Chapter 8

Clinical Implementation of the TG-51 Calibration Protocol

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1. Introduction

In 1999 when the AAPM's TG-51 protocol (Almond et al. 1999) for clinical reference dosimetry of high-energy photon and electron beams was published, many radiotherapy clinics across the United States and Canada began preparations for converting over from the TG-21 protocol (AAPM TG-21 1983) to this new protocol. This process of preparation included reading and understanding the requirements of the protocol, acquiring the necessary calibration equipment, and understanding the magnitude of the change in the reference calibration dose between the old and new protocols. To this end, the Radiological Physics Center (RPC), which had already implemented the TG-51 protocol by January 2000, was offering assistance and advice to the community on how to best clinically implement this new protocol. Although the TG-51 protocol was thought to have been written in a very clear prescriptive manner outlining each step of the calibration process, many in the medical physics community found parts of it to be confusing since it was quite different from the TG-21 protocol. Figure 8-1 shows the rate at

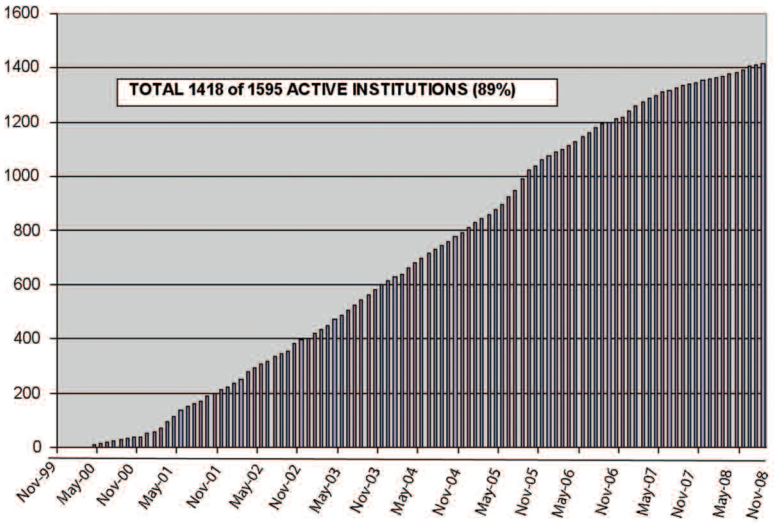

Figure 8-1. Number of institutions that converted to TG-51 protocol.

which clinics participating in clinical trials converted to the TG-51 protocol, according to the RPC records.

2. Equipment Needs

2.1 Water Phantom

One of the key aspects of the TG-51 protocol is that it is based on an absorbed-dose-to-water calibration coefficient and as such requires that the calibration measurements be performed in a liquid water phantom. Prior to TG-51, the TG-21 protocol had allowed reference calibrations to be performed in polystyrene, acrylic, or water (which was interpreted to also include the various solid-water plastics), and many clinics did not have an adequate water phantom to be used for calibration. Therefore, an appropriate water phantom must be obtained. One can use the commissioning water scanning tank, but this is not recommended due to its size and the time needed to set it up correctly. Typically a 30 cm $\times$ 30 cm $\times$ 30 cm water tank with clear walls through which one can see the chamber and a chamber holder that can move an ion chamber to various depths accurately without having to reset the SSD (source-to-surface distance) is preferred. This type of water phantom is commercially available from various vendors. A water phantom of this size ensures that there is adequate phantom material laterally and beneath the measurement point so that adequate scatter conditions exist. A phantom this size also allows for routine spot checks of other dosimetry parameters (output factors, depth dose data,

wedge transmission factors, etc.) for field sizes up to a 25 cm × 25 cm field and up to 20 cm depth.

2.2 Chamber Holder and Positioner

The chamber holder and positioner is an important component of the water phantom. The holder should be versatile enough to either hold the various waterproof ion chambers (cylindrical or parallel-plate) or the waterproof protective sleeves that might be used. The chamber holder should be rigid enough to keep the ion chamber's sensitive volume perpendicular to the water surface with zero lateral displacement as the chamber moves from one depth to another. The chamber positioner should be capable of placing the effective point of measurement at any depth to within submillimeter accuracy either by the use of an electronic motor system or a simple "hand crank" mechanism. Prior to using any chamber positioner, it should be tested for accuracy and reproducibility of positioning. Any small error in positioning will be magnified as the chamber is sent to multiple depths.

2.3 Ion Chambers

Calibration of photon beams requires an Accredited Dosimetry Calibration Laboratory (ADCL) calibrated cylindrical ion chamber, preferably with a 0.6 cm^3 sensitive volume. Smaller volume ion chambers (>0.1 cm^3) can be used but must have a calibration coefficient ($N_{D,w}$) traceable to another 0.6 cm^3 calibrated ion chamber at the institution. Parallel-plate ion chambers are not to be used for photon beam calibration. There are numerous cylindrical ion chambers that can be used that are waterproof and new ones regularly appear on the market. If an ion chamber that is not waterproof is to be used, then an appropriate waterproof protective sleeve should be obtained. Table 8-1 contains a list of cylindrical ion chambers, both waterproof and nonwaterproof, that are commonly used for photon beam calibration. This protective sleeve should have a thickness not greater than 1 mm. Prior to using any protective sleeve, whether made of PMMA (polymethylmethacrylate) or latex, verify that it is indeed waterproof. Each make and model of cylindrical ion chamber has its own unique characteristics that will influence how measurements are made. Specifically, how they react to changes in polarity and bias. These characteristics will be discussed in section 4.2.

Calibration of electron beams may be accomplished with either a parallel-plate or cylindrical ion chamber. However, cylindrical chambers are not to be used for electron beams with nominal energies of 6 MeV or less. Key considerations in the choice of chamber for calibrating electron beams include availability, steepness of the electron depth dose curve, and accuracy at placing the effective point of measurement to an exact depth. Balter and Lowenstein (2001) have shown that calibrating low-energy electron beams (5 and 6 MeV) with either a cylindrical or parallel-plate ion chamber gives the same result if great care is taken in positioning

Table 8-1. Cylindrical Ion Chambers Commonly Used for Photon Beam Calibration

	outer diameter (mm)	wall material	wall thickness (mm)	inner diameter (mm)	central electrode material	volume (mm^3)
Farmer chambers - NOT waterproof						
NE model 2571	7.0	Graphite	0.36	6.28	Al	0.69
NE model 2581	7.0	A-150	0.36	6.28	A-150	
NE model 2561/2611	8.4	Graphite	0.48	7.4	Al	0.3
Capintec model PR-06G	7.0	C-552	0.28	6.4	C-552	
PTW model 30001	7.0	Mixed [1]	0.43	6.15	Al	0.59
Farmer chambers - Waterproof						
Exradin model A12	7.1	C-552	0.5	6.1	C-552	0.65
Exradin model A12S	7.1	C-552	0.5	6.0	C-552	0.25
Exradin model A19	7.0	C-552	0.5	6.0	C-552	0.65
IBA model FC23-C	7.1	C-552	0.4	6.2	C-552	0.25
IBA model FC65-G	7.1	Graphite	0.4	6.2	Al	0.65
IBA model FC65-P	7.1	POM [3]	0.4	6.2	Al	0.65
PTW model 30013	6.9	Mixed [2]	0.43	6.05	Al	0.59

Mixed [1] 0.275 mm PMMA + 0.15 mm graphite (dag)
Mixed [2] 0.335 mm PMMA + 0.09 mm graphite (solid)
POM [3] Polyoxymethylate "acetal" which is similar to Delrin

(Courtesy of Malcolm McEwen)

the chamber. A parallel-plate ion chamber should always be used to calibrate a 4 MeV electron beam due to the extreme dose gradient of this beam. A caution to the user of a parallel-plate ion chamber is that it is not always obvious as to where the inside surface of the front window is located. Some parallel-plate chambers have a 1 mm protective cap over the window.

The list of ion chambers in the TG-51 protocol was generated more than 9 years ago and since that time, many new ion chambers have been developed and sold. Many of these new chambers are similar in design and construction to the original TG-51–listed chambers but now are waterproof. Section XI of the TG-51 protocol outlines a procedure for identifying listed chambers that would be expected to have the same k_Q, $k_{R50,}$ and k_{ecal} as the new chambers. The construction and material composition of the thimble and the collector are the most important, with the actual physical dimensions (aside from the radius) of the chamber being less important. Currently within the AAPM, there is a working group that is determining the k_Q, k_{R50}, and k_{ecal} for new chambers that have been placed on the market since the publication of TG-51 and the k_{ecal} values for parallel plate chambers listed in the TG-51 protocol.

Regardless of the type of ion chamber to be used for the calibration, it should have an ADCL $N_{D,w}$ calibration coefficient. The one exception to this rule is for parallel-plate chambers. It has been previously discussed by Tailor et al. (2003) and Mainegra-Hing et al. (2003) that if one uses the ADCL $N_{D,w}$ from an ADCL and the TG-51 k_{ecal} values, an error of up to 1% to 2% in dose may result. The error lies in the k_{ecal} values and not the $N_{D,w}$ value. It is the recommendation of the AAPM that one should cross-calibrate their parallel-plate chamber with a cylindrical chamber in a high-energy electron beam according to the guidelines in TG-51, which are based on the approach in TG-39 (Almond et al. 1994) in order to determine the product of ($N_{D,w} \cdot k_{ecal}$) for the parallel-plate chamber. The TG-51 protocol provides Worksheet C at the end of the protocol to assist the user in this calculation (Refer also to chapter 7, section 8 in this monograph). According to the data by Balter and Lowenstein (2001), the one parallel plate chamber that appears to have the correct k_{ecal} value is the Exradin P11. As mentioned above, there is an AAPM working group that will publish the corrected k_{ecal} values for parallel plate chambers used with electron beams, but until then it is recommended that the cross-calibration technique be used. Even with the availability of new factors, one can still derive the factors via the cross-calibration technique.

3. Measurement Techniques

3.1 Techniques for Setting the Chamber Depth

Regardless of what type of ion chamber is used for the calibration of the photon and electron beams, as mentioned before placing the chambers accurately at a known depth is crucial if one wants to determine the dose rate with minimal uncertainty.

Holding a ruler in the water with your hand at the end of a cylindrical ion chamber is not recommended for setting the depth of the chamber. Also remember that not all rulers give the same depth, depending on how they are manufactured. A 1 mm error in positioning the chamber for the low-energy electron beams can lead to a 1% to 3% error depending on the electron energy. An acceptable technique for a cylindrical chamber is to bring the chamber to the surface so that half of the chamber is outside of the water and half stays submersed (Das et al. 2008). The user can then establish the location of the center electrode and the water surface as the starting reference point and shift the chamber from that point using an electronic or manual chamber positioner (see figure 8-2). A second method of accurately placing a cylindrical chamber at a known depth is by the use of a water depth gauge described by Tailor and Tello (1995).

Briefly, this is an accurate ruler whose end has been cut to account for the distance (radius) between the center electrode and the outer surface of the waterproof chamber or sleeve, depending on what is used at your facility. The ruler is then mounted on an upside down U-shaped device with counterweights on each side such that the cut end of the ruler lies on top of the waterproof chamber or sleeve. An example of this can be seen in figure 8-3. The depth of the chamber can easily be set using this depth gauge with submillimeter accuracy as the reference depth upon which to set the mechanical or electronic chamber positioner. The depth gauge can also be used intermittently to confirm the chamber depth or reset the depth. Remember that except for the calibration reference depth, d_{ref}, all depths are to the effective point of measurement (0.6 r_{cav} and 0.5 r_{cav} shift for photons and electrons, respectively) and not to the center electrode of the cylindrical chamber.

Setting the depth of a parallel-plate ion chamber is somewhat easier than for a cylindrical chamber since there is a flat surface on which to place an accurate ruler to know the distance from the top surface of the chamber to the water surface as long as the ruler is perfectly vertical. For this measurement to be made, one must

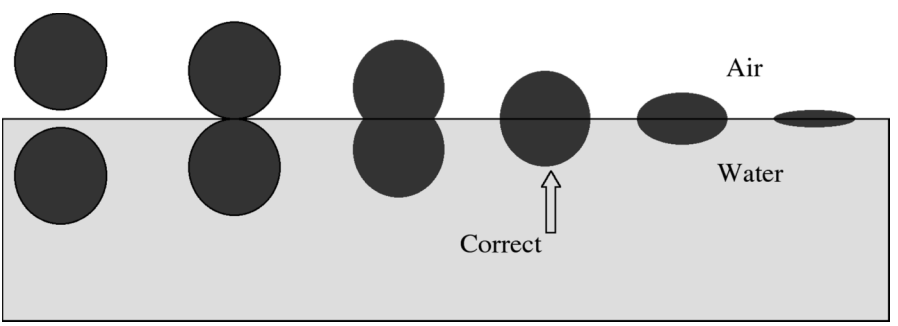

Figure 8-2. Sequential appearance of chamber and its reflection in water viewed for tank side. The correct position is when both images form a perfect circle. (Reprinted from Das et al. (2008) with permission from American Association of Physicists in Medicine.)

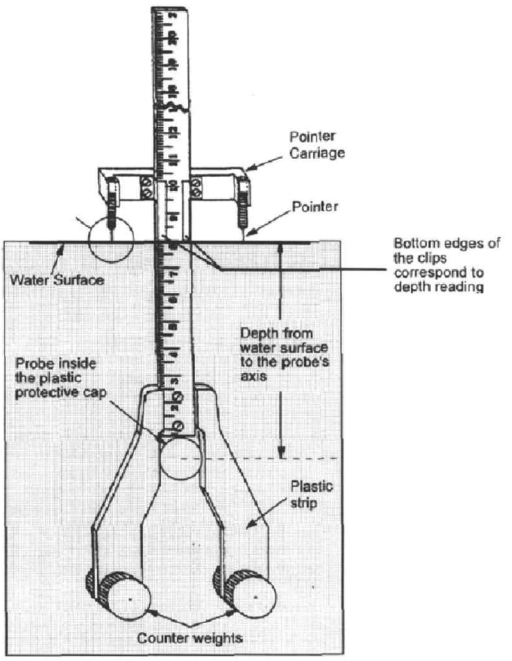

Figure 8-3. Cylindrical chamber depth gauge. (Reprinted from *Physics in Medicine and Biology* "Depth of ionization chamber in water," R. C. Tailor and V. M. Tello, vol 40, pp. 1389–1392, © 1995 with permission from IOP Publishing.)

know exactly where the inside surface of the parallel-plate front window is located within the chamber. For example, the Exradin P11 parallel-plate ion chamber has a 1 mm thick front window, which is not obvious when looking at the chamber. Remember that for parallel-plate chambers, there is no shift to the effective point of measurement; the effective point of measurement is at the inside surface of the parallel-plate's front window.

3.2 Effective Point of Measurement and Beam Quality Specification

The TG-51 protocol defines the "point of measurement" for calibration to be at the center electrode of the cylindrical chambers and to the front window of the parallel-plate chambers. Calibration of x-ray beams requires the point of measurement to be at 10 cm depth; for electron beams it is to be at d_{ref}.

Beam quality specification, however, should always be measured incorporating the effective point of measurement and be measured at 100 cm SSD regardless of the nominal SSD of the therapy unit. The effective point of measurement for cylindrical ionization chambers is a shift of 0.6 r_{cav} and 0.5 r_{cav} for photon and electron beams,

respectively, upstream from the "point of measurement" (closer to the radiation source). If one uses parallel-plate chambers to calibrate electron beams, there is no difference between the point of measurement and the effective point of measurement; they are the same. Therefore, when measuring the depth ionization curves to determine the beam quality, $\%dd(10)_x$ or R_{50}, with a cylindrical chamber, one can offset the chamber by the correct distance before performing the scan, or perform the scan assuming no shift and then shift the resulting curve by the required distance, depending on the radius of the chamber.

If instead of performing a depth ionization scan, one decides to make a few point measurements to determine the beam quality; then it is a good idea to record both the depth to the center electrode and the depth to the effective point of measurement, so that there is no confusion as to what the recorded depth actually represents. Either technique, scans or point measurements, will yield accurate beam quality data. The TG-51 protocol discusses this concept in great detail.

The photon beam quality specifier ($\%dd(10)_x$) is supposed to be the depth dose at 10 cm depth without any electron contamination. To determine the $\%dd(10)_x$ for x-ray beams of 10 MV and greater, TG-51 has chosen to use a sheet of 1 mm thick lead to replace the unknown amount of electron contamination at d_{max} with a known amount of contamination. The thickness of the lead should be 1±0.2 mm. For 10 MV or greater, the percent depth dose at 10 cm depth is determined with the lead sheet either at 30 cm or 50 cm from the surface of the phantom, and then the $\%dd(10)_x$ is calculated using equations (13) or (14) in the TG-51 protocol. A caution when using equations (13) and (14) is that the $\%dd(10)_{Pb}$ must be entered into the equation as a percent and not as a fractional number. The derived $\%dd(10)_x$ should not differ from the $\%dd(10)_{Pb}$ by more than 2.5%, otherwise an error is present. An alternative to the use of the lead sheet is to use the TG-51 "interim alternative" which is to measure the $\%dd(10)_o$ without the lead in place and use equation (15) in the TG-51 protocol to calculate the $\%dd(10)_x$ (see table 8-2). This technique works quite well and introduces no more than a 0.1% to 0.2% error in the resulting k_Q value while saving a great deal of time and minimizing the possibility of damage to your ion chamber from a falling lead sheet (Lowenstein et al. 2000).

4. Calibration Coefficients and Corrections

4.1 Beam Quality Conversion Factors

Once the specific beam quality, $\%dd(10)_x$ or R_{50}, for the beam to be calibrated has been measured, the beam quality conversion factors, k_Q or k_{R50}, respectively, must be determined. The TG-51 protocol provides Fig. 4 or Table I for the determination of k_Q values. The tabular values separated by ion chamber type are much easier to use than the curves in Fig. 4 which tend to overlay each other due to the similarity of the k_Q values for the various chamber types. A worthwhile recommendation for the physicists who may use a Microsoft Excel spreadsheet to assist them in the TG-51

Table 8-2. Differences in k_Q from Using Either the Lead Sheet To Determine the Beam Quality or the "Interim Alternative" in TG-51 Protocol

(Lowenstein et al. 2000 and Tailor et al. 2003). The quantity $\%\mathrm{dd}(10)\big|_0^{\mathrm{Pb@30}}$ is the ratio of the %dd(10) measured using the lead at 30 cm over that measured. using no lead. The quantity $\%\mathrm{dd}(10)_x\big|_0^{\mathrm{Pb@30}}$ is the ratio of the TG-51 beam qualities ($\%\mathrm{dd}(10)_x$) determined using TG-51 equation (14) in conjunction with $\%\mathrm{dd}(10)_{\mathrm{Pb}}$ or using equation 15 along with $\%\mathrm{dd}(10)_o$. The quantity $k_Q\big|_0^{\mathrm{Pb}}$ is the ratio of the quality conversion factors determined using $\%\mathrm{dd}(10)_x$ values from the lead sheet measurements vs. those determined without the lead sheet.

Nominal MV	$\%\mathrm{dd}(10)_{\mathrm{Pb}}$@30	$\%\mathrm{dd}(10)\big\|_0^{\mathrm{Pb@30}}$	$\%\mathrm{dd}(10)_x\big\|_0^{\mathrm{Pb@30}}$	$k_Q\big\|_0^{\mathrm{Pb}}$
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

(Reprinted from *Journal of Applied Clinical Medical Physics,* "TG-51: Experience from 150 institutions, common errors, and helpful hints." R. C. Tailor, W. F. Hanson, and G. S. Ibbott, vol 4, pp. 102–111, © 2003.)

calibration process is to use the tabular k_Q values from Table I for their institutions' specific chamber to derive an empirical fit to the data that is dependent on the measured $\%\mathrm{dd}(10)_x$ and to put that function in their spreadsheet. If one develops a spreadsheet with chamber-specific functions within the calculations a careful check of the spreadsheet should be performed by another physicist, and safeguards against using the wrong chamber type should be put in place to avoid any error in k_Q or the subsequent dose calculation.

The TG-51 protocol provides Fig. 5 through Fig. 8 for the determination of k_{R50}, for both cylindrical and parallel-plate chambers. The figures are small and difficult to read especially since many of the curves in Fig. 5 overlay each other, but there are high-quality versions of the figures available on-line.[1] There is no table of k_{R50} values for either chamber type. As mentioned earlier, there may be the possibility that a 4 MeV electron beam will need to be calibrated. This low-energy electron beam typically has an R_{50} of less than 2.0 cm for which TG-51 does not provide any k_{R50} values in Fig. 5 and Fig. 6 of the TG-51 protocol. Tailor and Hanson (2002) have shown that equations (19) and (20) in the TG-51 protocol for cylindrical and parallel-plate chambers, respectively, can be extrapolated out to an R_{50} = 1.0 cm without the introduction of any significant error because the original stopping-power ratio equation is based on a fit down to this energy (Burns et al. 1996).

[1] http://www.physics.carleton.ca/~drogers/pubs/papers/tg51_figures.pdf.

4.2 Charge Measurements

The next step in the calibration process once the phantom and chamber have been properly set up and the beam quality of the beam to be calibrated has been determined is to gather the charge reading for the beam to be calibrated. As stated in the TG-51 protocol, the fully corrected charge reading from an ion chamber, M, is given by equation (8) and is as follows:

$$M = P_{ion} \cdot P_{TP} \cdot P_{elec} \cdot P_{pol} \cdot M_{raw}, \tag{8.1}$$

where M is the raw ion chamber reading, P_{ion} is the ion recombination correction factor, P_{TP} is the temperature and pressure correction factor, P_{elec} is the electrometer scale correction factor, and P_{pol} is the polarity correction factor. The TG-51 protocol gives a full explanation on how to calculate each of these correction factors; however there are a few comments to be made about each correction.

4.2.1 P_{TP} *Correction Factor*

To determine the P_{TP} correction factor, the user must have access to an accurate thermometer and barometer. Mercury thermometers and barometers are considered to be the most accurate, however more and more hospitals are disposing of their mercury-containing devices as a potential personnel hazard. If your institution still has a mercury barometer, be sure to correct its raw reading by the temperature and gravity correction. These corrections come with the barometer or can be downloaded from the Internet by searching the key words "Princo Mercury Barometer". If you do not have a mercury barometer, then there are quality aneroid or digital barometers that can be purchased. Aneroid barometers are subject to incorrect readings if they experience any physical jarring. Whether you use an aneroid or digital barometer, it should, on an annual basis, be checked against another primary standard barometer such as a mercury barometer. Digital thermometers should be used instead of alcohol thermometers if a mercury one is not available. Similar to the barometers, any new digital thermometer should be compared to an accurate mercury thermometer both before use and on an annual basis. Barometers and thermometers that are purchased with a "calibration" means that a certificate will arrive with your device with a statement of what your device read at certain temperatures or pressures as compared to what it should have read. The calibration typically does not mean that the instrument gives an accurate measurement.

4.2.2 P_{elec} *Correction Factor*

The electrometer scale correction factor, P_{elec}, is obtained from sending your electrometer to one of the ADCLs in the United States or to the National Research Council (NRC) in Canada. It is important that P_{elec} be obtained for the electrometer

scale that will be used for the calibration. One cannot use the P_{elec} of one scale for one of the other electrometer scales.

4.2.3 P_{pol} Correction Factor

The polarity correction factor, P_{pol}, is a correction to account for the fact that an ion chamber may record a slightly different reading depending on the polarity of the voltage placed on the chamber. The use of equation (9) in the TG-51 protocol to calculate P_{pol} requires the user to preserve the sign of the charge reading; otherwise an incorrect value will be calculated. The P_{pol} correction factor should be measured carefully. Once the polarity has been changed, the chamber should be irradiated sufficiently such that the chamber has re-equilibrated to the new polarity and non-trending charge readings are measured. This may require an irradiation of the chamber with 600 to 800 cGy. The P_{pol} factor should be close to unity for most cylindrical chambers in photon and electron beams. The use of parallel-plate chambers with electron beams may have a slightly larger polarity correction than observed with the cylindrical chambers.

4.2.4 P_{ion} Correction Factor

The ion recombination correction factor, P_{ion}, corrects for the loss of signal due to the recombination of ionizations that occur within the sensitive volume of the chamber. P_{ion} depends on the dose per pulse for accelerators and some accelerators have high dose rate capabilities that result in higher P_{ion} correction values. Similar to the P_{pol} correction factor, P_{ion} should also be measured carefully by ensuring that the chamber re-equilibrates to the new bias when it is changed. The ion chamber should be given 600 to 800 cGy once the bias is changed before attempting to measure non-trending readings at the new bias. To calculate P_{ion}, equation (11) or (12) of the TG-51 protocol should be used for continuous and pulsed beams, respectively. The P_{ion} equation for ^{60}Co in Worksheet A of the TG-51 was misprinted and equation (11) should be used. As a redundancy check, if one measures P_{ion} for pulsed beams using the half-voltage technique ($V_H/V_L = 2$) and M^H/M^L is < 1.02, then P_{ion} is equal to M^H/M^L to within 0.1%. Similarly, for continuous beams, P_{ion} measured using the half-voltage technique can be approximated by the following expression as a quick redundancy check:

$$P_{ion} = \{(M^H/M^L - 1)/3\}+1 \qquad \text{for continuous beams.} \tag{8.2}$$

Both P_{pol} and P_{ion} depend on the chamber make and model, accelerator type, beam modality and beam energy. The trend is for P_{ion} to slightly increase with photon and electron energy and P_{pol} to be measurable for low-energy electron beams. It is a good idea to measure P_{ion} and P_{pol} very carefully once a year rather than frequently. As long as the chamber, accelerator, beam modality, and beam energy do not change from one year to the next, then P_{ion} or P_{pol} should not change either.

4.3 Gradient Correction Factor

The gradient correction factor for electron beams, P_{gr}, is only applicable for calibration for electron beams with a cylindrical chamber. Since the electron calibration depth d_{ref} is set to the center electrode and not to the effective point of measurement, a correction for this gradient effect needs to be included. This same correction for photon beams is not necessary since the photon beam quality conversion factor, k_Q, accounts for the gradient effect. P_{gr} is simply the ratio of the readings at d_{ref} + 0.5 r_{cav} to the reading at d_{ref} according to equation (21) of the TG-51 protocol. Since P_{gr} is a direct multiplier of the actual calibration reading at d_{ref}, the precision of the reading at d_{ref} + 0.5 r_{cav} should be the same as that for the reading at d_{ref}. One should expect P_{gr} to be near unity, but not necessarily equal to 1.000. Typically for nominal electron energies of less than or equal to 12 MeV, P_{gr} is ≥1.000 and for nominal energies of greater than 12 MeV, P_{gr} is <1.000. The reason for this is that at low energies, d_{ref} is normally equal to d_{max}, such that the effective point of measurement is in the build-up region and a correction is needed to have a reading as if the effective point of measurement were at d_{max}. Once the nominal electron energies start to get higher (≥12 MeV), the effective point of measurement is located either at d_{max} or beyond.

4.4 Clinical Depth Dose

The clinical depth-dose data for both photon and electron beams should always be measured using the effective point of measurement. Remeasurement of existing depth-dose data is not suggested as the correction is minimal and well within the 2% criterion for adjusting depth-dose data per the TG-40 guidelines (Kutcher et al. 1994), but any new depth-dose data generated for new machines or beams should incorporate the shift. If the institution's normalization point for its output and depth-dose data is at d_{max} or any other depth other than 10 cm for photon beams or d_{ref} for electron beams, then the absorbed dose at the reference depth for calibration must be converted to dose at the reference depth used by the treatment planning system or monitor unit calculation software. So that the dose at tumor depth is consistent with the measured absorbed dose at the reference calibration depth, the clinical depth-dose data at 10 cm for photons and d_{ref} for electron beams should be used for the conversion. The measured %dd(10)$_x$ should not be used to perform the conversion for photon beams or the percent ionization curves for electron beams. For electron beams, the clinical depth-dose correction for 16 and 20 MeV energies is approximately 98.5% and 95.5%, respectively. Failure to include this conversion can result in a significant error in the dose at d_{max}.

5. Summary

Implementation of the TG-51 protocol is fairly straightforward as long as one reads the protocol and follows the steps and suggestions in progression. There can

be areas of confusion that hopefully have been made a bit clearer in this chapter. Once a beam has been calibrated using the TG-51 protocol, it is always a good idea to have a second physicist independently check the work and calculations. Spreadsheets are an excellent way to perform the TG-51 calculations as long as they are verified by the hand calculation of another physicist. The Radiological Physics Center (RPC) is another independent resource to verify TG-51 protocol calculations.

If the therapy beams were already calibrated using another protocol such as the TG-21 or International Atomic Energy Agency (IAEA) TRS-398 protocol, then one can expect differences between the doses calculated using the older protocols and TG-51. The differences between TG-21 and TG-51 are dependent on the energy and chamber type and are typically less than 1% subsequent to the National Institute for Standards and Technology (NIST) change in the air-kerma factor. As a resource to the physicist, Tailor and Hanson (Tailor and Hanson 2002) have reported the expected TG-51/TG-21 ratios without the influence of the calibration coefficients.

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Problems

1. A WAFAC measurement of the strength of an ^{125}I brachytherapy seed yields the following currents, decay corrected to a reference date and time of January 12, 2009 at 00:00:01 EST: $I_1 = 2.08\times10^{-13}$ A for a chamber volume of 804 cm^3, $I_2 = 5.31\times10^{-14}$ A for a chamber volume of 216 cm^3. Find the air-kerma strength of the seed at the reference date and time given above in units of μGy m^2/h, assuming that $\bar{W}/e = 33.97$ J/C, $\rho_{air} = 1.18$ mg/cm^3, $K_{dr}(\dot{K}) = 1.0001$, and $d = 30$ cm.

2. A nominal 100 mCi ^{90}Sr/^{90}Y ophthalmic applicator gives rise to an absorbed dose rate to water of about 0.5 Gy/s on the surface of the applicator. This dose rate in turn yields a 200 pA/mm limiting value of the slope in the extrapolation chamber curve using the 4 mm diameter collecting electrode. If the system noise levels are such that the lower level of measurement is about 1 pA/mm, what is the minimum measurable dose rate with the system when using the 1 mm diameter collecting electrode?