Practical Aspects of Electron Beam Dosimetry

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Driven to Discover

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 $d_{ref} = 0.6\ R_{50} - 0.1$ cm
      - R_{50} is the depth in water in 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 <u>ionization</u> curve using:

$$R_{50} = 1.029\ I_{50} - 0.06\ \text{(cm)} \quad (\text{for } 2 \le I_{50} \le 10\ \text{cm})$$

or

$$R_{50} = 1.059\ I_{50} - 0.37\ \text{(cm)} \quad (\text{for } I_{50} > 10\ \text{cm})$$

- From central axis percentage depth <u>dose</u> curve determined…
  - Using ionization chambers, or
  - Diodes
    - Accuracy have been verified v. 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_{max}
- Ionization chamber considerations
  - The Corrected Reading, M, includes P_{ion} & P_{pol}
  - Make sure that P_{ion} and P_{pol} do not vary by more than 2% throughout the range of depths to be measured
    - Verify, near the surface, at d_{max}, R_{50}, and R_p
    - P_{pol} can vary by more than 4% at R_p for P-P chambers
    - Automated scanners do not take the above into account

P_{repl}

- P_{repl}, consists of two parts:
  - P_{gr} – the gradient correction

$$P_{gr}^{Q}(cyl) = \frac{M_{raw}(d_{ref}+0.5r_{cav})}{M_{raw}(d_{ref})}$$

    - Corrected by shifting the ionization curve upstream by 0.5 r_{cav} for electrons, cylindrical chambers
  - P_{fl} – 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 $\overline{E}_d$; use the Harder equation

$$\overline{E}_d = \overline{E}_0\left(1 - d/R_p\right)$$

$\overline{E}_0$ and R_p

- $\overline{E}_0$ (mean incident energy), can be determined in terms of R_{50} (IAEA 1996):

$$\overline{E}_0 = 0.656 + 2.059R_{50} + 0.022R_{50}^{\ 2}\ (MeV)$$

- or using I_{50}:

$$\overline{E}_0 = 0.818 + 1.935I_{50} + 0.040I_{50}^{\ 2} MeV$$

- R_p can be determined in terms of R_{50}

$$R_p = 1.271R_{50} - 0.23\ (cm)$$

P_{fl} - Cylindrical Chambers

$\overline{E}_d$* (MeV)	Inner diameter (mm)			
	3	5	6	7
2	0.977	0.962	0.956	0.949
3	0.978	0.966	0.959	0.952
5	0.982	0.971	0.965	0.960
7	0.986	0.977	0.972	0.967
10	0.990	0.985	0.981	0.978
15	0.995	0.992	0.991	0.990
20	0.997	0.996	0.995	0.995

*where $\overline{E}_d = \overline{E}_0(1 - d/R_p)$. $\overline{E}_0$ is the mean incident electron energy, $\overline{E}_d$ is the mean energy as a function of depth, d, in water

Table V from TG-25 Report

P_{fl} - Plane-parallel Chambers

$\bar{E}_d$ (MeV)*	Holt, NACP, Exradin	Markus	Capintec PS-033
2.5	1.000	0.985	0.956
3	1.000	0.988	0.961
4	1.000	0.992	0.970
5	1.000	0.994	0.977
6	1.000	0.996	0.982
7	1.000	0.997	0.986
8	1.000	0.998	0.989
10	1.000	0.999	0.994
12	1.000	1.000	0.996
15	1.000	1.000	0.998
20	1.000	1.000	1.000

*where $\bar{E}_d = \bar{E}_0(1 - d/R_p)$. $\bar{E}_0$ is the mean incident electron energy, $\bar{E}_d$ is the mean energy as a function of depth, d, in water, and R_p is the practical range of the electron beam.

From TG-39 Report

Percent Depth Ionization

- Given by:

$$\%di_w(d) = 100\frac{M(d)}{M(I_{\max})}$$

- where M is the fully corrected ion chamber reading, and I_{max} is the depth of the maximum ionization reading.

Determination of Percentage Depth Dose – in Water

- TG-70 equation:

$$\%dd_w(d) = \%di_w(d) \times \frac{k_{R_{50}}(d)}{k_{R_{50}}(d_{\max})} = \%di_w(d) \times \frac{\left(\frac{\bar{L}}{r}\right)^w_{air}(R_{50}, d) \diamond P_{fl}(E_d)}{\left(\frac{\bar{L}}{r}\right)^w_{air}(R_{50}, d_{\max}) \diamond P_{fl}(E_{d_{\max}})}$$

- Assuming that P_{wall} is unity for electron beams and low atomic number thin-walled chambers (Johansson *et al* 1978).
- P_{wall} cannot be assumed to be unity. Can vary by 0.6% at d_{ref} and as much as 2.5% between 0.5 cm and R_{50} for 6 MeV electrons (Buckley and Rogers, 2006)

Stopping Power Ratios for Realistic Electron Beams – Water/Air

$$\left(\frac{\bar{L}}{r}\right)^w_{air}(R_{50}, d) = \frac{a + b(\ln R_{50}) + c(\ln R_{50})^2 + d(d/R_{50})}{1 + e(\ln R_{50}) + f(\ln R_{50})^2 + g(\ln R_{50})^3 + h(d/R_{50})}$$

- 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%.†

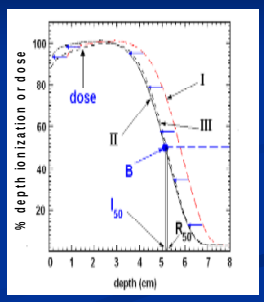
*From Burns et al. 1996
†From Rogers 2004

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 P_{gr} correction
  - P_{η} 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_{wall} – TG-70 recommends a value of unity

Output Factor - S_e

- Calibration done at d_{ref}
- Output (cGy/MU) defined at d_{max}
- Use clinical CA %DD to determine output at d_{max}
- d_{max} for electron beams – the depth at which the absorbed dose is maximum
  - Easily determined for low-energy electrons
  - For high-energy electrons, a broad region exists



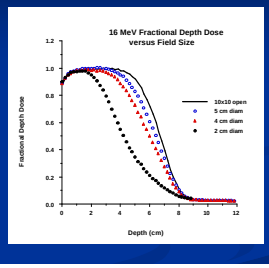
Output Factor – S_e, at any Treatment SSD

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

$$S_e\left(d_{\max}(r_a), r_a, SSD_{r_a}\right) = \frac{D/U\left(d_{\max}(r_a), r_a, SSD_{r_a}\right)}{D/U\left(d_{\max}(r_0), r_0, SSD_{r_0}\right)}$$

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 $0.88\sqrt{E_{p,0}}$ cm),
  - the depth of d_{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



$E_{p,0}$ - *most probable energy at the surface*

$$= 0.22 + 1.98R_p + 0.0025R_p^2 \ (MeV, in\ water)$$

Output Determination for Small or Irregular Electron Fields

- Starting with the previous equation for S_c:

$$S_e\left(d_{\max}(r_a), r_a, SSD_{r_a}\right) = \frac{D/U\left(d_{\max}(r_a), r_a, SSD_{r_a}\right)}{D/U\left(d_{\max}(r_0), r_0, SSD_{r_0}\right)}$$

- we have to recognize that the depth of d_{max} for r_a may be different from the depth of d_{max} for r_0, the calibration field.

$$S_e\left(d_{\max}(r_a), r_a, SSD_{r_a}\right) = \frac{\left(M/U\left[\left(\bar{L}/r\right)_{air}^{water} P_{fl}\right]_Q\right)\left(d_{\max}(r_a), r_a, SSD_{r_a}\right)}{\left(M/U\left[\left(\bar{L}/r\right)_{air}^{water} P_{fl}\right]_Q\right)\left(d_{\max}(r_0), r_0, SSD_{r_0}\right)}$$

- In most cases, P_{fl}, will be clinically insignificant.
- 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 corrections.
- Few systems apply the P_{repl} (P_{fl}) 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, the depth of maximum dose, d_{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 mean 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_{med}, can be scaled to its water-equivalent depth, d_w, using the following equation (TG-25 & TG-70):

$$d_w = d_{med}\, r_{eff} = d_{med}\left(\frac{R_{50}^{w}}{R_{50}^{med}}\right)$$

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_{repl} (P_{gr}, P_{fl}), P_{wall}, and P_{pol}
- TG-70, addendum to TG-25 just published (Med Phys, 39(7), 3239-3279, 2009)