"CALCULATED TG51 TO TG21 ABSORBED-DOSE RATIOS FOR MOST WIDELY USED CYLINDRICAL AND PARALLEL-PLATE ION CHAMBERS OVER A RANGE OF PHOTON AND ELECTRON ENERGIES"

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ABSTRACT

The change in absorbed dose determined using the TG51[1] rather than the TG21[2] calibration protocol, is expressed in this work as the ratio, TG51/TG21, of the doses based on the two protocols. These ratios are presented for a variety of ion chambers over a range of photon and electron energies. The TG51/TG21 dose ratios presented here are based on the dosimetry factors provided by the two protocols and the chamber-specific absorbed dose and exposure calibration factors ($N_{D,w}^{60Co}$ and N_X) provided by the ADCL at MD Anderson Cancer Center (MDACC). As such, the values presented here represent the expected discrepancies between the two protocols due only to changes in the dosimetry parameters and the differences in chamber-specific dose and air-kerma standards. They are independent of measurement uncertainties, setup errors, and inconsistencies arising from the mix of different phantoms and ion chambers for the two protocols, etc. Therefore, these ratios may serve as a guide to institutions performing measurements for the switch from TG21 to TG51 based calibration. Any significant deviation in the ratio obtained from measurements versus those presented here should prompt a review to identify possible errors and inconsistencies. For all cylindrical chambers included here, the TG51/TG21 dose ratios are the same, within ± 0.6%, irrespective of the make and model of chamber, for each photon and electron beam included. Photon beams show the TG51/TG21 dose ratios decreasing with energy, while electrons exhibit the opposite trend. For parallel-plate chambers, the situation is complicated by the two possible ways for obtaining calibration factors: one through an ADCL, and the other through a cross-comparison with a cylindrical chamber in a high-energy electron beam. The two methods, for some chambers, lead to significantly different calibration factors, which in turn lead to significantly different TG51/TG21 results for the same chamber. Data show that if both $N_{D,w}^{60Co}$ and N_X are obtained from the same source, namely an ADCL or a cross-comparison, the TG51/TG21 results for parallel-plate chambers are similar to those for cylindrical-chambers. However an inconsistent set of calibration factors, i.e. using $N_{D,w}^{60Co}$ k_{ecal} from an ADCL but N_{gas} from a cross-comparison or vice-versa, can introduce an additional uncertainty up to 2.5% in the TG51/TG21 dose ratios.

Keywords: Megavoltage, dosimetry, TG51 protocol, TG21 protocol, parallel-plate chambers, cross-comparison.

INTRODUCTION

Since publication of the AAPM absorbed-dose-standard based protocol, TG51[1], in September 1999, the Radiological Physics Center (RPC) has received numerous phone calls for a variety of related questions, concerns, and clarifications of the protocol. One of the important questions has been the difference in the absorbed-dose determined with the two protocols. Currently, this question is becoming more frequent as the switch from the TG21 protocol to the TG51 protocol is gaining momentum. The measured dose difference between the two protocols, for some selected ion chambers, has been presented as posters[3] and publications[4,5,6]. In these studies, a maximum difference of about 2% has been reported for both high energy photon and electron beams. However, differences from - 4 to + 6 %, especially for electron calibrations with parallel-plate ion chambers, have been reported to the RPC by a significant number of institutions. This work is aimed at responding to this issue. In this work, the difference between dose determined by the two protocols is presented as the ratio of the absorbed dose, at a specified 'reference' depth, determined using the TG51 protocol to that determined using the TG21 protocol at that same depth. In this work, this dose ratio will be identified as "TG51/TG21". The calculated ratios, TG51/TG21, are presented for the most commonly used cylindrical and parallel-plate ion chambers.

These calculations are based on the dosimetry factors from the two protocols and the average ratio of the absorbed dose calibration factor, $N_{D,w}^{60Co}$,to the exposure calibration factor, N_X, for the specific chamber. The latter ratio will be identified as $N_{D,w}^{60Co}$ / N_X. Uncertainty in TG51/TG21 due to that $N_{D,w}^{60Co}$ / N_X is resolved by removing this term from the TG51/TG21 results.

The dose ratios, TG51/TG21, presented in this work are expected to be a guide to institutions performing the switch from the TG21 to the TG51 protocol.

MATERIALS AND METHODS

Calculations of the absorbed dose, and therefore dose ratios presented in this work, are based on equations in TG51 and TG21 for absorbed dose to water at the same depth, for a specific irradiation time or monitor units. Since TG51 is more specific about the reference depth than is TG21, especially for electrons, the TG51 reference depth is chosen. The absorbed dose ratio, $(TG51/TG21)_x$, for photons at the reference depth (10cm) is given by:

$$(TG\ 51\ /\ TG\ 21)_x = \frac{k_Q}{P_{repl} \cdot P_{wall} \cdot L/\rho} \cdot \frac{\left(N_{D,w}^{60\,Co} / N_X\right)}{\left(N_{gas} / N_X\right)} \quad \text{-----------} \ (1)$$

The various symbols are those used in the two protocols. Similarly, the absorbed-dose ratio, $(TG51/TG21)_e$, for electrons at depth d_{ref} is given by:

$$(\mathrm{TG51/TG21})_e = \frac{k'_{R50}}{P_{repl} \cdot (L/\rho)} \ \frac{k_{ecal} \cdot \left(N_{D,w}^{60Co} / N_X\right)}{\left(N_{gas} / N_X\right)} \quad \text{-----------} \ (2)$$

This equation assumes an appropriate shift to the effective point of measurement for TG21, and exploits the fact that P_{gr} times the raw reading of a cylindrical chamber with its axis at d_{ref} in TG51, is effectively equal to just the raw reading with the chamber's axis at depth (d_{ref} + shift). The derivation of this equation uses the same shift, $0.5r_{cav}$ for both TG51 and TG21. Notice that this equation holds for parallel-plate chambers as well, since the effective point of measurement, in both protocols, is the inner surface of the front window of the chamber.

Equations (1) and (2) were used for calculating the results presented in this work. The various dosimetric parameters were taken from TG51 and TG21. For parallel-plate chambers, the values of P_{repl} were obtained from TG39.

The format of equations (1) and (2), explicitly employs the factor (N_{gas} / N_X) to exploit the use of published values for this ratio. The values for (N_{gas} / N_X) were taken from Gastorf et. al.[7], or calculated from Nath et.al.[8] using the manufacturer's specifications. The chamber factor ratio, ($N_{D,w}^{60Co}$ / N_X), also appears in the equations. Values for this ratio from the MDACC ADCL were used.

Table-I Ion chambers, their factors, and relevant charateristics

Ion chamber's Make / Model	Water proof ?	Thimble / Front window Material	mg/cm2	Sens. Volume (cc)	ID, or Gap (mm)	Collecting electrode Material	dia (thick) (mm)	N_{gas}/N_X (cGy/R)	K_{ecal}	N_{DW}/N_X (cGy/R)
Cylindrical:										
NEL 2505-3, -3A	No	Graphite	66.6	0.60	6.3	Alum	1.0	0.853	0.903	0.9642
NEL 2571	No	Graphite	66.6	0.69	6.3	Alum	1.0	0.854	0.903	0.9667
NEL 2581	No	Tissue-eq	40.0	0.60	6.3	Alum	1.0	0.837	0.885	0.9661
PTW N30001 (N23333)	No	Acryl/Graph	60.3	0.60	6.1	Alum	1.0	0.848	0.897	0.9646
PTW N30002	No	Graphite	78.6	0.60	6.1	Graph	1.0	0.854	0.900	0.9652
PTW N30004	No	Graphite	78.6	0.60	6.1	Alum	1.0	0.854	0.906	0.9696
[a] PTW N30006	Yes	Acryl/Graph	56.3	0.60	6.1	Alum	2.0	0.850	0.897	0.9641
PTW N31003 (N233641)	Yes	Acryl/Graph	83.0	0.30	5.5	Alum	1.5	0.850	0.898	0.9680
Capintec PR-O6C	No	Air-eq	49.9	0.65	6.4	Air-eq	1.6	0.851	0.900	0.9631
Capintec PR-O6G	No	Air-eq	49.9	0.65	6.4	Air-eq	1.6	0.851	0.900	0.9637
Exradin A-12	Yes	Air-eq	89.0	0.651	6.1	Air-eq	1.0	0.866	0.906	0.9703
Parallel-plate:										
Holt MPPK	No	Polystyrene	420.0	1.00	2	Polystyren	4.0	0.855	0.900	?
Capintec PS-033	No	Mylar	0.5	0.50	2	Mylar	0.0036	0.884	0.921	?
Markus PTW N23343	Yes	Acryl / Poly	187.0	0.06	2	Acryl / Poly	1.03	0.859	0.905	0.9918
[b] Roos-type PTW N34001	Yes	Acryl ic	118.5	0.35	2	Acryl ic	1.0	0.852	0.901	0.9942
[b] Roos-type Wellh PPC35	Yes	Acryl ic	118.0	0.35	2	Acryl ic	1.0	0.852	0.901	0.9921
NACP-02	Yes	Reksolite / Myl	66.4	0.16	2	Reksolite /	0.6	0.845	0.888	0.9995
Exradin P11	Yes	Poly-eq	106.0	0.62	2	Poly-eq	1.0	0.848	0.888	0.9989

[a] Not included in TG51 (assume K_Q & K_{ecal} same as those for N30001).

[b] Not included in TG39 (assume P_{repl} = 1).

RESULTS &DISCUSSION

The relevant characteristics of various cylindrical and parallel-plate chambers used for this study are presented in table-I. The calculated dose ratios, $(TG51/TG21)_x$ and $(TG51/TG21)_e$, are presented in table-II, and figures 1 through 3. The beam energy-specifier in figure 1 is the ionization ratio, "IR", from TG21; the corresponding specifier for TG51, $\%dd(10)_x$, can be found in table-II. The shaded area in each figure is an envelope of the data, intended to direct the eye to trends with respect to beam energy. The solid curve inside the shaded area is the average of the trend.

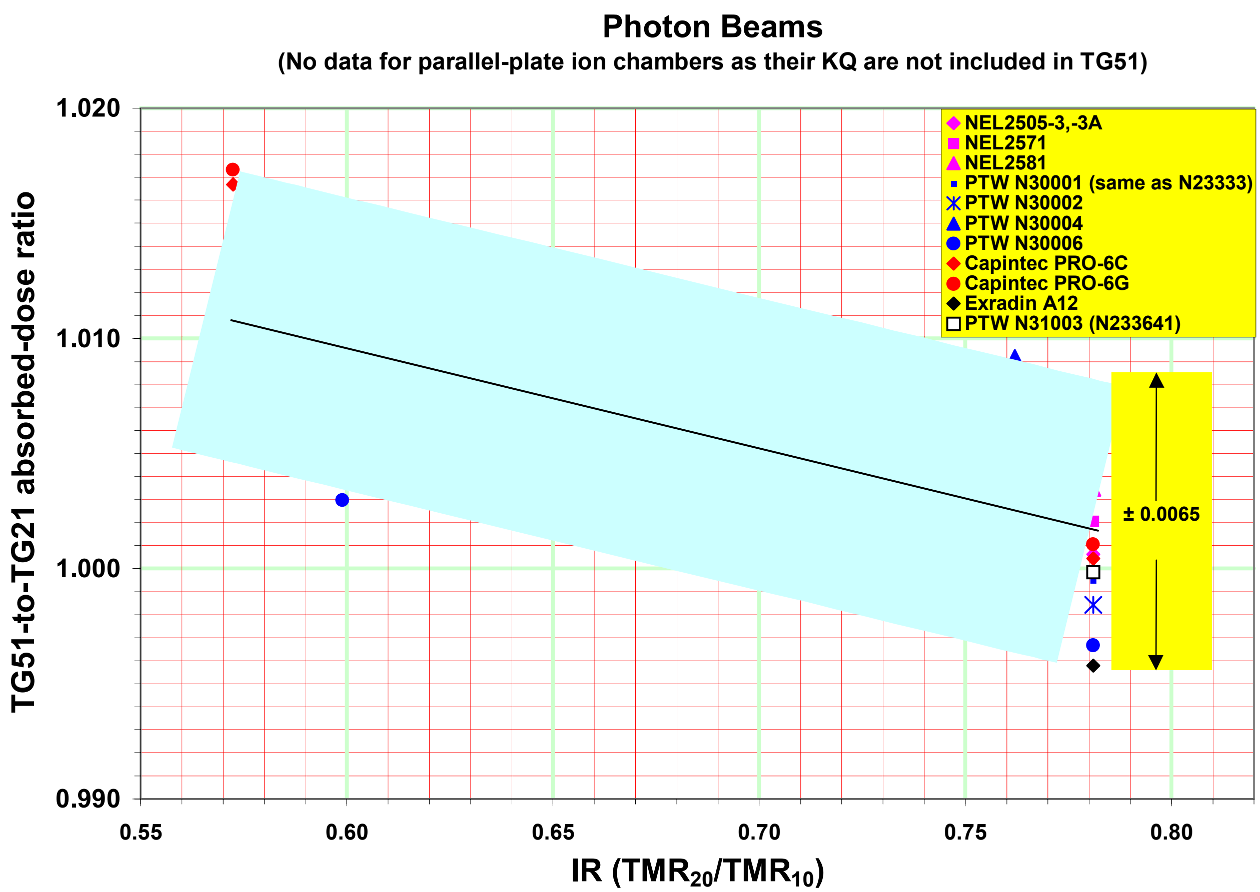
The photon beam results, displayed in figure 1, show the dose-ratio $(TG51/TG21)_x$ to be highest (1.01) at Co-60, diminishing with increasing beam energy to near 1.00 at 18 MV. All 11 cylindrical chambers included in this study show similar results within tight limits (envelope of ± 0.6%) at all energies.

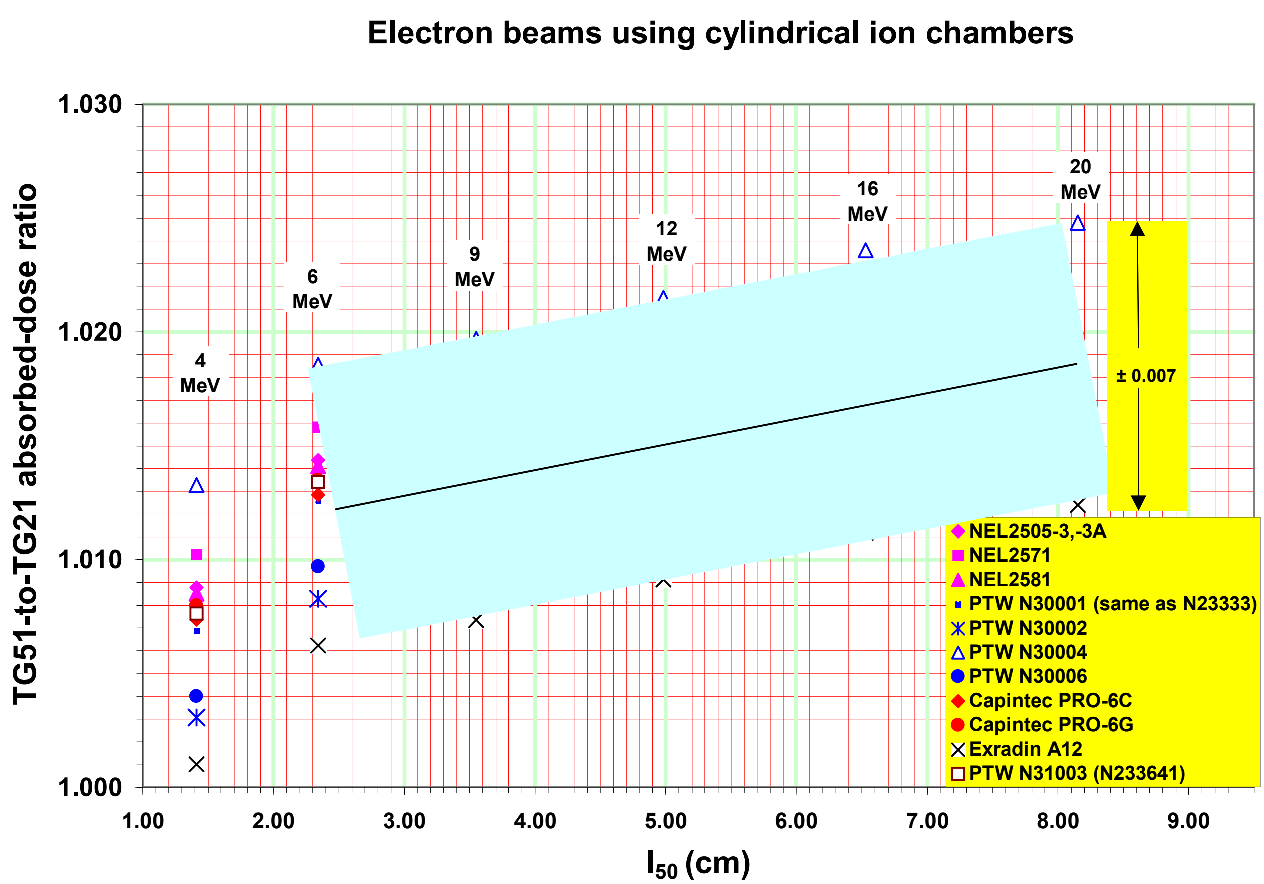
Electron results for cylindrical and parallel-plate chambers are presented in figures 2 and 3 respectively. Both classes of chambers show that the trend with respect to energy is opposite to that seen for photons. For cylindrical-chambers, the dose-ratio $(TG51/TG21)_e$ is highest (1.02) at the highest beam energy 20 MeV, and diminishes with decreasing beam energy to 1.01 at 6 MeV. All 11 cylindrical chambers included in this study again show similar results within tight limits (envelope of ± 0.6%) over the range of energies. The parallel-plate chambers show results similar to cylindrical chambers with an even narrower envelope. However, these similar results are only "apparent" and deserve additional discussion under 'parallel-plate chambers' below.

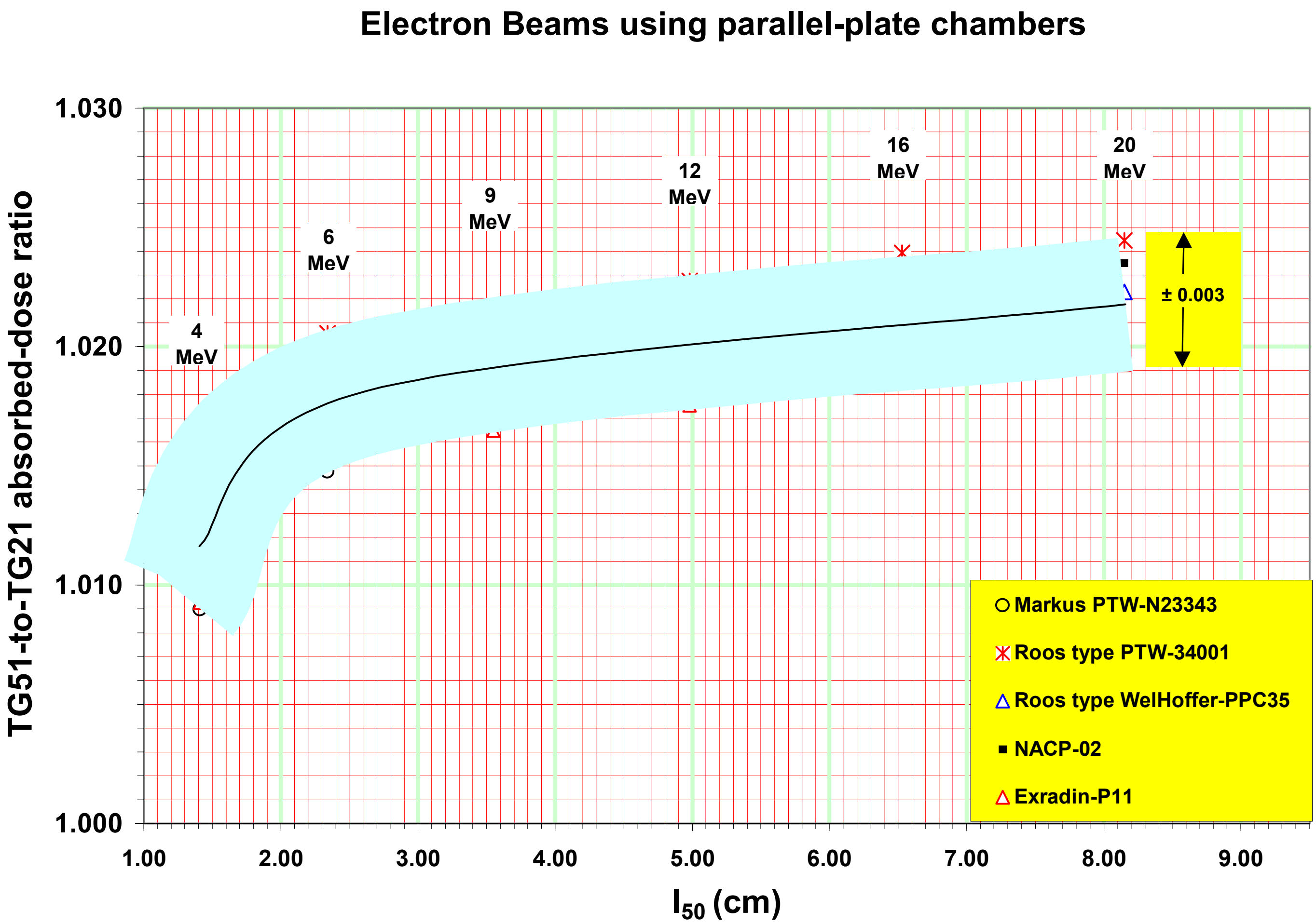
The TG51 protocol does not allow the use of cylindrical chambers for energies of 6 MeV or less, so the shading in figure 2 was stopped just above 6 MeV. However, the results shown by the cylindrical chambers at all energies, including 6 and 4 MeV, are similar to those shown by parallel-plate chambers. All results appear well behaved (with the possible exception of the 4 MeV electrons), however, there are several issues that can have a significant impact on these results, and therefore deserve special attention.

Table-II Absorbed-dose ratios TG51/TG21

Ion chamber	Photons: Nominal Energy (MV)						Electrons: Nominal Energy (MeV)					
	Co-60	4	6	10	15	18	4	6	9	12	16	20
Cylindrical:												
NEL 2505-3, -3A	1.0085	1.0065	1.0070	1.0048	1.0041	1.0006	1.0088	1.0144	1.0154	1.0166	1.0177	1.0183
NEL 2571	1.0100	1.0079	1.0085	1.0062	1.0055	1.0021	1.0102	1.0158	1.0168	1.0180	1.0192	1.0198
NEL 2581	1.0148	1.0086	1.0103	1.0075	1.0072	1.0035	1.0085	1.0141	1.0151	1.0163	1.0175	1.0180
PTW N30001 (N23333)	1.0102	1.0058	1.0062	1.0034	1.0028	0.9995	1.0069	1.0126	1.0138	1.0152	1.0165	1.0173
PTW N30002	1.0084	1.0055	1.0059	1.0033	1.0022	0.9984	1.0031	1.0083	1.0094	1.0112	1.0133	1.0145
PTW N30004	1.0130	1.0109	1.0115	1.0098	1.0092	1.0060	1.0133	1.0186	1.0197	1.0215	1.0236	1.0248
PTW N30006	1.0073	1.0030	1.0033	1.0005	0.9999	0.9967	1.0040	1.0097	1.0109	1.0123	1.0136	1.0144
PTW N31003 (N233641)	1.0103	1.0060	1.0065	1.0038	1.0031	0.9999	1.0076	1.0134	1.0145	1.0156	1.0166	1.0170
Capintec PR-O6C	1.0167	1.0136	1.0113	1.0055	1.0044	1.0004	1.0074	1.0129	1.0138	1.0149	1.0160	1.0164
Capintec PR-O6G	1.0173	1.0142	1.0120	1.0062	1.0050	1.0011	1.0080	1.0135	1.0144	1.0155	1.0166	1.0171
Exradin A-12	1.0095	1.0078	1.0056	1.0002	0.9994	0.9958	1.0010	1.0062	1.0073	1.0091	1.0112	1.0124
Parallel-plate:												
Markus PTW N23343	K_Q for parallel-plate chambers not included in TG-51.						1.0090	1.0148	1.0167	1.0183	1.0191	1.0193
Roos-type PTW N34001							1.0144	1.0206	1.0217	1.0228	1.0239	1.0245
Roos-type Wellh PPC35							1.0123	1.0184	1.0195	1.0206	1.0218	1.0223
NACP-02							1.0135	1.0196	1.0207	1.0218	1.0230	1.0235
Exradin P11							1.0092	1.0154	1.0165	1.0175	1.0187	1.0192
Beam Characteristics:												
NAP	2.47	2.86	4.49	8.40	12.52	16.19	-	-	-	-	-	-
IR	0.572	0.599	0.664	0.729	0.762	0.781	-	-	-	-	-	-
$\%DD_{(10)X}$ or, I_{50}	58.7*	63.6	66.2	73.0	77.0	81.7	1.41	2.34	3.55	4.98	6.53	8.15
R_p	-	-	-	-	-	-	1.91	3.06	4.53	6.27	8.17	10.15
d_{ref}	-	-	-	-	-	-	0.75	1.30	2.05	2.95	3.90	4.90


Photon Beams
(No data for parallel-plate ion chambers as their KQ are not included in TG51)
TG51-to-TG21 absorbed-dose ratio
1.020
1.010
1.000
0.990
0.55
0.60
0.65
0.70
0.75
0.80
IR (TMR20/TMR10)
NEL2505-3,-3A
NEL2571
NEL2581
PTW N30001 (same as N23333)
PTW N30002
PTW N30004
PTW N30006
Capintec PRO-6C
Capintec PRO-6G
Exradin A12
PTW N31003 (N233641)
± 0.0065


Electron beams using cylindrical ion chambers
TG51-to-TG21 absorbed-dose ratio
1.030
1.020
1.010
1.000
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
I50 (cm)
4 MeV
6 MeV
9 MeV
12 MeV
16 MeV
20 MeV
± 0.007
NEL2505-3,-3A
NEL2571
NEL2581
PTW N30001 (same as N23333)
PTW N30002
PTW N30004
PTW N30006
Capintec PRO-6C
Capintec PRO-6G
Exradin A12
PTW N31003 (N233641)



UNCERTAINTY IN ($N_{D,w}^{60Co}$ / N_X)

The results presented in table-II and Figures 1 through 3 are based on the empirical values of ($N_{D,w}^{60Co}$ / N_X) provided by the MDACC ADCL. The reproducibility of these values, for a specific make and model of chamber, within one ADCL, is extremely tight ($\sigma < 0.2\%$ at the MDACC ADCL). However, among various calibration laboratories (NIST, NRCC, and other ADCLs), differences up to ±1% in the values for ($N_{D,w}^{60Co}$ / N_X) have been noticed by the RPC.

REFINED TG51/TG21 DOSE RATIOS

The impact of the uncertainty in ($N_{D,w}^{60Co}$ / N_X) on the TG51/TG21 results in table-II, is eliminated by removing this factor from equations 1 and 2. The resulting ratios (TG51/TG21) / ($N_{D,w}^{60Co}$ / N_X) are presented in table III. The user, then, can obtain rather precise estimates of their expected (TG51/TG21) dose-ratios by multiplying the values shown in Table III by the calculated ($N_{D,w}^{60Co}$ / N_X) ratio based on the actual ADCL calibration reports for their own chamber. The uncertainty in the TG51/TG21 dose ratio is then limited to the uncertainty in the choice of the protocol factors or the additional uncertainties discussed below.

Table-III " Absorbed-dose ratio "TG51/TG21" divided by ($N_{D,w}/N_X$)

Ion chamber	Photons: Nominal Energy (MV)						Electrons: Nominal Energy (MeV)					
	Co-60	4	6	10	15	18	4	6	9	12	16	20
Cylindrical:												
NEL 2505-3, -3A	1.0460	1.0438	1.0444	1.0421	1.0413	1.0378	1.0462	1.0520	1.0531	1.0543	1.0555	1.0561
NEL 2571	1.0448	1.0426	1.0432	1.0409	1.0401	1.0366	1.0450	1.0508	1.0519	1.0531	1.0543	1.0549
NEL 2581	1.0515	1.0450	1.0469	1.0440	1.0436	1.0398	1.0450	1.0508	1.0518	1.0531	1.0543	1.0549
PTW N30001 (N23333)	1.0472	1.0427	1.0431	1.0402	1.0396	1.0362	1.0438	1.0498	1.0510	1.0524	1.0538	1.0546
PTW N30002	1.0447	1.0418	1.0422	1.0395	1.0384	1.0344	1.0392	1.0446	1.0458	1.0476	1.0498	1.0510
PTW N30004	1.0447	1.0425	1.0432	1.0414	1.0408	1.0375	1.0450	1.0504	1.0516	1.0535	1.0556	1.0569
PTW N30006	1.0448	1.0403	1.0407	1.0378	1.0372	1.0338	1.0414	1.0473	1.0485	1.0499	1.0513	1.0521
PTW N31003 (N233641)	1.0437	1.0393	1.0397	1.0370	1.0363	1.0329	1.0410	1.0469	1.0481	1.0492	1.0502	1.0506
Capintec PR-O6C	1.0556	1.0524	1.0501	1.0441	1.0429	1.0388	1.0460	1.0517	1.0527	1.0538	1.0549	1.0554
Capintec PR-O6G	1.0556	1.0524	1.0501	1.0441	1.0429	1.0388	1.0460	1.0517	1.0527	1.0538	1.0549	1.0554
Exradin A-12	1.0404	1.0386	1.0364	1.0308	1.0299	1.0263	1.0317	1.0370	1.0382	1.0400	1.0421	1.0434
Parallel-plate:												
Holt MPPK	K_Q for parallel-plate chambers not included in TG-51.						1.0156	1.0218	1.0229	1.0240	1.0251	1.0257
Markus PTW N23343							1.0173	1.0232	1.0251	1.0267	1.0276	1.0277
Capintec PSO33							1.0099	1.0153	1.0179	1.0210	1.0233	1.0241
Roos-type PTW N34001							1.0203	1.0265	1.0277	1.0287	1.0299	1.0304
Roos-type Wellh PPC35							1.0203	1.0265	1.0277	1.0287	1.0299	1.0304
NACP-02							1.0139	1.0201	1.0212	1.0223	1.0235	1.0240
Exradin P11							1.0104	1.0165	1.0176	1.0187	1.0198	1.0204
Beam Characteristics:												
NAP	2.47	2.86	4.49	8.40	12.52	16.19	-	-	-	-	-	-
IR	0.572	0.599	0.664	0.729	0.762	0.781	-	-	-	-	-	-
$\%DD_{(10)X}$ or, I_{50}	58.7*	63.6	66.2	73.0	77.0	81.7	1.41	2.34	3.55	4.98	6.53	8.15
R_P	-	-	-	-	-	-	1.91	3.06	4.53	6.27	8.17	10.15
d_{ref}	-	-	-	-	-	-	0.75	1.30	2.05	2.95	3.90	4.90

SOME ASSUMPTIONS AND APPROXIMATIONS EMPLOYED IN THIS WORK

Values for k_Q, k_{ecal}, and k'_{R50} for the 0.6 cc waterproof cylindrical chamber, PTW N30006, are not included in TG51. For these factors, this chamber was assumed to be identical to the PTW N30001, and hence identical to the PTW N23333. The Roos-type parallel-plate chamber is not included in TG39, however, it was specifically designed to have an adequate guard, so it's P_{repl} value has been assumed to be 1.000. The value of $N_{D,w}^{60Co}$ / N_X for the cylindrical PTW N30004 used in this work, was obtained from the University of Wisconsin's ADCL. For all other chambers, the values of $N_{D,w}^{60Co}$ / N_X were obtained from the MDACC ADCL. The curves for k'_{R50} (figures 5 and 7 in TG51) have inconsistent labeling for the cylindrical chambers NE 2581 and PRO6C/G. In this work, these chambers have been assumed to be grouped with the NE2505-3A chamber.

PARALLEL-PLATE CHAMBERS

For parallel-plate chambers, ($N_{D,w}^{60Co}$ • k_{ecal}) and N_{gas} can each be determined in two ways which we will identify as techniques A and B. In technique A, $N_{D,w}^{60Co}$ or N_X is obtained from an ADCL, and k_{ecal} or N_{gas} / N_X is obtained from the protocol or literature. In technique B, as recommended by TG51[1] or TG39[7], the product ($N_{D,w}^{60Co}$ • k_{ecal}) or N_{gas} is determined by cross-comparison with a cylindrical chamber in a high-energy electron beam. This high energy beam refers to R_{50} near 7.5 cm which is approximately 18 MeV. The two techniques, for some parallel-plate chambers, can give significantly different values. As an illustration, the product ($N_{D,w}^{60Co}$ • k_{ecal}) for a Marcus chamber (model PTW N23343), determined from the ADCL calibration, is reported[9,10] to be more than 2% higher than that determined from the cross-comparison technique. Our own measurements with this chamber yield similar results for N_{gas}. The dual values for ($N_{D,w}^{60Co}$ • k_{ecal}) and N_{gas} lead to the following 4 possible combinations, and consequently 4 possible dose ratios, TG51/TG21.

(i) Both ($N_{D,w}^{60Co}$ • k_{ecal}) and Ngas are based on an ADCL calibration (technique-A).

(ii) Both ($N_{D,w}^{60Co}$ • k_{ecal}) and N_{gas} are based on an cross-comparison (technique-B).

(iii) ($N_{D,w}^{60Co}$ • k_{ecal}) based on technique-A, but N_{gas} based on technique-B.

(iv) ($N_{D,w}^{60Co}$ • k_{ecal}) based on technique-B, but N_{gas} based on technique-A.

The TG51/TG21 dose ratios, presented in Table-II, are based on the use of combination (i) above. Use of the combination (ii) for parallel plate chambers should yield the same results. However, an inconsistent combination, such as (iii) or (iv), would compromise the presented TG51/TG21 ratios. Continuing with the previous illustration of the Markus chamber, the $(TG51/TG21)_e$ value (1.019) at 20 MeV in Table-II, would change by an additional ±2% to 1.04 if combination (iii) was used, or 1.00 if combination (iv) was used.

A word of caution is in order. The parallel-plate results, based on either combination (i) or (ii), agree with those for cylindrical chambers presented in table-II and figures 2 & 3. From this apparent agreement, one should not conclude that the two classes of chambers would necessarily agree in absolute doses as well. In fact, as mentioned above, the Markus chamber is reported [9] to measure ~2% higher dose than a cylindrical chamber (Farmer type, NEL 2571 or PTW N30001) at all electron energies. The reason for this is not fully understood, however, the TG-51 protocol indicates an appreciable uncertainty in the value of k_{ecal} for parallel-plate chambers due to its high sensitivity to chamber design. For that reason, the protocol indicates a preference for determining ($N_{D,w}^{60Co} \bullet k_{ecal}$) from cross-comparison with a cylindrical chamber.

SOURCES OF ADDITIONAL UNCERTAINTY

Differences in the experimental set-up between TG21 and TG51 may result in measurable differences in the TG51/TG21 values versus those reported in this work. These include:

(i) Measurement at different depths for the two protocols, which would result in different raw readings. Moreover, the depth-dose factors required to transfer doses between these two depths, may have inconsistencies which could lead to an extra uncertainty in the TG51/TG21 value.

(ii) Use of different P_{ion}, and $P_{polarity}$ values for the two protocols.

(iii) Set-up error could also contribute to uncertainty if dose measurements for both protocols are not done with the same undisturbed set-up.

(iv) Use of different phantom materials for the two protocols

(v) Use of different ion chambers for the two protocols. This would not allow calculation of $N_{D,w}^{60Co}$ / N_X.

(vi) Use of parallel-plate chambers, where the selection of calibration techniques can introduce uncertainties in excess of 2%.

CONCLUSIONS

- All the chambers listed in this work show similar TG51/TG21 results irrespective of beam energy/modality. Mutual agreements are within ± 0.7% limits.
- For electrons, TG51/TG21 is highest (~ 1.02) at the highest beam energy (20 MeV), and diminishes with decrease in beam energy to less than 1.01.
- Photons show an opposite trend, with the TG51/TG21 value lowest (~1.00) at the highest beam energy (18MV), increasing with decreasing beam energy to ~1.01 at 4 MV.
- The TG51/TG21 values in table-II are being currently used as reference standards in reviewing the values reported by various institutions.
- More accurate TG51/TG21 values are obtainable by use of the "TG51/TG21 divided by N_D/N_X" values in table-III and the specific N_D & N_X for the chamber in use.
- The TG51/TG21 results in this work should serve as a guide for TG51-toTG21 switch. Any significant departure in measured TG51/TG21 values from the values presented in this work should prompt a review of measurements and dose calculations for both protocols.

- For PP chambers, discrepancies up to 2.5% in absolute dose determination can be avoided by deriving ($N_{D,w}^{60Co}$ • k_{ecal}) from cross-comparison with a cylindrical chamber in a high energy (~18 MeV) electron beam.

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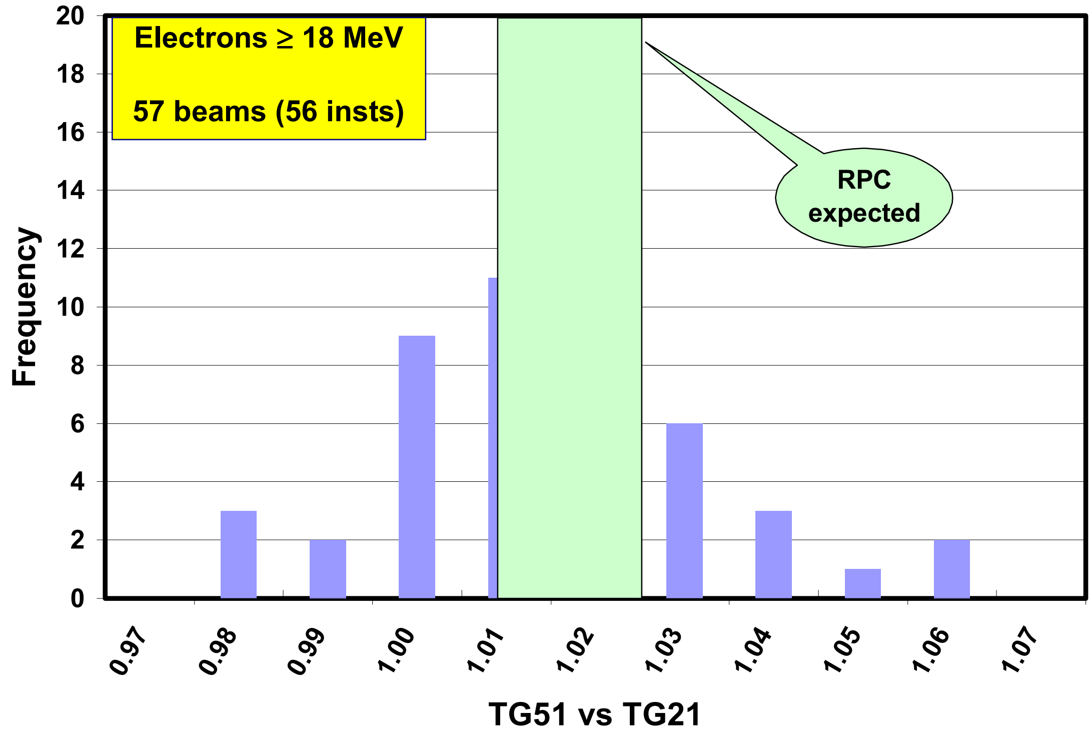
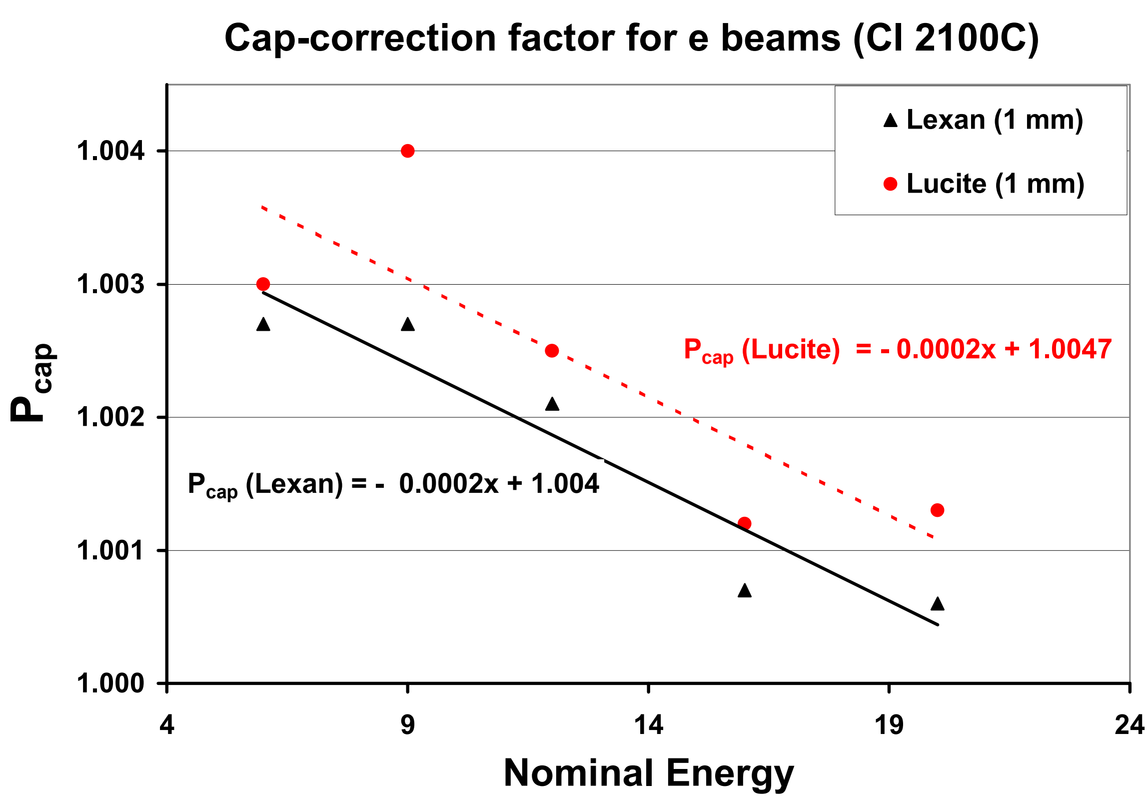

Electrons ≥ 18 MeV
57 beams (56 insts)
RPC expected
Frequency
0
2
4
6
8
10
12
14
16
18
20
0.97
0.98
0.99
1.00
1.01
1.02
1.03
1.04
1.05
1.06
1.07
TG51 vs TG21


Cap-correction factor for e beams (CI 2100C)
Lexan (1 mm)
Lucite (1 mm)
P_cap (Lucite) = - 0.0002x + 1.0047
P_cap (Lexan) = - 0.0002x + 1.004
P_cap
1.000
1.001
1.002
1.003
1.004
4
9
14
19
24
Nominal Energy