Updated Calibration Protocol for Medical Photon Beams – 'TG-51':

(electron beams only briefly discussed in this brief overview)

- This improved protocol replaces the AAPM TG-21 protocol, and it can be applied to both photon and electron beams, but we will only discuss photon beams here. This protocol will be the focus of future classes.

- One must use water phantoms for this protocol, and it is not based on exposure or even air Kerma. This move simplifies the calculations, and uses a better set of restricted mass stopping powers for the Monte-Carlo calculations of some parameters. Note: tap water is fine to use.

- The dose to water, D_w^Q, for a beam 'quality' ('quality' refers to beam type and energy spectrum), Q, in a reference condition is given by the following:

$$D_w^Q = MN_{D,w}^Q$$

Where,

-- M is the ion chamber reading (absolute charge value)

-- $N_{D,w}^Q$ is the absorbed dose to water calibration factor for an ion chamber located in the reference condition in a beam of quality, Q.

- The key $N_{D,w}^Q$ quantity is determined from the calibration factor obtained in a calibration laboratory using a Co-60 beam again. It is found from

$$N_{D,w}^Q = k_Q N_{D,w}^{^{60}Co}$$

Where,

-- k_Q converts the absorbed dose to water calibration factor for a Co-60 beam into the calibration factor for an arbitrary beam of quality Q: photon or electron. A lot of the physics discussed previously is now wrapped into this one factor!

- The reading, M, now must be fully converted from the raw reading, M_{raw}. Now, more factors than just the temperature and pressure corrections end up in this correction step:

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

Where we must calculate/consider for these factors:

-- P_{TP} corrects for temperature and pressure as before, and now is stated as

$$P_{TP} = \frac{273.2 + T(^oC)}{295.2} \cdot \frac{101.33kPa}{P(kPa)}$$

-- P_{elec} corrects for the electrometer being calibrated at a separate time or procedure.

-- P_{pol} corrects for polarization effects. One takes a reading at each polarity, '+' and '-.' Then, these readings respectively, M^{+}_{raw} and M^{-}_{raw} are used in the equation below. Important: retain the signs of these readings !! The reading, M_{raw}, is the one used in the reference condition dosimetry and it should be the same as used in the Co-60 calibration as well.

$$P_{pol} = \left| \frac{M^{+}_{raw} - M^{-}_{raw}}{2M_{raw}} \right|$$

-- P_{ion} corrects for ion recombination. Recall the linearity discussion in the recombination lecture. An ion chamber should be used in the saturation region: voltage should be large enough to prevent recombination, but small enough so that electrons do not further ionize on their way to the central electrode. Note that small chambers will have trouble finding this regime. Recombination is more likely for high LET, high dose rate, higher temperatures, less voltage, and more space between electrodes.

The procedure for calculating this is very elegant here. For the continuous beam, Co-60:

$$P_{ion} = \frac{1 - (V_H / V_L)^2}{(M^H_{raw} / M^L_{raw}) - (V_H / V_L)^2}$$

For a pulsed beam (linac), it is the following {note the exponent changes!}:

$$P_{ion} = \frac{1 - (V_H / V_L)}{(M^H_{raw} / M^L_{raw}) - (V_H / V_L)}$$

Where, here, V_H and V_L are the high and low voltage settings (by at least a factor of two), and M_{raw}^{H} and M_{raw}^{L} are the corresponding readings respectively.

-- Note that the two-voltage techniques ignores: initial recombination, ionic diffusion, and any charge multiplication. Therefore, it is an incomplete account of recombination.

- Now, the improved ICRU-37 restricted collisional mass stopping power tables are used in Monte-Carlo calculations for k_Q. One MUST have an ion chamber that is listed or shown in the table and graph below. The beam quality is specified by the percent depth dose found at 10 cm depth: %dd(10)$_x$. More about this quantity, next page.

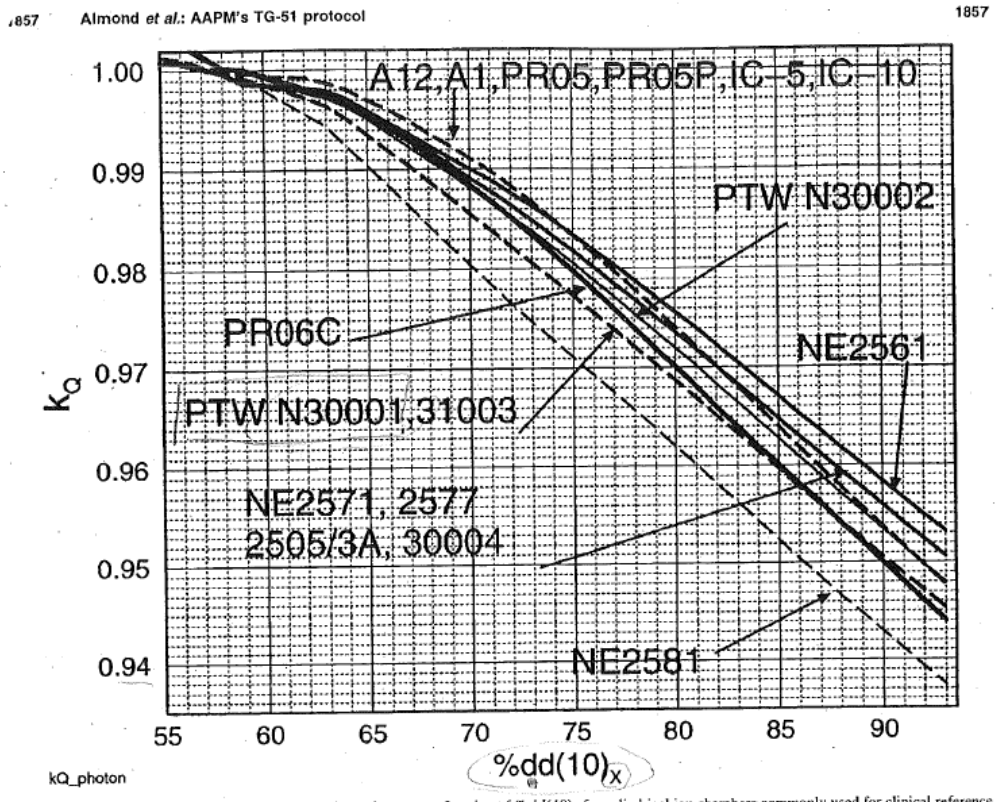


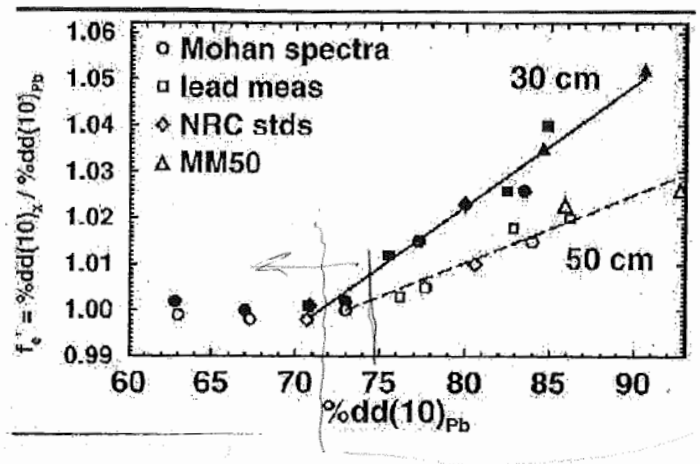
FIG. 4. Values of k_Q at 10 cm depth in accelerator photon beams as a function of $\%dd(10)_x$ for cylindrical ion chambers commonly used for clinical reference dosimetry. When values were the same within 0.1%, only one curve is shown. Explicit values are given in Table I, as is a list of equivalent chambers. For ^{60}Co beams, $k_Q = 1.000$.

TABLE I. Values of k_Q for accelerator photon beams as a function of $\%dd(10)_x$ for cylindrical ion chambers commonly used for clinical reference dosimetry. Values calculated as described in Refs. 45 and 51. The tabulated values can be interpolated linearly in $\%dd(10)_x$. The ion chamber specifications used in these calculations are found in Table III. Figure 4 presents the same data within 0.1%. For ^{60}Co beams, $k_Q = 1.000$ by definition.

	k_Q					
	$\%dd(10)_x$					
Ion chamber	58.0	63.0	66.0	71.0	81.0	93.0
Capintec PR-05/PR-05P	0.999	0.997	0.995	0.990	0.972	0.948
Capintec PR-06C/G 0.6cc Farmer	1.000	0.998	0.994	0.987	0.968	0.944
Exradin A1 Shonka[a]	0.999	0.998	0.996	0.990	0.972	0.948
Exradin A12 Farmer	1.000	0.999	0.996	0.990	0.972	0.948
NE2505/3,3A 0.6cc Farmer	1.000	0.998	0.995	0.988	0.972	0.951
NE2561 0.3cc NPL Sec. Std[b]	1.000	0.998	0.995	0.989	0.974	0.953
NE2571 0.6cc Farmer	1.000	0.998	0.995	0.988	0.972	0.951
NE2577 0.2cc	1.000	0.998	0.995	0.988	0.972	0.951
NE2581 0.6cc robust Farmer	1.000	0.994	0.988	0.979	0.960	0.937
PTW N30001 0.6cc Farmer[c]	1.000	0.996	0.992	0.984	0.967	0.945
PTW N30002 0.6cc all Graphite	1.000	0.997	0.994	0.987	0.970	0.948
PTW N30004 0.6cc Graphite	1.000	0.998	0.995	0.988	0.973	0.952
PTW 31003 0.3cc waterproof[d]	1.000	0.996	0.992	0.984	0.967	0.946
Wellhofer IC-10/IC-5	1.000	0.999	0.996	0.989	0.971	0.946

[a]The cavity radius of the A1 here is 2 mm although in the past Exradin has designated chambers with another radius as A1.
[b]The NE2611 has replaced the equivalent NE2561.
[c]PTW N30001 is equivalent to the PTW N23333 it replaced.
[d]PTW N31003 is equivalent to the PTW N233641 it replaced.

- For beams with a nominal energy greater than or equal to 10 MV, TG-51 recommends that one use a 1 mm thick lead foil about 50 cm from the source to *standardize* (not eliminate!) the electron contamination. There is a legitimate debate on this issue – it may add a complication that introduces error for no good reason. The IAEA protocol does not recommend this foil. The $\%dd(10)_x$ is the result of first doing $\%dd(10)_{Pb}$ or just %dd(10) if no lead is used. One goes into the tables with $\%dd(10)_x$. Below is a figure showing the error one gets from the lead foil correction not being used. It is suggested by some that one need only use the lead if the $\%dd(10)_{Pb}$ is > 75:



Tailor and Hanson published a paper (Med Phys 2002 29:1464-1472) describing the difference between using the two protocols. The following is a figure from their publication comparing the two protocols.

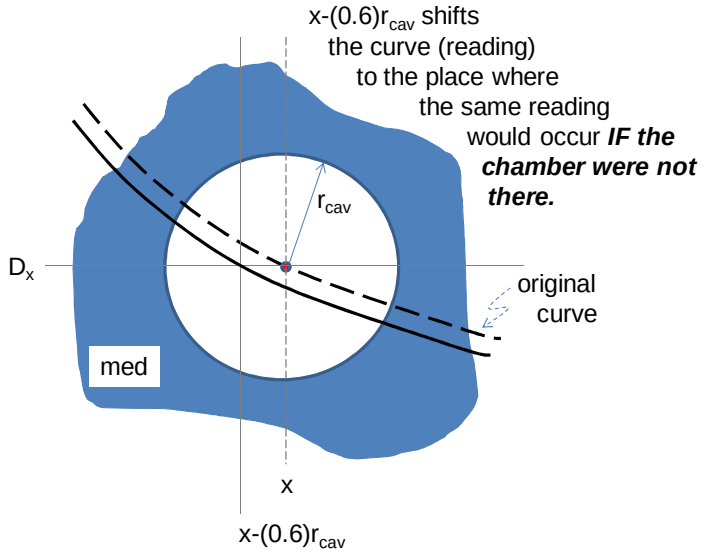
Tailor, Hanson, and Ibbott (J. Appl. Clin. Med. Phys. **4** (2003) 102) produce this table showing only a 0.2% error if lead foil not used:

TABLE I. Error in k_Q if lead sheet is not used.

	Nominal MV	$\%dd(10)_{Pb}@30$	$\%dd(10)\|_0^{Pb@30}$	$\%dd(10)_x\|_0^{Pb@30}$	$k_Q\|_0^{Pb}$
Varian machines	23	80.0	1.010	1.018	1.002
	18	79.7	1.008	1.015	1.002
	10	73.4	1.004	1.009	1.001

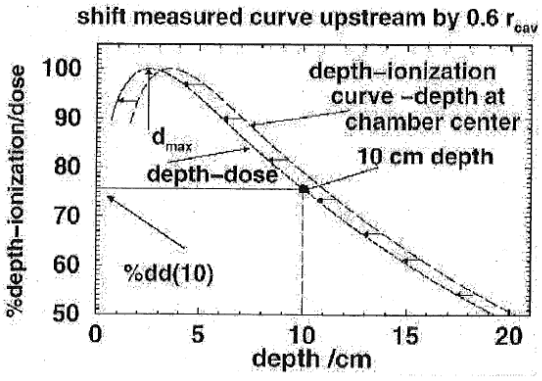
- TG-51 page 1855 claims 2% error in $\%dd(10)_x$, therefore 0.4% dose error in extreme cases.

- 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 photon beams, we shift reading upstream by $0.6 \cdot r_{cav}$. Where r_{cav} is the radius of the ion chamber cavity.



- Since this protocol does not use an ionization ratio for beam quality, it is important to perform this shift. A ratio like TPR would be more robust to this issue.

- Therefore, TG-51 instructs us to perform this *shift of the curve*: Note: TG-51 defines the shifted curve as the depth-ionization curve!



-- Note that the caption in Fig. 1 of TG-51 explains that for photons, the shifted curve is the depth-ionization curve and that it is the same as the depth-dose curve. In any case, the ionizations happen in the place that the shift represents! If in tcpe, the shift is the same for all the depths beyond dmax. For electrons, near dref, that is not true and a second shift at one point is needed.

- The k_Q factor contains a lot of physics. In 'TG-21 terms,' I have seen it written as the following: (from Rock's old notes)

$$k_Q = \frac{\left\{(\bar{L}/\rho)_{air}^{water} P_{wall} P_{fl} P_{gr} P_{cel}\right\}_Q}{\left\{(\bar{L}/\rho)_{air}^{water} P_{wall} P_{fl} P_{gr} P_{cel}\right\}_{^{60}Co}} \equiv \frac{N_{D,w}^{Q}}{N_{D,w}^{^{60}Co}}$$

Where,

-- A new factor is considered here: P_{cel}. It is the correction to account for the central electrode!

-- Another new factor is here: P_{gr}. It is the correction to account for the effective center of the ion chamber. Note that: $P_{fl}P_{gr} = P_{repl}$.

- If we were to discuss electrons, we would have $N_{D,w}^{Q_{ecal}}$ instead of $N_{D,w}^{Q}$. Also there would be a more complicated gradient correction, $P_{gr}^{Q_{ecal}}$, and k'_{ecal} with $k'_{R_{50}}$. However, the spirit is the same.

- A better way to compare TG-21 and TG-51 may be to access the discussion in TG-21 that describes the absorbed dose to water as a calibration basis, instead of exposure – the predecessor of TG-51! See TG-21, Eq. 8:

$$N_{gas} = N_D \frac{A_{ion} A_{repl}}{\left(\frac{\overline{L}}{\rho}\right)_{gas}^{wall} \left\{\frac{\overline{\mu}_{en}}{\rho}\right\}_{wall}^{water}}$$

Where,

-- $N_D \equiv \frac{D_{water}}{M}$

- Compare this to Eq. 5 of TG-21 (easier to derive when "air' distinguished from 'gas'):

$$N_{gas} = N_X \frac{A_{wall} \beta_{wall} A_{ion} k\left(\overline{W}/e\right)_{air}}{\left(\frac{\overline{L}}{\rho}\right)_{gas}^{wall} \left\{\frac{\overline{\mu}_{en}}{\rho}\right\}_{wall}^{air}}$$

- Therefore, it must be that:

$$N_X \frac{A_{wall} \beta_{wall} k\left(\overline{W}/e\right)_{air}}{\left\{\frac{\overline{\mu}_{en}}{\rho}\right\}_{wall}^{air}} \Leftrightarrow N_D \frac{A_{repl}}{\left\{\frac{\overline{\mu}_{en}}{\rho}\right\}_{wall}^{water}}$$

Or,

$$N_X = N_D \left(\frac{A_{repl}}{A_{wall} \beta_{wall}}\right) \left\{\frac{\overline{\mu}_{en}}{\rho}\right\}_{water}^{air} \left[k\left(\overline{W}/e\right)_{air}\right]^{-1}$$

- Substitute this into D_{med} with α=1, medium = water, cancel terms, and consider a beam quality, Q:

TG-21: $$D_{water}^{Q} = MN_D \left(P_{ion}^{Q} A_{ion}\right)\left(P_{repl}^{Q} A_{repl}\right) \left(\frac{\overline{L}}{\rho}\right)_{Co-60}^{Q}{}_{wall}^{water} \left\{\frac{\overline{\mu}_{en}}{\rho}\right\}_{water}^{wall}{}_{Co-60}^{Co-60} \left(\frac{\overline{L}}{\rho}\right)_{Q}^{water}{}_{wall}^{Co-60}$$

TG-51: $$D_{water}^{Q} = Mk_Q N_{D,w}^{Co-60} = MN_{D,w}^{Q}$$

- I would like to define *my own variables* now – to better compare A's versus P's …

$$P_{ion}^{Co-60} \equiv A_{ion}^{-1}$$
$$P_{repl}^{Co-60} \equiv A_{repl}^{-1}$$

And recall: $k_Q \equiv \dfrac{N_{D,w}^{Q}}{N_{D,w}^{Co-60}}$

- Therefore,

$$N_{D,w}^{Q} = k_Q N_{D,w}^{Co-60} \quad \text{and} \quad k_Q = \frac{D_{water}^{Q}}{D_{water}^{Co-60}}$$

and substitute this in …

- Using the above, **<u>to convert between TG-21 and TG-51</u>**, I think it's better to formulate it as follows:

$$k_Q = \left(P_{ion} P_{repl}\right)_{Co-60}^{Q} \left[\left(\frac{\overline{L}}{\rho} \right)_{gas}^{water} \right]_{Co-60}^{Q}$$

$$N_{D,w}^{Co-60} = N_D \left[\left(\frac{\overline{L}}{\rho} \right)_{wall}^{water} \left\{ \frac{\overline{\mu}_{en}}{\rho} \right\}_{water}^{wall} \right]_{Co-60}$$

Where,

-- $N_D = N_X k \left(\overline{W} / e \right)_{air} \left(\dfrac{A_{wall} \beta_{wall}}{A_{repl}} \right) \left\{ \dfrac{\overline{\mu}_{en}}{\rho} \right\}_{air}^{water}$

-- $P_{ion}^{Co-60} \equiv A_{ion}^{-1}$ and $P_{repl}^{Co-60} \equiv A_{repl}^{-1}$ {my variables – not in any book}

- A key point is that TG-51 has no in between step like N_{gas}.

- Tailor and Hansen (Med. Phys. **29** (2002) 1464-72) provide this comparison between TG-21 and TG-51:

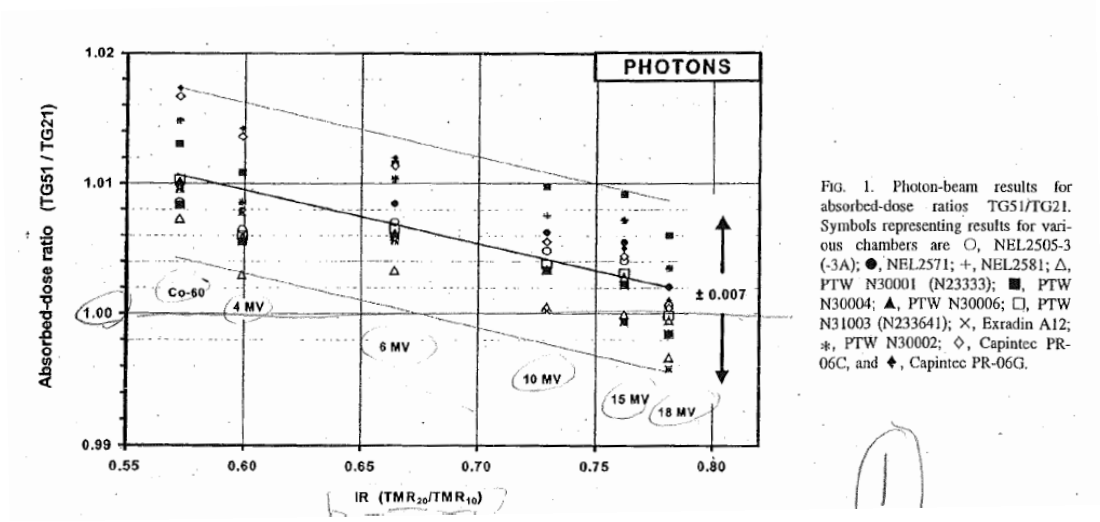


FIG. 1. Photon-beam results for absorbed-dose ratios TG51/TG21. Symbols representing results for various chambers are ○, NEL2505-3 (-3A); ●, NEL2571; +, NEL2581; △, PTW N30001 (N23333); ■, PTW N30004; ▲, PTW N30006; □, PTW N31003 (N233641); ×, Exradin A12; ✳, PTW N30002; ◇, Capintec PR-06C, and ♦, Capintec PR-06G.

- **A Few Key Concepts for TG-51 Calibration of Electron Beams:**

- In TG-21, calibration was at $d_{\max}$, but using introduces a lot of uncertainty (see Ding, Rogers, and Mackie Med. Phys. **22** (1995) 489-501). In addition, the place where the ionization falls to 50% is where the beam energy is calculated from, and the gradient is strong there.

- **In TG-51, a big change is that we now have a specific reference position, dref**. See TG-51 on page 1856, Fig. 2 and just below, to the end of the section and Eqs. 16 and 17. Note that dref is now on a gradient, And:

  -- **The text says to shift the measured curve to get the depth-ionization curve and get I_{50}. One then shifts again, but only one point to get R_{50} via Eqns. 16, and 17, and then we calculate dref.**

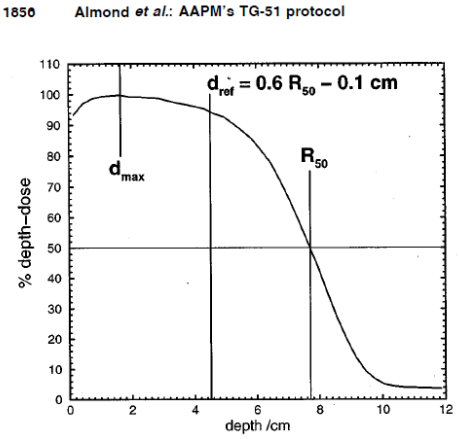


FIG. 2. Here R_{50} is defined as the depth, in cm, at which the absorbed dose falls to 50% of its maximum value in a $\geq 10\times10$ cm^2 ($\geq 20\times20$ cm^2 for $R_{50} > 8.5$ cm) electron beam at an SSD of 100 cm. The depth for clinical reference dosimetry is $d_{ref} = 0.6R_{50} - 0.1$ cm, in the same sized beam at an SSD between 90 and 110 cm. Note that for low-energy beams, d_{ref} is usually at d_{max}.

- Remember, we want to get the effective position for the chamber reading, given its current position. That will mean, we need to not only correct for the effective center relative to where the electrons are launched as with photon beams, but there is a second shift!! And it is a conceptually very important cpe concept.

- **The second shift accounts for disequilibrium gradient effects, because we are not in transient charged particle equilibrium at dref! A single shift does not work for all depths as it did for photons.**

- See Fig. 1 now of TG-51, and read the caption carefully as one also reads the text following Fig. 2:

  -- The solid lines are the depth ionization curves, after a first shift from the raw data for both photons and electrons:
  i. for photons, the depth-ionization is the same as the depth-dose because of transient charged particle equilibrium, tcpe past dmax is rigorous for all energies.
  ii. for electrons, the depth-ionization is DIFFERENT from the depth-dose, and is almost maximum right where the dref is located.
  iii. For lower energy electron beams, dmax ~ dref, but for higher energy electron beams, the situation gets more complicated. The caption says the whole depth-dose curve is not needed for this protocol, but a second shift is needed (so last sentence of caption could have been more clear).

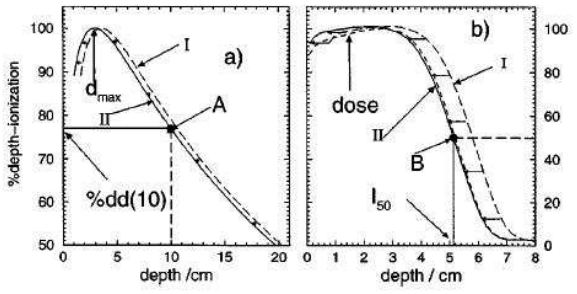


FIG. 1. Effect of shifting depth-ionization data measured with cylindrical chambers upstream by 0.6 r_{cav} for photon beams [panel (a)] and 0.5 r_{cav} for electron beams [panel (b)] (with r_{cav} = 1.0 cm). The raw data are shown by curve I (long dashes) in both cases and the shifted data, which are taken as the depth-ionization curve, are shown by curve II (solid line). The value of the % ionization at point A (10 cm depth) in the photon beam gives $\%dd(10)$ and the depth at point B (solid curve, 50% ionization) in the electron beam gives I_{50} from which R_{50} can be determined (see Sec. VIII C). For the photon beams, curve II is effectively the percentage depth-dose curve. For the electron beams, curve II must be further corrected (see Sec. X D) to obtain the percentage depth-dose curve shown (short dashes—but this is not needed for application of the protocol).

i.e., convert I_{50} to R_{50}

Sec. XD is a second alternative method.

- For electron beams, follow the instructions in the text below to get R_{50} and then one can get dref.

-- Note that gradient corrections are already in the depth-ionization curve.
-- For parallel-plate chambers, the chamber averaging implicitly averages to the correct effective measurement position.
-- In a sense then, this shift is really a shift to account a finite lateral ion chamber dimension, like cylindrical chambers!

To determine R_{50} one must first measure a central-axis depth-ionization curve in a water phantom at an SSD of 100 cm [curve I in Fig. 1(b)]. For cylindrical chambers, correct for gradient effects by shifting the curve upstream by 0.5 r_{cav} to give curve II.[22,39,40] For plane-parallel chambers no shift is needed. Curve II is taken as the depth-ionization curve.

Next, locate point B at the level of 50% of the maximum ionization on the depth-ionization curve corrected for gradient effects [i.e., curve II in Fig. 1(b)]. The depth of point B gives I_{50}. The beam quality specifier for the electron beam, R_{50}, is determined from the measured value of I_{50} using[47,48]

$$R_{50}=1.029I_{50}-0.06 \text{ (cm)} \quad (\text{for } 2 \leqslant I_{50} \leqslant 10 \text{ cm}) \qquad (16)$$

or

$$R_{50}=1.059I_{50}-0.37 \text{ (cm)} \quad (\text{for } I_{50}>10 \text{ cm}). \qquad (17)$$

A second alternative is to determine the percentage depth-dose curve using a good-quality diode detector which responds as a dose-detector in an electron beam,[22,49] although one must establish that this condition is fulfilled.[50] A third alternative is to convert the depth-ionization curve for an ion chamber to a percentage depth-dose curve (see Sec. XD).

- Now, we have curve II in TG-51, Fig. 1, the depth-ionization curve, but for high-energy electron beams measured with an ion chamber, this is not the depth-dose curve!

- See Fig. 1 of M.S. Hug et al., Med. Phys. **24** (1997) 1609-13, on page 1611, (much more clear than the short dashes and solid lines in TG-51 Fig. 1b.):

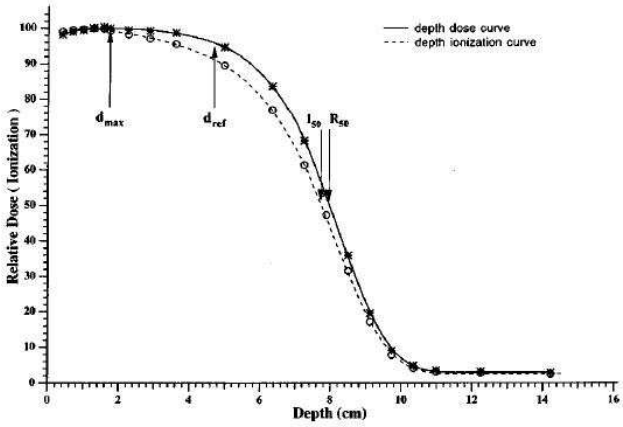


FIG. 1. Percent depth ionization and depth dose curves for a 20-MeV electron beam in clear polystyrene. The depths of d_{max}, d_{ref}, I_{50}, and R_{50} are indicated.

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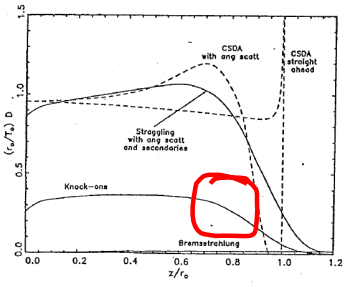
- **The second shift is then the conversion between I_{50} and R_{50}.** It depends on energy, and is handled empirically. See Eqns. 16 and 17. **Two other ways are mentioned: use a solid state detector, or correct the whole curve with knowledge of the spectrum.** These are all clues to the origin behind this second shift!

- The real answer is found in one of my favorite figures, from lecture 14 (see below), which is also a high energy electron beam. Recall in Spencer-Attix theory, we worried about some of the delta-rays being like primary particles depending on the size of the ion chamber! In a solid state detector, this would not be an issue because the radiological distance is so different (see: Rikner Acta Radiol. Oncol. **24** (1985) 71-4) !

- **In an ion chamber, the stopping powers need to have Spencer-Attix corrections, but in this case, the corrections will vary with depth, and this is handled by adding a second shift!**

- Notice below where the delta-rays (knock-ons) loose cpe: it would be right where dref is located!



From Seltzer in Jenkins et al (eds) Monte Carlo Transport of Electrons and Photons (Plenum Press) 1988

Figure 7.9. Absorbed-energy distribution for a broad beam of 20-MeV electrons incident perpendicularly on a thick slab of water. Results are given in terms of the dimensionless quantity $(r_o/T_o)D$, where $D(z)$ is the dose absorbed per unit depth at depth z, r_o is the incident electron's mean range and T_o its kinetic energy, and are plotted as a function of the scaled depth z/r_o. Results are shown for three transport-model choices: (a) primary electrons only, in the continuous-slowing-down approximation (csda) and with no angular deflections (straight ahead); (b) primary electrons only, csda and with angular deflections; and (c) energy-loss straggling with angular deflections and the transport and subsequent energy deposition by secondary electrons and bremsstrahlung photons. In cases (a) and (b), all bremsstrahlung was assumed to escape the target; for case (c), the contribution to the depth-dose is shown also separately for the knock-on electron (> 1 keV) and the bremsstrahlung components.

- **Therefore, I_{50} and R_{50} will not be the same because of the distances the charged particles move. Because of delta-ray disequilibrium that changes with depth, electrons need a further correction!**

- **For photons, the 'equivalent' of this difference between I_{50} and R_{50} is the same for all depths because of tcpe for the whole spectrum that is not changing nearly as much over depth.**

- Note: There is now an Addendum to TG-51:

  The k_Q values are refined as well as good uncertainty analysis: See:
  M. McEwen, et al., Med. Phys. 41 (2014) 041501-1 – 041501-20, i.e., Fig. 2 in Appendix B:

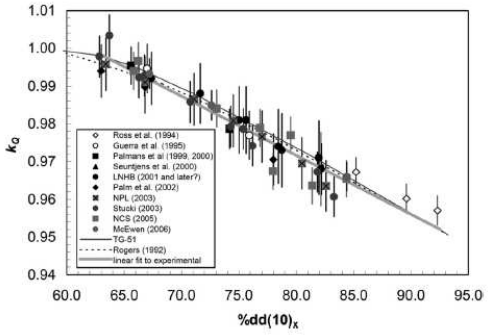


FIG. 2. k_Q factors for the NE2571 chamber as a function of beam-quality specifier $\%dd(10)_x$. The references are those given in the report by Aalbers *et al.* (Ref. 102). Uncertainties are given as one standard uncertainty (Ref. 58). ^{60}Co is assigned a $\%dd(10)_x$ value of 58.4. A value of 85.0 represents the highest linac energy typically found in radiotherapy clinics. Figure courtesy of NCS.

- Also, TG-51 is further corrected for electrons by more accurate shifts to get R50: See: Table III of Muir & Rogers, Med. Phys. 41 (2014) 111701-1 – 111701-15.

TABLE III. Offsets upstream from the central axis giving the EPOM for accurate R_{50} determination with cylindrical chambers. The statistical uncertainty in the optimal shift for accurate R_{50} determination is less than 0.05 mm (between 0.01 and 0.02 r_{cav}, depending on the cavity radius) for all chambers.

Manufacturer	Chamber	r_{cav} (mm)	Δz as a fraction of r_{cav} for R_{50} determination
NE	2571[a]	3.14	0.33
	2611[b]	3.70	0.24
Exradin[c]	A12	3.04	0.35
	A19	3.00	0.34
	A12S	3.04	0.37
	A18	2.43	0.18
	A1SL	2.01	0.11
PTW	30010	3.05	0.33
	30011	3.05	0.31
	30012	3.05	0.31
	30013	3.05	0.38
	31013	2.75	0.35
IBA	FC65G	3.10	0.35
	FC65P	3.10	0.37
	FC23C	3.10	0.29
	CC25	3.00	0.29
	CC13	3.00	0.23
Capintec	PR06C/G	3.22	0.31

[a]Manufactured by Elektron Technology.
[b]Manufactured by NPL.
[c]Manufactured by Standard Imaging.

Note that the numbers in the last column are all very different from 0.5!

- In Summary (**good to remember these**!):

TG-21	TG-51
Air Kerma, or really exposure, based	Water dose based
Beam quality = TPR_{10}^{20} (ionization ratio)	Beam quality = $\%dd(10)_x$
Water or solid water type phantoms can be used.	ONLY water can be used.
No inclusion of the central electrode.	Central electrode included.
Intermediate factors: P's and N_{gas} cannot be directly measured.	One can directly measure the intermediate factors like k_Q
Complicated – more errors possible	Simpler – more robust for a busy clinic
Uses ICRU 35 stopping powers (1% off!) (worse at lower e-beam energies)	Uses better ICRU 37 tables
Overall precision: 3-4%, but errors mostly can cancel by luck. (TG-40 requires 2%, so potentially an issue.)	Overall precision < 1% !!