Machine Calibration (*TG-51*)

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TG-51: Overview

The Report

- The Task Group 51 dosimetry protocol was first published in 1999
- It is used for photon beams from ^{60}Co to 50 MV
- It is used for electron beams with energies between 4 and 50 MeV
- The TG51 formulism uses different equations and setups compared to the old TG21 formalism

AAPM's TG-51 protocol for clinical reference dosimetry of high-energy photon and electron beams

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A protocol is prescribed for clinical reference dosimetry of external beam radiation therapy using photon beams with nominal energies between ^{60}Co and 50 MV and electron beams with nominal energies between 4 and 50 MeV. The protocol was written by Task Group 51 (TG-51) of the Radiation Therapy Committee of the American Association of Physicists in Medicine (AAPM) and has been formally approved by the AAPM for clinical use. The protocol uses ion chambers with absorbed-dose-to-water calibration factors, $N_{D,w}^{^{60}Co}$, which are traceable to national primary standards, and the equation $D_w^Q = M k_Q N_{D,w}^{^{60}Co}$, where Q is the beam quality of the clinical beam, D_w^Q is the absorbed dose to water at the point of measurement of the ion chamber placed under reference conditions, M is the fully corrected ion chamber reading, and k_Q is the quality conversion factor which converts the calibration factor for a ^{60}Co beam to that for a beam of quality Q. Values of k_Q are presented as a function of Q for many ion chambers. The value of M is given by $M = P_{ion} P_{TP} P_{elec} P_{pol} M_{raw}$, where M_{raw} is the raw, uncorrected ion chamber reading and P_{ion} corrects for ion recombination, P_{TP} for temperature and pressure variations, P_{elec} for inaccuracy of the electrometer if calibrated separately, and P_{pol} for chamber polarity effects. Beam quality, Q, is specified (i) for photon beams, by $\%dd(10)_x$, the photon component of the percentage depth dose at 10 cm depth for a field size of 10×10 cm^2 on the surface of a phantom at an SSD of 100 cm and (ii) for electron beams, by R_{50}, the depth at which the absorbed-dose falls to 50% of the maximum dose in a beam with field size ≥10×10 cm^2 on the surface of the phantom (≥20×20 cm^2 for R_{50}>8.5 cm) at an SSD of 100 cm. R_{50} is determined directly from the measured value of I_{50}, the depth at which the ionization falls to 50% of its maximum value. All clinical reference dosimetry is performed in a water phantom. The reference depth for calibration purposes is 10 cm for photon beams and $0.6R_{50} - 0.1$ cm for electron beams. For photon beams clinical reference dosimetry is performed in either an SSD or SAD setup with a 10×10 cm^2 field size defined on the phantom surface for an SSD setup or at the depth of the detector for an SAD setup. For electron beams clinical reference dosimetry is performed with a field size of ≥10×10 cm^2 (≥20×20 cm^2 for R_{50}>8.5 cm) at an SSD between 90 and 110 cm. This protocol represents a major simplification compared to the AAPM's TG-21 protocol in the sense that large tables of stopping-power ratios and mass-energy absorption coefficients are not needed and the user does not need to calculate any theoretical dosimetry factors. Worksheets for various situations are presented along with a list of equipment required.

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Machine Calibration

Difference Between TG21 and TG51

- The TG21 report describes both the theory and application of machine calibration
- The TG51 report is more of a "how-to" guide for machine calibration
- TG51 is based on an Absorbed dose to water Standard (*at a reference energy* ^{60}Co):
  - *More robust standard than AIR-KERMA*
  - *Closer to absorbed dose in tissue*

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Machine Calibration

Difference Between TG21 and TG51

N_X : EXPOSURE CALIBRATION FACTOR: (*Roentgen/ Charge*)
Exposure at the chamber-center with the chamber removed

N_{gas}: CAVITY GAS CALIBRATION FACTOR: (*Gray/Charge*)
Absorbed dose to the gas in the chamber at chamber-center
[*N_{gas} related to N_X through calculational algorithm*]

$N_{D,w}$: ABSORBED DOSE (*water*) CALIBRATION FACTOR: (*Gy/Charge*)
Absorbed dose to water at chamber-center, with chamber removed and replaced by water.

Machine Calibration

Difference Between TG21 and TG51

- Conversion to absorbed dose
  - Photon: Single factor; $\mathbf{k_Q}$
  - Electron: 3 Factors;
- Chamber specific corrections in "classes"
  few $\mathbf{k_Q}$ values
- Calibration in water (*annually*)

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Machine Calibration

Why use absorbed dose to water calibration factors?

- The standard would be easier to conceptualize
- Primary standards can be developed for absorbed dose in accelerators, which is impossible with exposure or air-kerma protocols
- Absorbed dose has less uncertainty
- Does not require the large look up tables of mass-energy absorption coefficients and stopping power ratios

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Equipment for TG51

- NIST traceable Ion Chamber and Electrometer
  - *Cylindrical Chambers are the primary standard*
  - *Parallel plate chambers may be used for electron beams >6MeV*
  - *Parallel plate chambers are required for electron beams <6MeV*
  - *An electrometer with a variable voltage*
- Equipment to allow for two independent checks of the ion chamber (*e.g. check sources or an independent dosimetry system*)

Equipment for TG51

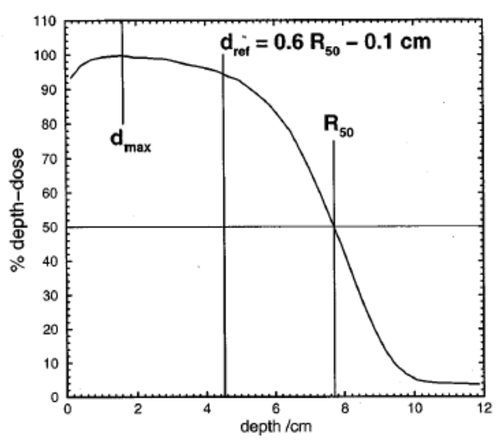
- A water phantom (*liquid*) of sufficient dimensions to provide full scatter
- A lead foil for photon beam energy's greater than 10 MV
  - *The lead foil is used to remove electron contamination*
- A calibrated device to measure local pressure
- A device to measure the temperature of the water

Clinical Reference Geometry for Electrons

- All dosimetry measurements must be performed in a liquid water phantom
- Plastics (*even water equivalent plastics*) are not allowed for the annual QA check
- They can be used for more frequent QA checks with the correct transfer factor
- The reference dosimetry is performed with a field size ≥ 10 cm x 10 cm for R_{50} <8.5 cm and ≥ 20 cm x 20 cm for R_{50} >8.5 cm
- SSD setup between 90 and 110 cm

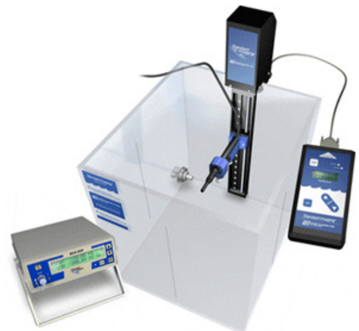
Clinical Reference Geometry for Electrons

- The depth for electron calibrations is located at a calculated reference depth
  - *d_{ref} = 0.6 R_{50} - 0.1 cm*
  - *R_{50} is the depth at which the absorbed dose falls to 50% o the maximum dose)*
- For Example:
  - *R_{50} = 7.7-cm*
  - *d_{ref} = (0.6 x 7.7) - 0.1*
  - *d_{ref} = 4.5-cm*



Clinical Reference Geometry for Photons

- All dosimetry measurements are performed in a water phantom
- The reference depth for calibration purposes is at 10-cm
- The reference dosimetry is performed at either SSD or SAD
- A 10 cm x 10 cm field size is defined on the surface for an SSD setup and defined at the depth of the detector for an SAD setup



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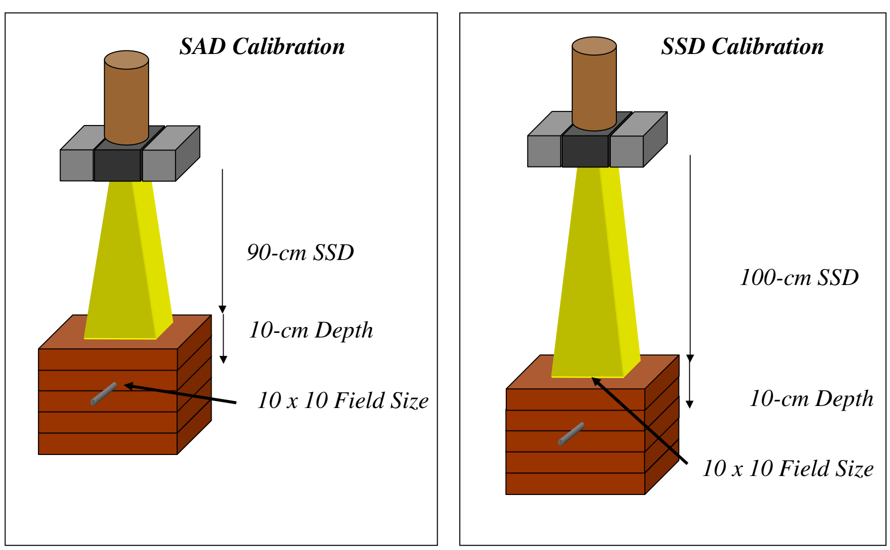
Clinical Reference Geometry for Photons



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TG51: Absorbed Dose from Photons

$$D_{Q,Water} = M \cdot k_Q \cdot {}_{D,W} N^{Co}$$

- $D_{Q,Water}$ is the absorbed dose to water at the point of measurement of the ion chamber placed under reference conditions for a clinical beam with beam quality Q
- Q is specified by the $\%dd(10)_x$ (*percentage depth dose at 10 cm depth in a water phantom with an SSD of 100 cm and field size of 10x10*)
- For photon energies > 10 MeV, $\%dd(10)_x$ must be obtained using a 1-mm lead foil placed 30 to 50 cm from the phantom surface

TG51: Absorbed Dose from Photons

$$D_{Q,Water} = M \cdot k_Q \cdot {}_{D,W} N^{Co}$$

$$M = M_{raw} P_{ion} P_{TP} P_{elec} P_{pol}$$

- M is the charge collected in a measuring chamber in coulombs corrected for recombination effects, temperature and pressure variations, electrometer inaccuracies, and polarity effects
- M_{raw} is the uncorrected reading of the charge collected by the ion chamber

TG51: Absorbed Dose from Photons

$$D_{Q,Water} = \boxed{M} \cdot k_Q \cdot {}_{D,W} N^{Co}$$

$$M = M_{raw} P_{ion} P_{TP} P_{elec} P_{pol}$$

- P_{ion} corrects for ionization recombination losses that occur at the time of calibration
- P_{ion} is measured with the following by applying two different bias voltages to the detector:

$$P_{ion}(V_H) = \frac{1-(V_H/V_L)^2}{M_{Raw}^H / M_{Raw}^L - (V_H/V_L)^2}$$

TG51: Absorbed Dose from Photons

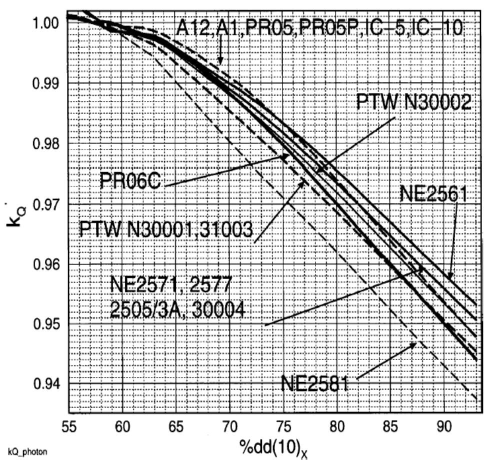
$$D_{Q,Water} = \boxed{M} \cdot k_Q \cdot {}_{D,W} N^{Co}$$

$$M = M_{raw} P_{ion} P_{TP} P_{elec} P_{pol} \qquad P_{TP} = \frac{273.2+T}{273.2+22.0} \times \frac{760}{P}$$

- P_{TP} corrects for temperature and pressure variations at the time of calibration
- P_{elec} corrects for the inaccuracy of the electrometer if it is calibrated separately from the ion chamber
- P_{elec} is given by the accredited laboratory that performs the calibration

TG51: Absorbed Dose from Photons

$$D_{Q,Water} = M \cdot k_Q \cdot N_{D,W}^{Co}$$



- k_Q is the quality conversion factor which converts the calibration factor for a ^{60}Co beam to that for a photon beam of quality Q
- k_Q has been measured or calculated as a function of Q for many ion chambers (*Figure 4 in TG51*)
- Values of k_Q have not been determined for parallel-plate chambers because there is insufficient information about wall correction factors

TG51: Absorbed Dose from Photons

$$D_{Q,Water} = M \cdot k_Q \cdot N_{D,W}^{Co}$$

$$K_Q = \frac{\left(\frac{L}{\rho}\right)_{air}^{water} \bullet P_{repl} \bullet P_{wall} \bullet P_{cel} \,\Big|_{\text{evaluated at the energy Q}}}{\left(\frac{L}{\rho}\right)_{air}^{water} \bullet P_{repl} \bullet P_{wall} \bullet P_{cel} \,\Big|_{\text{evaluated at cobalt energy}}}$$

P_{repl} and P_{wall} same as for TG-21

P_{cel} corrects for the influence of the Al center electrode

P_{repl} is weakly dependent on chamber diameter

P_{wall} is strongly dependent on thimble materials, less dependent on exact dimensions

TG51: Absorbed Dose from Photons

$$D_{Q,Water} = M \cdot k_Q \cdot {}_{D,W} N^{Co}$$

- Similar chambers have similar P_{wall} and $P_{cel,}$ so few k_Q needed
- TG-51 does not list values for my Chamber ???
  - Choose chamber in Protocol that has
    - *Same wall material*
    - *Same center electrode material*
    - *Approximately same wall thickness*
    - *Similar length and diameter -- weak depend*

TG51: Absorbed Dose from Photons

$$D_{Q,Water} = M \cdot k_Q \cdot {}_{D,W} N^{Co}$$

- ${}_{D,W}N^{Co}$ is the absorbed-dose calibration factor obtained in reference conditions for a ^{60}Co beam
- ${}_{D,W}N^{Co}$ is returned on the calibration report for the specific ion chamber
- It is dependant on the chambers characteristics (*volume, build-up cap, wall material, etc…*)

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TG51: Absorbed Dose from Photons

$$D_{Q,Water} = M \cdot k_Q \cdot {}_{D,W}N^{Co}$$

- Although ${}_{D,W}N^{Co}$ is supplied by an accredited laboratory, it is the physicist's responsibility to ensure that the calibration factor is still correct and that there are no problems with the ion chamber
  - *Inspect Chamber For Damage (Visual and Radiographic)*
  - *Ratio of full and half bias readings less than 1.01*

TG51: Absorbed Dose from Electrons

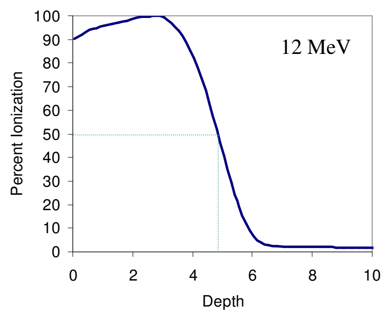
$$D_{Q,Water} = M \cdot k_Q \cdot {}_{D,W}N^{Co}$$

- Calculation of absorbed dose in water is very similar for electrons
- M and ${}^{D,W}N_{Co}$ remain the same
- The difference between the equations lies in the quality conversion factor k_{Qe} and the specification of beam quality Q
- The beam quality for electrons is specified by R_{50}, which is the depth at which the absorbed-dose falls to 50% of the maximum dose with a field size ≥ 10 cm x 10 cm for R_{50} <8.5 cm and ≥ 20 cm x 20 cm for R_{50} >8.5 cm

TG51: Absorbed Dose from Electrons

$$D_{Q,Water} = M \cdot k_Q \cdot {}_{D,W} N^{Co}$$

- R_{50} is determined directly from the measured value of I_{50}, the depth at which the ionization falls to 50% of its maximum value, using the equations:



$$R_{50} = 1.029 \cdot I_{50} - 0.06\,cm \quad (for\ 2\,cm \le I_{50} \le 10\,cm)$$
$$R_{50} = 1.059 \cdot I_{50} - 0.37\,cm \quad (for\ I_{50} > 10\,cm)$$

TG51: Absorbed Dose from Electrons

$$D_{Q,Water} = M \cdot k_Q \cdot {}_{D,W} N^{Co}$$

- k_{Qe} is the quality conversion factor that converts the calibration factor for a ^{60}Co beam to that for an electron beam of any beam quality
- Q and is determined by: $k_{Qe} = P^Q_{gr}\, k'_{R50}\, k_{ecal}$
  - *P^Q_{gr} corrects for gradient effects and is required for only cylindrical chambers*
  - *P^Q_{gr} is determined by the ratio of uncorrected ionization currents measured at two depths*

TG51: Absorbed Dose from Electrons

$$D_{Q,Water} = M \cdot k_Q \cdot {}_{D,W}N^{Co}$$

- k_{Qe} is the quality conversion factor that converts the calibration factor for a ^{60}Co beam to that for an electron beam of any beam quality
- Q and is determined by: $k_{Qe} = P^Q_{gr} k'_{R50} k_{ecal}$

$$P^Q_{gr} = \frac{M(d_{ref} + 0.5r_{cav})}{M_{raw}(d_{ref})}$$

- *NOTE: $M(d_{ref} + 0.5r_{cav})$ and $M(d_{ref})$ are the reading at the depth, (d_{ref}+05r_{cav} and d_{ref})*
- *NOT the reading times the depth.*

TG51: Absorbed Dose from Electrons

$$D_{Q,Water} = M \cdot k_Q \cdot {}_{D,W}N^{Co}$$

- k_{Qe} is the quality conversion factor that converts the calibration factor for a ^{60}Co beam to that for an electron beam of any beam quality
- Q and is determined by: $k_{Qe} = P^Q_{gr} k'_{R50} k_{ecal}$
  - *k'_{R50} is the electron quality conversion factor that converts ${}_{D,W}N^{Qecal}$ into ${}_{D,W}N^{Q}$, an electron beam absorbed dose calibration factor for a specific beam quality Q (Energy Dependent Factor)*
  - *k'_{R50} is a function of the electron beam quality specified by R_{50}*
  - *Values for many models of ion chambers are presented in Figures 5-8 of TG51*

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TG51: Absorbed Dose from Electrons

$$D_{Q,Water} = M \cdot k_Q \cdot {}_{D,W}N^{Co}$$

$$k_{ecal} = \frac{\left(\frac{L}{\rho}\right)_{air}^{water} \bullet \mathrm{P}_{repl} \bullet \mathrm{P}_{cel}\Big|_{\text{evaluated at energy } R_{50}=7.5}}{\left(\frac{L}{\rho}\right)_{air}^{water} \bullet \mathrm{P}_{repl} \bullet P_{wall} \bullet \mathrm{P}_{cel}\Big|_{\text{evaluated at Cobalt 60}}}$$

$$k'_{R_{50}} = \frac{\left(\frac{L}{\rho}\right)_{air}^{water} \bullet \mathrm{P}_{repl} \bullet \mathrm{P}_{cel}\Big|_{\text{evaluated at the energy } R_{50}}}{\left(\frac{L}{\rho}\right)_{air}^{water} \bullet \mathrm{P}_{repl} \bullet \mathrm{P}_{cel}\Big|_{\text{evaluated at energy } R_{50}=7.5}}$$

TG51: Absorbed Dose from Electrons

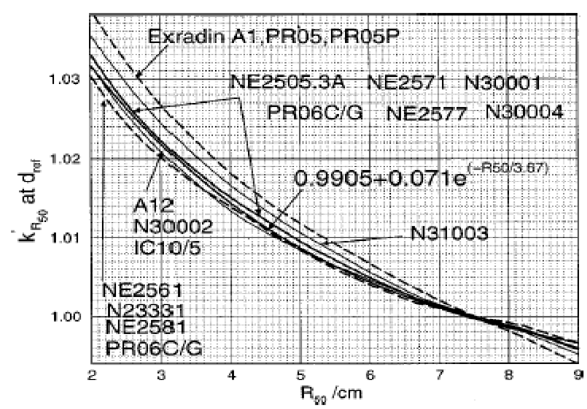

FIG. 5. Calculated values of $k'_{R_{50}}$ at d_{ref} as a function of R_{50} for several common cylindrical ion chambers. These values can be used with Eq. (6) (with a measured value of P^Q_{gr} and a k_{ecal} value from Table III) to determine the absorbed dose to water at the reference depth of $d_{ref}=0.6R_{50}-0.1$ cm.

TG51: Absorbed Dose from Electrons

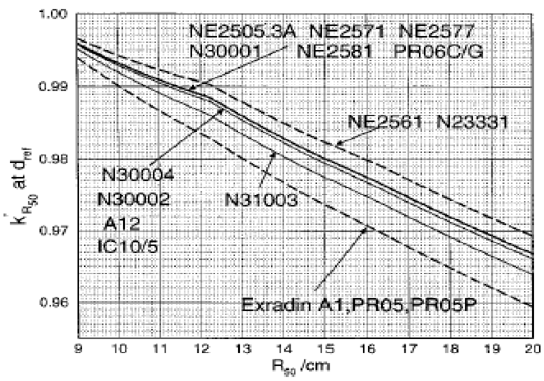

FIG. 7. Calculated values of $k'_{R_{50}}$ at d_{ref} for high-energy electron beams, as a function of R_{50} for cylindrical ion chambers. These values can be used with Eq. (6) (with a measured value of P^{Q}_{gr} and a k_{ecal} value from Table III) to determine the absorbed dose to water at the reference depth of $d_{ref}=0.6R_{50}-0.1$ cm.

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TG51: Absorbed Dose from Electrons

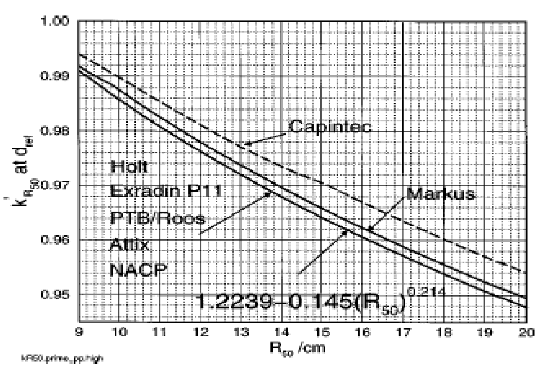

FIG. 8. Calculated values of $k'_{R_{50}}$ at d_{ref} for high-energy electron beams, as a function of R_{50} for plane-parallel chambers. Note that the values for the five well-guarded chambers lie on the same line in the figure. These values can be used with Eq. (6) (with $P^{Q}_{gr}=1.0$ and a k_{ecal} value from Table II) to determine the absorbed dose to water at the reference depth of $d_{ref}=0.6R_{50}-0.1$ cm.

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TG51: Absorbed Dose from Electrons

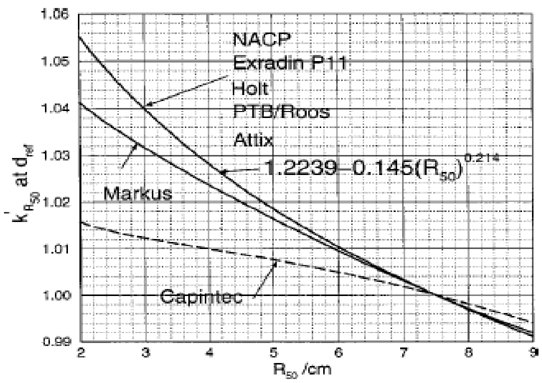

FIG. 6. Calculated values of $k'_{R_{50}}$ at d_{ref} as a function of R_{50} for several common plane-parallel chambers. Note that the values for the five well-guarded chambers lie on the same line in the figure. These values can be used with Eq. (6) (with $P^{Q}_{gr}=1.0$) to determine the absorbed dose to water at the reference depth of $d_{ref}=0.6R_{50}-0.1$ cm.

TG51: Absorbed Dose from Electrons

$$D_{Q,Water} = M \cdot k_Q \cdot {}_{D,W} N^{Co}$$

- k_{Qe} is the quality conversion factor that converts the calibration factor for a ^{60}Co beam to that for an electron beam of any beam quality
- Q and is determined by: $k_{Qe} = P^{Q}{}_{gr}\, k'_{R50}\, k_{ecal}$
  - *k_{ecal} is the photon – electron conversion factor that converts ${}_{D,W}N^{Co}$ into ${}_{D,W}N^{Qecal}$, which is an electron beam absorbed dose calibration factor for a specific beam quality Q_{ecal}*
  - *k_{ecal} is fixed for a given chamber model and the values for most chambers can be found in Table III of TG51*
  - *Energy independent (actually a fixed energy)*

TG51: Absorbed Dose from Electrons

TABLE III. Values of the photon-electron conversion factor, k_{ecal}, for commercial cylindrical chambers, calculated as described in Ref. 52 and adopting a beam quality Q_{ecal} of R_{50}= 7.5 cm.

Chamber	k_{ecal}	Wall Material	Wall Thickness g/cm^2	Cavity radius r_{cav} (cm)	Al electrode diameter (mm)
Farmer-like					
Exradin A12	0.906	C-552	0.088	0.305	
NE2505/3,3A	0.903	Graphite	0.065	0.315	1.0
NE2561[a]	0.904	Graphite	0.090	0.370[e]	1.0
NE2571	0.903	Graphite	0.065	0.315	1.0
NE2577	0.903	Graphite	0.065	0.315	1.0
NE2581	0.885	A-150	0.041	0.315	
Capintec PR-06C/G	0.900	C-552	0.050	0.320	
PTW N23331	0.896	Graphite	0.012	0.395[e]	1.0
		PMMA	0.048		
PTW N30001[b]	0.897	Graphite	0.012	0.305	1.0
		PMMA	0.033		
PTW N30002	0.900	Graphite	0.079	0.305	
PTW N30004	0.905	Graphite	0.079	0.305	1.0
PTW N31003[c]	0.898	Graphite	0.012	0.275	1.0[f]
		PMMA	0.066		
Other cylindrical					
Exradin A1[d]	0.915	C-552	0.176	0.200	
Capintec PR-05/PR-05P	0.916	C-552	0.210	0.200	
Wellhofer IC-10/IC-5	0.904	C-552	0.070	0.300	

Questions

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