TG-51
Output Calibration
for
Electron Beams

Reference Conditions

- Clinical reference dosimetry for electron beams is performed in an open beam with the point of at a water-equivalent depth of

$$d_{ref} = 0.6 \ R_{50} \ - 0.1$$

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

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

- Where the R_{50} is calculated from the depth ionization curve (I_{50})
- For beams with R_{50} <=8.5 cm, field size = 10x10 cm^2 at the phantom surface with SSD=100cm
- For higher-energy beams (R_{50} >8.5 cm), field size is 20x20 cm^2, SSD=100cm
- By going to d_{ref}, this protocol makes use of stopping power ratios which account for the realistic nature of the electron beams.
  - $d_{ref} \approx d_{max}$ for E < 10 MeV; $d_{ref} > d_{max}$ for E > 10 MeV

Formalism

$$D_w^Q = M k_Q N_{D,w}^{^{60}\mathrm{Co}} \quad (\mathrm{Gy})$$

Formalism

- D_w^Q
  - absorbed dose to water (Gy) for electron beam quality Q at the point of measurement of the ion chamber when it is absent.

- M
  - fully corrected electrometer reading in coulombs

- $N_{D,w}^{^{60}\mathrm{Co}}$
  - absorbed-dose to water ion chamber calibration factor for a 60Co beam (Gy/C). Traceable to national standards of absorbed dose to water maintained by Primary Standard Laboratories (NIST). Direct traceability is also obtained from an Accredited Dosimetry Calibration Laboratory (ADCL).

Formalism

$$D_w^Q = M k_Q N_{D,w}^{^{60}\mathrm{Co}} \quad (\mathrm{Gy})$$

$$k_Q = P_{\mathrm{gr}}^Q \, k_{R_{50}} \qquad\qquad k_{R_{50}} = k'_{R_{50}} k_{\mathrm{ecal}}$$

Dose to water at reference depth, d_{ref} :

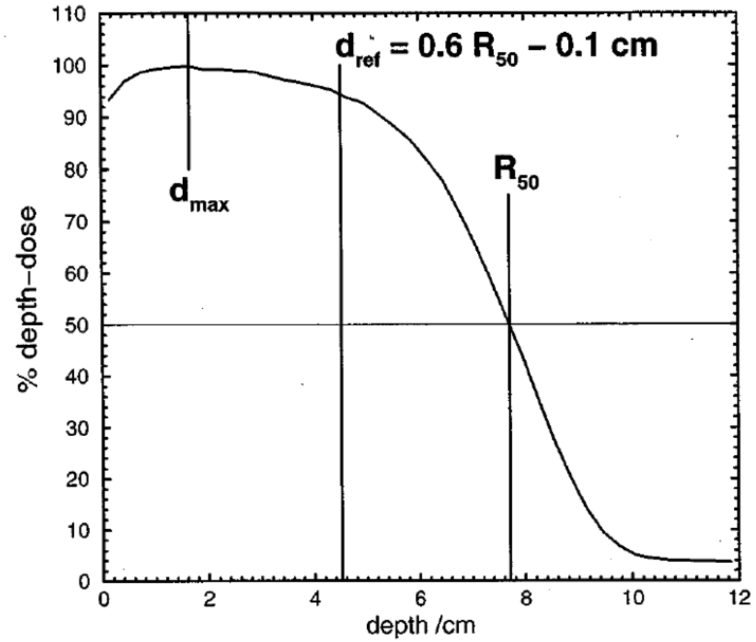
$$D_w^Q = M P_{gr}^Q k'_{R_{50}} k_{ecal} N_{D,w}^{^{60}Co} = [9 \cdot 10a \cdot 5b \cdot 5a \cdot 2c]$$

Formalism

- k_{ecal}
  - photon-electron conversion factor. Fixed for a given chamber model. Converts absorbed dose to water calibration factor for a Co-60 beam to the calibration factor for an electron beam with beam quality Qecal (R50 = 7.5 cm).
- $k'_{R_{50}}$
  - electron beam quality conversion factor. Beam quality dependent; small variation chamber-to-chamber. Converts absorbed dose to water calibration factor for a electron beam with quality Q_{ecal} to calibration factor for electron beam with beam quality Q.
- P_{gr}^{Q}
  - ionization gradient correction factor. Only necessary for cylindrical chambers. Depends on radius of chamber cavity and ionization gradient at point of measurement.

Beam Quality

- Beam quality for electrons is specified by the depth at which the dose falls to 50% of dmax (R_{50}) in a beam with a field size >= 10x10 cm^2 on the surface of the phantom at an SSD of 100 cm (>=20x20 cm^2 for R_{50}>8.5 cm).



Beam Quality (Sec.VIII.C)

Measure I_{50} by measuring depth-ionization curve and, for cylindrical chambers only, shifting curve upstream by 0.5 r_{cav}

I_{50}: ______________________ cm

a.i. If $2 \le I_{50} \le 10$ cm:

$R_{50} = 1.029 I_{50} - 0.06$ ______________________ cm

ii. If $I_{50} > 10$ cm:

$R_{50} = 1.059 I_{50} - 0.37$ ______________________ cm

b. Reference depth $d_{ref} = 0.6 R_{50} - 0.1$ ______________________ cm (water equivalent)

Beam Quality

- Can calculate $k'_{R_{50}}$ and P_{gr}^{Q} analytically for Farmer-like cylindrical chambers, given that R_{50} is between 2-9cm (with max error of 0.2%)

$$k'_{R_{50}}(\mathrm{cyl}) = 0.9905 + 0.0710 e^{(-R_{50}/3.67)}$$

$$P_{gr}^{Q} = \frac{M_{\mathrm{raw}}(d_{\mathrm{ref}} + 0.5 r_{\mathrm{cav}})}{M_{\mathrm{raw}}(d_{\mathrm{ref}})} \text{ (for cylindrical chambers)}$$

- Similarly for plan-parallel chambers, given R_{50} is between 2-20cm

$$k'_{R_{50}}(\mathrm{pp}) = 1.2239 - 0.145 (R_{50})^{0.214}$$

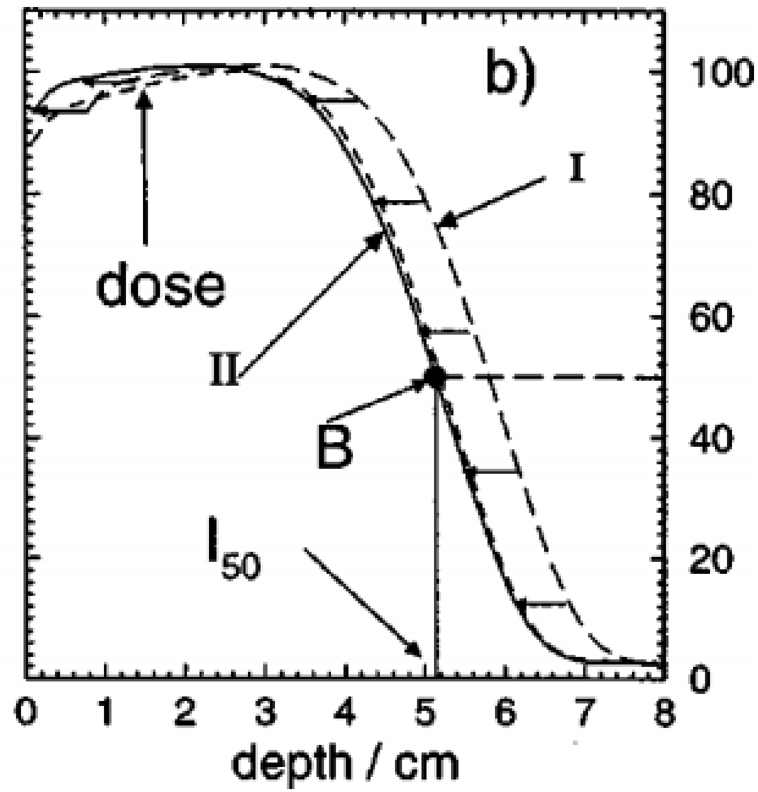
Beam Quality

- For photon beams 6 MV - 18 MV, k_Q varies by < 3% (~ 0.995 - 0.974).

  For electron beams 6 MeV - 20 MeV, $k'_{R_{50}}$ varies by < 3% (~1.026 - 0.997)

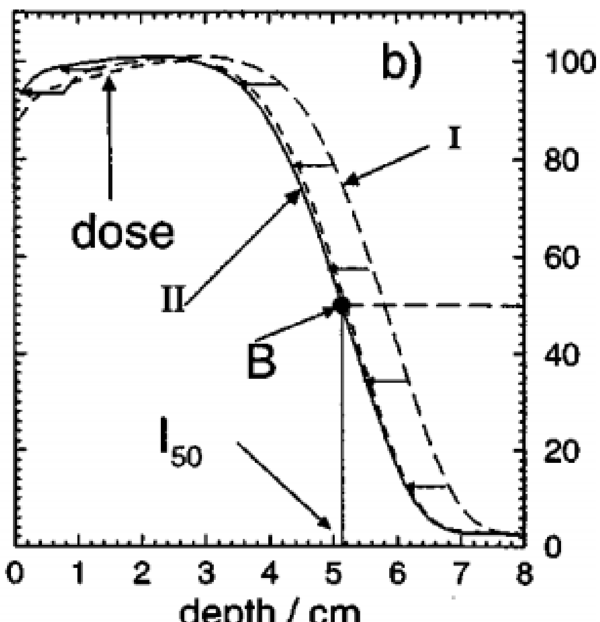
Depth Dose Corrections

- For electrons, there is significant change in the stopping power ratio with depth
- Therefore the measured depth-ionization must be further corrected to obtain depth-dose (TG-25).
- However, the conversion is not needed in this protocol.
- TG 51 provides equations to convert the depth of 50% maximum ionization (I50) - determined from the shifted depth-ionization curve - to R50.



Depth Dose Corrections

- Measure percent depth-ionization (PDI) distribution with a well-guarded plane-parallel ionization chamber. The water equivalent thickness (in g.cm-2) of the front window and any waterproofing material should be taken into account when positioning the chamber at the position of interest. Determine the depth of the 50% of the maximum ionization on the depth-ionization curve. This depth gives I50. Determine R50 using eq. (16) or (17) of the protocol as appropriate.



$$\left(\frac{\overline{L}}{\rho}\right)_{air}^{w}(z, R_{50}) = \frac{a + b(\ln R_{50}) + c(\ln R_{50})^2 + d(z/R_{50})}{1 + e(\ln R_{50}) + f(\ln R_{50})^2 + g(\ln R_{50})^3 + h(z/R_{50})}$$

where z denotes the depth of measurement and

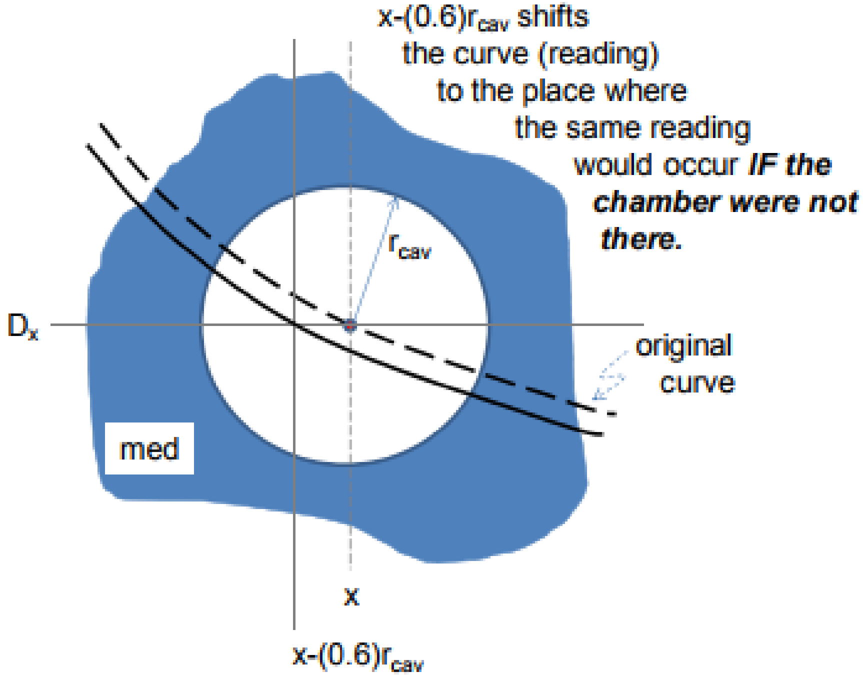
a = 1.0752 b = -0.50867 c = 0.088670 d = -0.08402

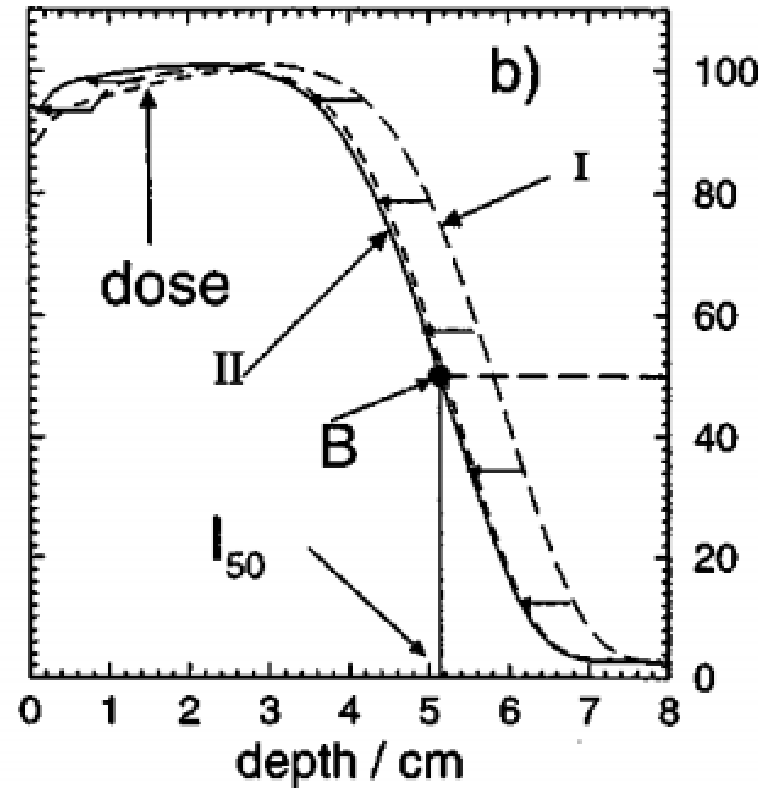
e = -0.42806 f = 0.064627 g = 0.003085 h = -0.12460

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

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

Depth Dose Corrections





- One must also shift the chamber reading UPSTREAM for the effective point of measurement – it is an implicit correction for the chamber's inherent charged particle fluence perturbation. For electron beams, we shift reading upstream by $0.5r_{cav}$. Where r_{cav} is the radius of the ion chamber cavity

Depth Dose Corrections

- The effective point of measurement for a cylindrical chamber is upstream of the point of measurement (CAX of chamber) due to the predominantly forward direction of the secondary electrons.
- For cylindrical and spherical chambers, the measured depth ionization curve is shifted upstream by $0.6r_{cav}$ and $0.5r_{cav}$ for photons and electrons respectively.
- These shifted curves are used to determine beam quality.
- For pp chambers, the center of the front face of the chamber is the point of measurement and is taken as the effective point of measurement.
- No shift in the depth-ionization curve is required for the purposes of beam quality specification.

TG-51 v. TG-21

TG-51

- Dose in water: N_D
- Msmts in water phantom with dimensions >= 30x30x30 cm3.
- Measurement at d_{ref}
- $E_o = 2.33\ R_{50}$
- Stopping power corrections are more realistic

TG-21

- Dose in cavity gas: N_{gas}
- Measurement at depth of ionization maximum
- $E_o = 2.33\ I_{50}$
- Stopping power corrections are monoenergetic

TG–51 Worksheet B: Electron Beams – Cylindrical Chambers

For electrons with $R_{50} \geq 2.6$ cm (energies > 6 MeV) only and preferably $\geq$ 4.3 cm (10 MeV).

- For beams with R_{50} < 4.3cm (10 MeV or less), well-guarded plane parallel chambers are preferred
- Plane parallel chambers must be used for beams with R_{50} <= 2.6cm (6 MeV or less)

TG–51 Worksheet D: Electron Beams using Plane-Parallel Chambers

- Electrons: 4-50 MeV

Chambers

- For electrons, minor construction details significantly alter response of pp chambers in 60Co beams and this makes determination of kecal uncertain. PP chambers should be cross-calibrated in high-energy electron beams against calibrated cylindrical chambers.

TG–51 Worksheet C: $k_{\mathrm{ecal}} N_{D,w}^{60Co}$ for plane-parallel chambers

There are two methods for determining $k_{\mathrm{ecal}} N_{D,w}^{60Co}$ for a plane-parallel chamber. Method A uses cross-calibration against a calibrated cylindrical chamber and is the preferred method. Method B uses a ^{60}Co absorbed-dose calibration factor.

Chambers

- $M = P_{\text{ion}} P_{\text{TP}} P_{\text{elec}} P_{\text{pol}} M_{\text{raw}} \quad (\text{C or rdg})$

Corrected ion. ch. rdg M (Sec.VII) at d_{ref}

$$M = P_{ion} P_{TP} P_{elec} P_{pol} M_{raw} = [8 \cdot 6c \cdot 2bi \cdot 7b \cdot 7a]$$

Fully corrected M (Eq (8)): ____________________ C or rdg

M_{raw} = raw ion chamber reading (C)
P_{pol} = polarity effect correction factor
P_{TP} = temperature-pressure correction factor
P_{ion} = ion recombination correction factor
P_{elec} = electrometer calibration factor

P_{pol}

- Polarity effects vary with beam quality and conditions such as cable position.
- If the polarity correction is 0.3% or greater from unity for photon beams <= 6MV then one must establish the value of P_{pol} for the calibration laboratory beam.
- If there is a significant correction for the calibration beam, the user must use N(60Co) / Ppol(60Co).

Polarity Correction (Sec.VII.A)

M^{+}_{raw} : ____________________ C or rdg

M^{-}_{raw} : ____________________ C or rdg

a. M_{raw} (for polarity of calibration): ____________________ C or rdg

b. P_{pol}: ____________________ $\left[\text{Eq.}(9) = \left| \frac{\left(M^{+}_{raw} - M^{-}_{raw}\right)}{2M_{raw}} \right| \right]$

P_{TP}

- Calibration factors are given for standard environmental conditions of temperature at T=22°C and pressure at P=101.33 kPa (1 atm).

- It is assumed that the relative humidity is always in the range of 20%-80%. Error introduced by ignoring variation is humidity in this range is +/- 0.15%. Humid air may cause condensation inside the ion chamber volume and this can affect chamber response.

Temperature /Pressure Correction (Sec.VII.C)

a. Temperature: ________________ °C

b. Pressure: ________________ $\text{kPa}\left[= \text{mmHg} \cdot \dfrac{101.33}{760.}\right]$

c.P_{TP}: ________________ $\left[\text{Eq.}(10) = \left(\dfrac{273.2 + 6\text{a}}{295.2}\right)\left(\dfrac{101.33}{6\text{b}}\right)\right]$

P_{ion}

- The ion chamber readings in the user's beam must be corrected for the lack of complete collection efficiency.
- P_{ion} is a function of the dose per pulse in accelerator beams, and will change if either the pulse rate for a fixed dose rate, or the dose rate is changed.
- P_{ion} determined using this method is accurate to within <0.5%.However, if Pion > 1.05, the uncertainty becomes unacceptably large and another chamber should be used.

P_{ion} measurements (Sec.VII.D.2)

Operating voltage= V_H: ____________________V

Lower voltage V_L: ____________________V

M_{raw}^{H}: ____________________C or rdg

M_{raw}^{L}: ____________________C or rdg

P_{ion} (V_H) (pulsed/swept beam, Eq.(12)): ____________________ $\left[\left(1.-\frac{V_H}{V_L}\right)\Big/\left(\frac{M_{raw}^{H}}{M_{raw}^{L}}-\frac{V_H}{V_L}\right)\right]$

If P_{ion} > 1.05, another ion chamber should be used.

When should you calibrate your ion chamber?

- Ion chamber should be calibrated when first purchased, when repaired, when redundant checks suggest a need, or once every two years.
- The physicist must perform at least two independent checks prior to sending a chamber for calibration and repeat the same checks when the chamber is returned to ensure that the chamber characteristics have not changed during transit.
- Electrometer should also be calibrated. All ranges routinely used for clinical reference dosimetry should be calibrated.