Implementation of TG-51: Practical Considerations

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The AAPM Task Group 51[1] (TG-51) recently published its protocol for clinical reference dosimetry of megavoltage radiation therapy. Explicit application of TG-51 to a high energy accelerator with electron capability requires the clinical physicist to have a 1mm thick sheet of lead and a parallel plate chamber. Many clinical physicists have neither, therefore we have studied the impact of alternative measurement techniques on output calibration to solve this problem. Depth dose measurements with a lead sheet in the beam are required to determine the beam quality (k_Q) by obtaining the $\%dd(10)_x$ (depth dose with electron contamination removed) for energies ≥10 MV. TG-51 also states that a parallel plate chamber is recommended for electron calibration and is required for reference dosimetry for electron energies ≤ 6 MeV. To determine if these requirements are necessary, the Radiological Physics Center (RPC) made measurements on Varian, GE, and Siemens units for 10 and 18 MV photons and 5 – 20 MeV electrons. The comparison of lead versus no lead revealed that the k_Q value, thus the calibration of the beam, will vary by no more than 0.2%. The comparison between a parallel plate and a cylindrical Farmer chamber showed no measurable difference in the calibration across the range of electron energies. Omission of the lead to determine k_Q and use of a cylindrical chamber for low electron energies have an insignificant effect on the calibration.

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METHODS

A. Lead vs. No Lead

- Measurements were made for 10 MV, 15 MV, 18 MV, and 23 MV photon energies on several Varian Clinac 2100Cs (with and without MLC), a Siemens Mevatron KD, several Siemens Primus's, an Elekta SL-18, an Elekta SL-20 and a GE Saturne 41.

- Measurements were made with Farmer-type 0.6 cm^3 ion chambers (NEL 2571 and PTW N23333) with a Keithley model 602 electrometer.

- The effect of having the lead sheet mounted on the bottom side of a Lucite tray or suspended by tape to the head of the gantry was investigated. Also investigated was the effect of incasing the lead sheet in plastic.

- The $\%dd(10)_x$ was determined for all situations and the k_Q value determined. The values of k_Q were compared for the various combinations measured. Differences in k_Q are directly proportional to differences in dose determination.

B. Parallel Plate Chamber vs. Graphite Cylindrical Farmer Chamber

- Measurements were made in a water phantom using a Farmer-type 0.6 cm^3 cylindrical ion chamber (NEL 2571) and plane parallel plate ion chambers (Exradin P11 and Wellhofer Roos) with a Keithley 602 electrometer.

- Electron energies ranged from 5 MeV to 20 MeV produced on a Varian Clinac 2100C or a Siemens Mevatron 6740.

- Depths of maximum ionization and 50% ionization were searched out using the graphite Farmer chamber to determine R_{50} and d_{ref}. Measurements were made to determine the gradient correction ($P_{gr}^{Q}(cyl)$), polarity correction (P_{pol}), and ionization recombination correction (P_{ion}). This process was completed for all electron energies. The Farmer chamber was then replaced with the plane parallel plate chamber and the above process was repeated again for all energies.

- A comparison of absorbed dose between the two chamber types was performed at all energies.

C. Polarity

- Measurements were made in a water phantom using a Farmer-type 0.6 cm^3 cylindrical ion chamber (NEL 2571 and Exradin A12) and plane parallel plate ion chamber (Exradin P11 and Wellhofer Roos) with a Keithley 602 electrometer.

- Measurements were made for photon energies ranging from 4 MV to 18 MV and electron energies ranging from 5 MeV to 20 MeV on several different makes and models of machines.

LEAD vs. NO LEAD

- For photon energies ≥ 10 MV; to determine k_Q it is necessary to obtain the $\%dd(10)_x$ (depth dose with electron contamination removed).

- This is accomplished by either:

  - placing a 1mm (±20%) piece of lead within the beam either 30 cm (±1cm) or 50cm (±5cm) from the phantoms surface

  <u>OR</u>

  - using the algebraic expression provided by TG-51 in the interim of obtaining a sheet of lead, as long as there is ≥ 45 cm clearance.

Comparison of Pb vs. Algebraic Expression to determine k_Q

Machine	Energy (MV)	$\%dd(10)_x$ (Pb)/(No Pb)	k_Q Pb)/(alg.exp)
GE Saturne 41	10 (50cm)	1.011	0.999
Philips SL-18	15 (50cm)	1.008	0.999
Philips SL-20	18 (50cm)	1.002	0.999
Mevatron KD	18 (50cm)	1.003	1.000
Primus	18 (50cm)	1.002	1.000
Primus	23 (50cm)	0.998	1.000
Clinac 2100	10 (50cm)	1.014 ±0.3%[+]	0.998 <0.1%
Clinac 2100	15 (30cm)‡	1.010	0.999
Clinac 2100 (MLC)	18 (30cm)	1.015 <0.1%	0.998 <0.1%
Clinac 2100	18 (50cm)	1.015 ±0.5%	0.998 <0.1%

NOTE: [+]Any value presented with uncertainties represents more than 1 determination. The stated uncertainty is total spread.

‡The interim equation to determine $\%dd(10)_x$ without lead was used to determine $\%dd(10)_x$ for these 2 energies with the lead placed at 30 cm from the phantoms surface, although this is a violation of the protocol.

Table 1: The difference in $\%dd(10)_x$ with lead and without lead in the beam is at most 1.5%. Therefore k_Q will vary no more than 0.2% if lead foil is not used in the determination of $\%dd(10)_x$. The resulting beam calibration without using the lead foil will be only 0.2% higher, a value we believe to be insignificant.

LEAD vs. LEAD incased in plastic

Machine	Energy (MV)	k_Q(Pb)	k_Q(Pb plastic)	k_Q(Pb)/ k_Q(plastic)
Clinac 2100	18	0.968	0.968	1.000

Suspended LEAD vs. LEAD on underside of Lucite Tray

Machine	Energy (MV)	k_Q(Pb)	k_Q (Pb Lucite Tray)	k_Q(Pb)/ k_Q(Pb Lucite Tray)
Clinac 2100	18	0.966	0.969	0.997

Table 2: The two tables are the comparison of (1) lead foil versus lead incased in plastic and (2) suspended lead foil versus lead on underside of a Lucite tray. The thickness of the plastic coating surrounding the 1.25 mm piece of lead is 0.5mm. This thickness of plastic is negligible in the determination of k_Q. There is a 0.3% difference in k_Q if the lead foil is attached to the underside of a Lucite tray versus if it is suspended. This difference in k_Q is comparable to the difference in k_Q determined with and without lead in the beam.

Parallel Plate vs. Cylindrical

- TG-51 recommends when calibrating electrons:
  - for energies > 6 MeV, a parallel plate chamber should be used, but a cylindrical chamber may be used.
  - for energies $\leq$ 6 MeV, a parallel plate chamber is required.

Comparison of Parallel Plate & Cylindrical Chambers

Dose determined: Parallel plate/Cylindrical

Energy(MeV)	Wellhofer Roos	Exradin P11
5		1.001
6	1.021$^+$	0.997$^+$
7		1.001
8		1.000
9	1.019	0.998$^+$
12	1.019	0.997$^+$
16	1.021	0.997$^+$
20	1.022$^+$	0.995$^+$

$^+$Note: The above values are the average of several sets of measurements. The total spread in the measurements for a given energy/chamber combination is less than 0.6%

Table 3: This is the ratio of the TG-51 dose determined from measurements with two parallel plate chambers (Wellhofer Roos and Exradin P11) to that determined from measurements with a Farmer type cylindrical chamber (NEL 2571 0.6 cm^3). No energy dependence can be seen (total spread < 0.6%).

Polarity

- TG-51 provides an equation to determine a polarity correction at d_{ref} when reference dosimetry is performed, by taking several stable readings at full voltage and then at the opposite sign full voltage:

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

Polarity Correction for Cylindrical Chambers (photons)

Energy	(n)	P_{pol}	s
4x	2	1.001	
6x	16	1.000	±0.001
10x	2	1.000	
15x	3	1.001	
18x	10	1.001	±0.001

Polarity Correction for Cylindrical Chambers (electrons)

Energy	(n)	P_{pol}	s
5e	2	0.996	
6e	15	0.997	±0.002
7e	3	0.997	
8e	1	0.997	
9e	18	0.999	±0.001
12e	6	0.999	±0.001
14e	1	1.000	
15e	1	1.001	
16e	8	1.000	±0.001
20e	2	1.000	

Tables 4 & 5: The polarity correction was determined using several Farmer type cylindrical chambers (NEL 2571, PTW N23333, Capintec PRO6G, and Exradin A12). "n" is the number of data sets that were used to determine the polarity correction for a given energy. These data were obtained from the beta testing[3] of the TG-51 protocol, RPC physicists during on-site review visits, and several long evenings of measurements.

Polarity Correction for Parallel Plate (electrons)

Energy	(n)	P_{pol}	s
5e	2	0.994	
6e	15	0.998	±0.003
7e	3	0.995	
8e	1	0.996	
9e	18	0.997	±0.002
12e	6	0.999	±0.001
16e	8	0.999	±0.002
20e	2	0.999	

Table 6: The polarity correction was determined using two parallel plate chambers (Wellhofer Roos and Exradin P11). "n" is the number of data sets that were used to determine the polarity correction for a given energy.

CONCLUSIONS

The use of a lead foil to determine beam quality:

- For common linear accelerators, k_Q, thus beam calibration, varied by no more than 0.2% if the interim algebraic expression was used to determine $\%dd(10)_x$, rather than the sheet of lead.
- If the lead sheet is incased within a thin layer of plastic, no measurable difference will be seen in the determination of k_Q.
- If a sheet of lead is placed on the underside of a Lucite tray, one may see up to a 0.3% difference in the determination of k_Q.

The use of plane parallel chambers for low energy electron beams:

- The discrepancy between absorbed dose determined with cylindrical chambers or plane parallel chambers is essentially independent of energy from 20 MeV (R_{50} = 8.4) down to 5 MeV (R_{50} = 2.1).
- Even with an ADCL determined $N_{D,w}^{^{60}Co}$, it is essential to verify $k_{ecal}N_{D,w}^{^{60}Co}$ by cross calibration with a cylindrical chamber in a high energy electron beam (R_{50} near 7.5 cm).

Polarity corrections:

- For photon energies, measured on several different machine makes and models with several different Farmer type chambers, the polarity correction was found to be 1.000 ±0.001.

- For electron energies ≥ 12 MeV, measured on several different machine makes and models, using several different Farmer type chambers and several parallel plate chambers, the polarity correction was found to be 1.000 ±0.001.

- For electron energies less than 12 MeV, the polarity correction is measurable for both cylindrical and parallel plate chambers.

- The commissioning of a new ionization chamber by a user should include an assessment of the polarity effects at all energies and modalities measured. An informed decision can then be made as to which energies and modalities require a polarity correction.

RPC POLICY

Based on data presented here, the RPC has adopted the following policies.

The use of the lead foil to determine beam quality:

- The RPC will use the sheet of lead until data are published in a peer review journal that demonstrate that it is not necessary.

The use of plane parallel plate chambers for low energy electrons:

- The RPC is an auditing body, so for convenience, will use cylindrical chambers to verify electron calibrations. Significant discrepancies for energies ≤ 10 MeV will be investigated using a plane parallel plate chamber, if necessary.

Polarity effects:

- The RPC will use a polarity correction of 1.000 for all photon energies for the chambers checked here.

- The RPC will use a polarity correction of 1.000 for electron energies > 10 MeV.

- The RPC will measure the polarity correction for electron energies ≤ 10 MeV.

REFERENCES

[1]American Association of Physicists in Medicine, Radiation Therapy Task Group 51, “AAPM’s TG-51 protocol for clinical reference dosimetry of high-energy photon and electron beams,” Med. Phys. 26, 1847-1870 (1999).

[2]American Association of Physicists in Medicine, Radiation Therapy Task Group 21, “A protocol for determination of absorbed dose from high-energy photon and electron beams,” Med. Phys. 10, 41- 771 (1983).

[3]S. H. Cho, J. R. Lowenstein, P. A. Balter, N. H. Wells, and W. F. Hanson, "Comparison between TG-51 and TG-21: Calibration of photon and electron beams in water using cylindrical chambers," Journal of Applied Clinical Medical Physics,Vol. 1, No. 3, 2000, 108-115.