

Neutrons $D = K \overset{\text{CPE}}{=} \Phi F_n$

$D = K(1 + \mu'\bar{x}) \overset{\text{TCPE}}{=} K\beta = \Phi F_n \beta$

Consider now a dosimeter of material g with wall w and thick enough to exclude all cp generated elsewhere. If the volume is small enough to satisfy BG conditions and CPE exists, BG or Spencer theory can be used to determine the dose in the wall from the dose in the cavity g.

But more importantly dose to another medium replacing the dosimeter can be determined by:

$$D_x \overset{\text{CPE}}{=} D_w \frac{(\overline{\mu_{\text{en}}/\rho})_x}{(\overline{\mu_{\text{en}}/\rho})_w} \quad \text{for photons}$$

$$D_x \overset{\text{CPE}}{=} D_w \frac{(\overline{F_n})_x}{(\overline{F_n})_w} \quad \text{for neutrons}$$

For g=air $X \overset{\text{CPE}}{=} D_{\text{air}} \left(\frac{e}{W} \right)_{\text{air}} = \frac{D_{\text{air}}}{33.97}$

For high energy photons \rightarrow CPE \rightarrow TCPE

Advantages of media matching

- $w \cong g$
 - If w and g are identical then $D_w = D_g$
- $w = g \cong x$
 - If w , g and x are all identical then $D_w = D_g = D_x$
 - More frequently, we match the wall to the medium x and rely on the cavity theory to calculate D_w from D_g

Media matching of w and g in photon dosimeters

$$\frac{\bar{D}_g}{D_w} = d \cdot {}_m\bar{S}_w^g + (1 - d) \left(\frac{\bar{\mu}_{en}}{\rho} \right)_w^g$$

$${}_m\bar{S}_w^g = \left(\frac{\bar{\mu}_{en}}{\rho} \right)_w^g = 1$$

$${}_m\bar{S}_w^g = \left(\frac{\bar{\mu}_{en}}{\rho} \right)_w^g = n$$

$$\frac{\bar{D}_g}{D_w} = dn + (1 - d)n = n$$

Matching the dosimeter to the medium of interest when $w \neq g$

Which is better to match to medium x?

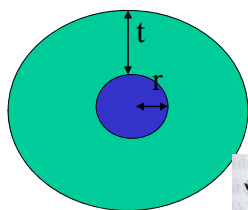
If $d=1$ (small sensitive volume) w is closed matched to x

$$\frac{\bar{D}_g}{D_x} = \frac{\bar{D}_g}{D_w} \cdot \frac{D_w}{D_x} = {}_m\bar{S}_w^g \left(\frac{\mu_{en}}{\rho} \right)_x^w$$

If $d=0$ (large sensitive volume) g is closed matched to x

$$\frac{\bar{D}_g}{D_x} = \frac{\bar{D}_g}{D_w} \cdot \frac{D_w}{D_x} = \left(\frac{\mu_{en}}{\rho} \right)_w^g \left(\frac{\mu_{en}}{\rho} \right)_x^w = \left(\frac{\mu_{en}}{\rho} \right)_x^g$$

Correcting for attenuation of radiation



$$\begin{aligned} \Psi_{\text{dos}} &\cong \Psi_0 \exp \left[- \left(\frac{\mu_{en}}{\rho} \right)_w \rho_w t - \left(\frac{\mu_{en}}{\rho} \right)_g \rho_g r \right] \\ &\cong \Psi_0 \left[1 - \left(\frac{\mu_{en}}{\rho} \right)_w \rho_w t - \left(\frac{\mu_{en}}{\rho} \right)_g \rho_g r \right] \end{aligned}$$

$$\Psi_{\text{wat}} \cong \Psi_0 \exp \left[- \left(\frac{\mu_{en}}{\rho} \right)_{\text{wat}} \rho_{\text{wat}}(t + r) \right] \cong \Psi_0 \left[1 - \left(\frac{\mu_{en}}{\rho} \right)_{\text{wat}} \rho_{\text{wat}}(t + r) \right]$$

Correction = $\frac{\Psi_{\text{wat}}}{\Psi_{\text{dos}}}$

Importance of dosimeter wall thickness

- Characteristics of the local photon or neutron field
- Characteristics of the charged particle field

General guidelines on the interpretation of dosimeter measurements

FOR CHARGED PARTICLES

1. Dosimeter size

have to be small or thin enough to satisfy BG conditions

wall has to be thin enough so it does not significantly perturb the field

extrapolation to zero thickness

δ -ray equilibrium

One of the wall functions is to generate δ -rays to take place of those that are generated in, and escape from, the sensitive volume.

This is a problem with measurements in free space, since the energy of the maximum energy of the δ -ray is $T/2$, it is not possible to provide a wall with a thickness that does not perturb the primary beam.

δ -ray spectrum is heavily weighted towards the lower energy and a smaller thickness can be used.

Cavity theory for electron beams

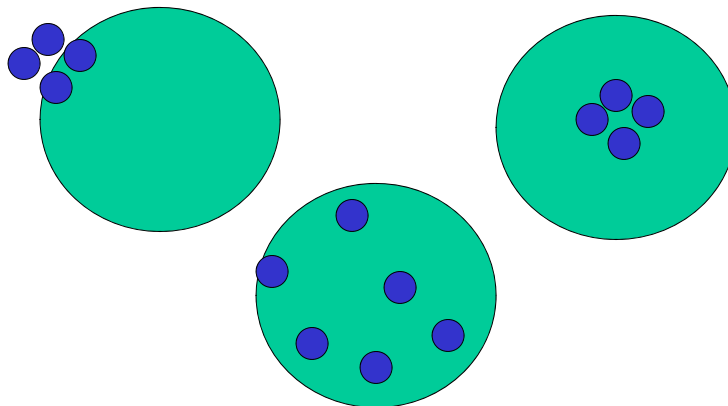
- There is no general and physically realistic cavity theory for electron beams. The problem is to treat electron scattering as a first-order effect.

General characteristics of dosimeters

- Absoluteness
 - Calorimetric dosimeters
 - Ionization chambers
 - Fricke ferrous sulfate dosimete

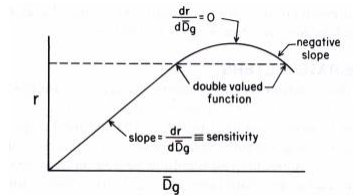
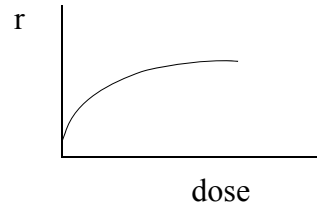
General characteristics of dosimeters

- Precision and Accuracy



Dose range

- Dose sensitivity
 - Linear
 - It could be non-linear
- Background
- Upper limit of the dose range



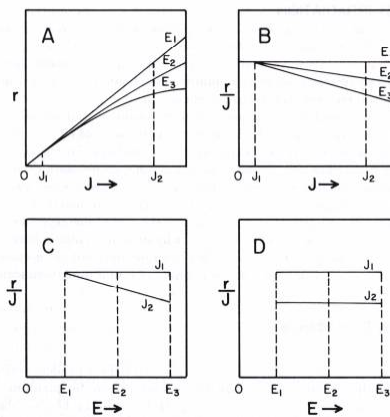
Dose rate range

- For integrating dosimeters
 - Reciprocity law failure in films for low dose rate range
 - Recombination losses for high dose rate range
- For dose rate meters
 - Jamming of GM tubes

Stability

- Before irradiation
 - Effect of temperature, atmospheric oxygen and humidity, light etc
- After irradiation
 - fading

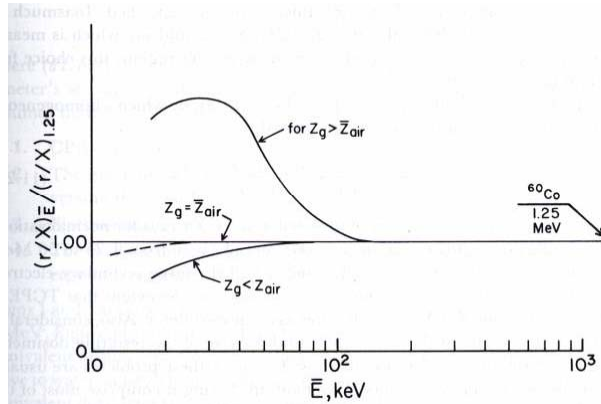
Energy dependence



a. Energy Dependence = Dependence of the Dosimeter Reading, per Unit of X- or γ -ray Exposure, on the Mean Quantum Energy or Quality of the Beam, r/X vs. \bar{E}

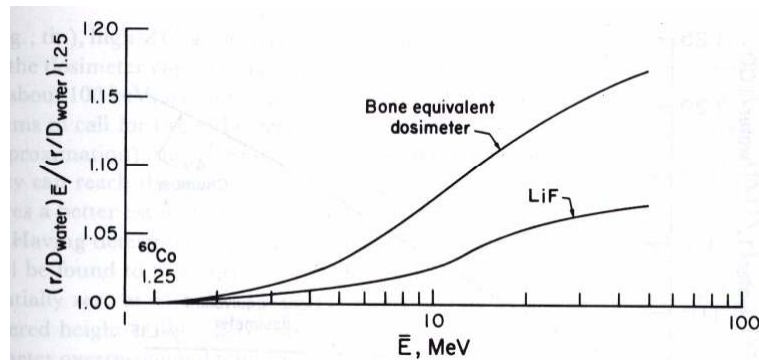
$$\left(\frac{r}{X}\right)_{\bar{E}} \cong \frac{[(\mu_{en}/\rho)_g]}{[(\mu_{en}/\rho)_{air}]_{\bar{E}}}$$

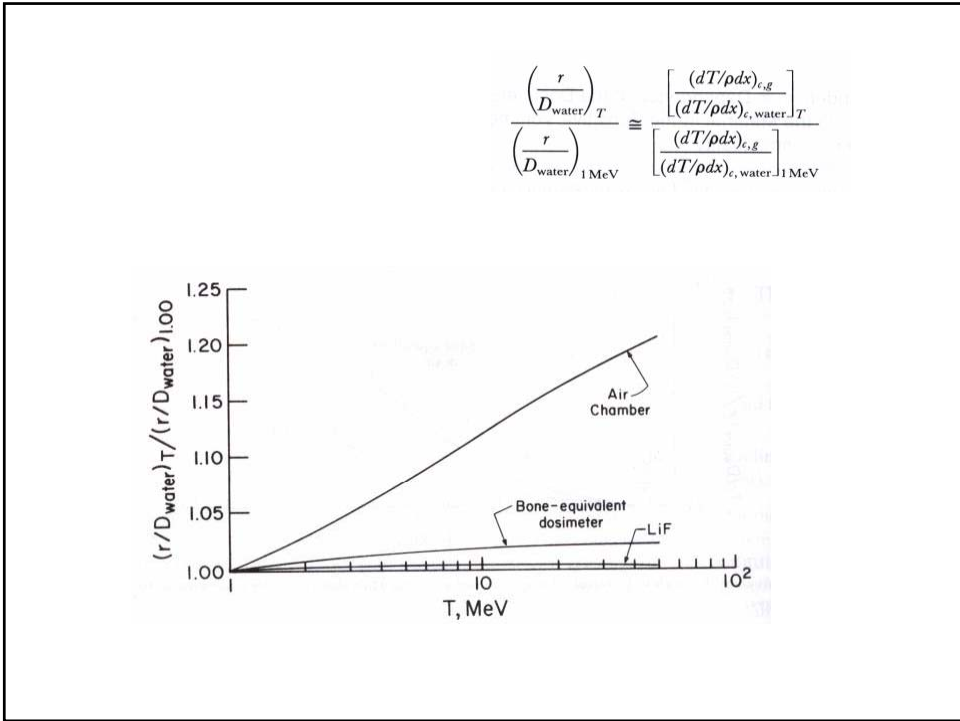
$$\left(\frac{r}{X}\right)_{1.25} \cong \frac{[(\mu_{en}/\rho)_g]}{[(\mu_{en}/\rho)_{air}]_{1.25}}$$



b. Energy Dependence = Dependence of the Dosimeter Reading per Unit of Absorbed Dose in Water on the Photon or Electron-Beam Energy

$$\frac{(r/D_{water})_{\bar{E}}}{(r/D_{water})_{1.25}} \cong \frac{[(\mu_{en}/\rho)_g / (\mu_{en}/\rho)_{water}]_{\bar{E}}}{[(\mu_{en}/\rho)_g / (\mu_{en}/\rho)_{water}]_{1.25}}$$





c. Energy Dependence = Dependence of the Dosimeter Reading per Unit of Absorbed Dose to the Material in the Sensitive Volume Itself, on the Radiation Energy or Beam Quality

This kind of energy is the most fundamental. It reflects the dosimeter's energy efficiency. The ability of the dosimeter to give the same amount of absorbed energy in its sensitive volume independent of energy

2. MODIFICATION

