Practical Aspects of Electron Beam Dosimetry

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Objectives

- Measurement of electron central axis %DD in water using cylindrical ionization chambers
- Measurement of electron central axis %DD in water using plane-parallel ionization chambers
- Measurement in small and irregular electron fields
- Use of non-water phantoms for electron beam dosimetry

Calibration of Electron Beams

- Done according to TG-51
  - Dose rate at one point
    - Done in water
    - Central axis of the beam
    - Particular cone size
    - At depth of $d_{50} = 0.6 R_{50} - 0.1$ cm
      - $R_{50}$ is the depth in water at a 10x10 cm$^2$ or larger beam (when $R_{50} > 8.5$ cm, a 20x20 cm$^2$ or larger field is needed) of electrons at an SSD of 100 cm at which the absorbed dose falls to 50% of the maximum dose.
  - Uses realistic stopping powers for water

$R_{50}$

- This value is absolutely essential for calibration
- Can be determined from the central axis depth ionization curve using:
  - $R_{50} = 1.029 I_{50} - 0.06$ (cm) (for $2 \leq I_{50} \leq 10$ cm)
  - $R_{50} = 1.059 I_{50} - 0.37$ (cm) (for $I_{50} > 10$ cm)
- From central axis percentage depth dose curve determined...
  - Using ionization chambers, or
  - Diodes
  - Accuracy have been verified vs. ion chamber data
Central Axis Percentage Depth Dose Determination – Ionization Chambers

- Remember that CA %DD is the ratio of two measurements made at different depths, \( d \) and \( d_{\text{max}} \).

- Ionization chamber considerations
  - The Corrected Reading, \( M \), includes \( P_{\text{ion}} \) & \( P_{\text{pol}} \).
  - Make sure that \( P_{\text{ion}} \) and \( P_{\text{pol}} \) do not vary by more than 2% throughout the range of depths to be measured.
  - Verify, near the surface, at \( d_{\text{max}} \), and \( R_{50} \).
  - \( P_{\text{ion}} \) can vary by more than 4% at \( R_{50} \) for P-P chambers.
  - Automated scanners do not take the above into account.

\[ P_{\text{repl}} \] consists of two parts:
- \( P_{g} \) – the gradient correction
  - Corrected by shifting the ionization curve upstream by 0.5 \( r_{\text{avg}} \) for electrons, cylindrical chambers.
- \( P_{f} \) – the fluence correction
  - Depends on the cavity radius (cylindrical chamber) and energy of the electron beam at the depth of measurement.
  - Should be investigated and applied if effect >2%.
  - Need to determine \( F \) use the Harder equation.

\[ E_{j} = E_{0}(1 - \frac{d}{R_{p}}) \]

\( E_{0} \) and \( R_{p} \)

- \( E_{0} \) (mean incident energy), can be determined in terms of \( R_{50} \) (IAEA 1996):
  \[ E_{0} = 0.656 + 2.059R_{50} + 0.022R_{50}^{2} \text{ (MeV)} \]

  or using \( I_{50} \):
  \[ E_{0} = 0.818 + 1.935I_{50} + 0.040I_{50}^{2} \text{ MeV} \]

- \( R_{p} \) can be determined in terms of \( R_{50} \):
  \[ R_{p} = 1.271R_{50} = 0.23 \text{ (cm)} \]

\( P_{f} \) - Cylindrical Chambers

- Table V from TG-25 Report
**Percent Depth Ionization**

- Given by:
  \[
  \%d_i_w(d) = 100 \frac{M(d)}{M(l_{\text{max}})}
  \]

- where \(M\) is the fully corrected ion chamber reading, and \(l_{\text{max}}\) is the depth of the maximum ionization reading.

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**Determination of Percentage Depth Dose – in Water**

- **TG-70 equation:**
  \[
  \%d_i_w(d) = \left( \frac{\sum (R_{0i} d) \delta P(E_d)}{\sum (R_{0i} l_{\text{max}}) \delta P(E_d)} \right) \%
  \]

- Assuming that \(P_{\text{wall}}\) is unity for electron beams and low atomic number thin-walled chambers (Johannson et al. 1978).

- \(P_{\text{wall}}\) cannot be assumed to be unity. Can vary by 0.5\% at \(d_{\text{ref}}\) and as much as 2.5\% between 0.5 cm and \(R_{50}\) for 6 MeV electrons (Buckley and Rogers, 2006)

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**Stopping Power Ratios for Realistic Electron Beams – Water/Air**

\[
\left( \frac{P}{E_d} \right)_{v=0} = \frac{a + b (\ln R_{50}) + c (\ln R_{50})^2 + d (d \ln R_{50})}{1 + e (\ln R_{50}) + f (\ln R_{50})^2 + g (\ln R_{50})^3 + h (d \ln R_{50})}
\]

- where \(a = 1.0752\)  \(b = -0.50867\)  \(c = 0.088670\)
  \(d = -0.08402\)  \(e = -0.42806\)  \(f = 0.064627\)
  \(g = 0.003085\)  \(h = -0.12460\) \(*\)

- Can be used to determine the entire central axis percentage depth dose curve in water to an accuracy of \(~1\%\)\(\dagger\)

*From Burns et al. 1996
††From Rogers 2004
Measurements using plane-parallel ionization chambers in water

- Plane-parallel ionization chamber considerations
  - Minimize the error in the effective point of measurement determination
  - Inner surface of the front window is taken as the point of measurement
  - The thickness of the front window can be 1-2 mm thick and has to be taken into account during measurements
  - Well-guarded p-p chambers do not require a Pgr correction
  - Pfl correction is considered unity except for the Markus and Capintec PS-033 chambers. This correction should be made as above for cylindrical chambers using data from TG-39.
  - \( P_{\text{wall}} \) – TG-70 recommends a value of unity

Output Factor – \( S_e \), at any Treatment SSD

- \( S_e \) for a particular electron field size, \( r_a \), at any treatment SSD, is defined as the ratio of the dose per monitor unit, \((\text{Gy/MU})\), on the central axis at the depth of maximum dose for that field, \( d_{\text{max}}(r_a) \), to the dose per monitor unit for the reference applicator, or field size, \( r_0 \), and standard SSD at the depth of maximum dose for the reference field used in calibration, \( d_{\text{max}}(r_0) \).

\[
S_e(d_{\text{max}}(r_a) | r_a, \text{SSD}_{r_a}) = \frac{D}{\mu}(d_{\text{max}}(r_a) | r_a, \text{SSD}_{r_a}) \frac{d_{\text{max}}(r_0) | r_0, \text{SSD}_{r_0}}{D/\mu(d_{\text{max}}(r_0) | r_0, \text{SSD}_{r_0})}
\]

Small or Irregular Electron Fields

- When electron fields are smaller than, or comparable to, the radius required for lateral scattering equilibrium (field radius less than \( 0.88E_p \) cm),
  - the depth of \( d_{\text{max}} \) moves towards the surface
  - the central-axis percentage depth dose decreases,
  - and the output (dose/monitor unit) decreases from that of the unrestricted applicator

\[
E_p = 0.22 + 1.96R + 0.0025R^2 \text{ (MeV, in water)}
\]
Output Determination for Small or Irregular Electron Fields

- Starting with the previous equation for $S_e$:
  \[ S_e \left( d_{\text{max}}(r_e, \phi, \text{SSD}) \right) = \frac{D}{D_{\text{max}}(r_e, \phi, \text{SSD})} \]

- We have to recognize that the depth of $d_{\text{max}}$ for $r_e$ may be different from the depth of $d_{\text{max}}$ for $r_e$, the calibration field:
  \[ S_e \left( d_{\text{max}}(r_e, \phi, \text{SSD}) \right) = \frac{M/U \left\{ \left[ \tau(r_e) \right]^{\text{eff}} \right\} d_{\text{max}}(r_e, \phi, \text{SSD})}{M/U \left\{ \left[ \tau(r_e) \right]^{\text{eff}} \right\} d_{\text{max}}(r_e, \phi, \text{SSD})} \]

- In most cases, $P_e$ will be initially magnified.
  - If the measurements are in water, the Burns equation can be used for determination of realistic stopping powers in water in the equation above.

Measurements of CA %DD using Automated Scanning Systems

- Commissioning data (CA %DD & isodose curves) are almost always measured using automated water scanning systems.
  - Many scanning systems correctly apply the corrections for the effective point of measurement for cylindrical ionization chambers and the stopping power ratio correction.

- Few systems apply the $P_{\text{eff}}$ correction or corrections for polarity effect.
  - In most instances, these corrections are small due to the small size of the cylindrical chambers employed and have little impact on clinical practice.

- The algorithms and the correction factors applied by these automated systems should be thoroughly understood.

- The final data from the automated scanning system should be checked against data that takes all correction factors into account.

Measurements in Non-Water Phantoms

- For cylindrical chamber in non-water phantoms, several corrections are required to convert the output measurement to water.
  - To determine the relative output factor for an electron field of size $r_e$ the depth of maximum dose, $d_{\text{max}}$, must first be found in the non-water phantom.

- Application of depth scaling converts a depth in a solid phantom to its water equivalent depth. At these equivalent depths, the beam energies of the electron beam are identical.

- The same chamber correction coefficients can be used at the two positions in the two phantom materials.

- The depth in plastic phantoms, $d_{\text{eff}}$, can be scaled to its water-equivalent depth, $d_{\text{w}}$, using the following equation (TG-25 & TG-70):
  \[ d_{\text{w}} = d_{\text{eff}} \left( \frac{R_{50}^{\text{eff}}}{R_{50}^{\text{w}}} \right) \]

Summary

- Measurement of central axis percentage depth dose in water and other materials is key.
- Proper electron beam measurement involve many details.
- Need to keep correction coefficients in mind, $P_{\text{eff}}$, $P_{\text{pol}}$, $P_{\text{wall}}$, and $P_{\text{eff}}$.
- TG-70, addendum to TG-25 just published (Med Phys, 39(7), 3239-3279, 2009)