

# Are photon and electron beam calibrations more consistent with TG-51 than with TG-21?

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## Abstract:

One reason for updating calibration protocols is to improve the accuracy of beam calibration. Equally important is the necessity to improve the variability of dose determined by different institutions using a wide variety of dosimeters. A number of authors have discussed the expected change in therapy beam calibration when institutions switch from TG-21 to TG-51 calibration practices. However, no one has yet discussed whether TG-51 has improved the variability of the dose determined by various chambers. This presentation compares the determination of beam output for 6 & 18 MV x-rays and for 6 and 16 MeV electrons, for 21 different make and model of ion chambers, using both TG-21 and TG-51 calibration protocols. Both cylindrical and plane parallel chambers were used. A high degree of precision, <0.3%, was achieved by measuring all chambers on the same beam in a single setting, monitoring with external ion chambers. For plane-parallel chambers,  $N_{\text{gas}}$  and the product  $N_{\text{D,w}} \cdot k_{\text{ecal}}$  were determined from calibration by an ADCL with  $N_{\text{gas}}/N_X$  and  $k_{\text{ecal}}$  from the appropriate literature, and by cross calibration with an ADCL calibrated cylindrical chamber in a high energy electron beam. For photons, TG-51 appears to improve the variability of output dose determination over TG-21 but not significantly (SD difference less than 0.5%). The results for electron beams are more complex because of the several ways to calibrate a plane-parallel chamber.

## Introduction:

The current AAPM recommended calibration protocol (TG-51)<sup>1</sup> was published in 1999. Based on the Radiological Physics Center (RPC) mailed-TLD records, ~44% of US institutions have switched from the previous recommended protocol (TG-21)<sup>2</sup> to TG-51. An important question emerges, namely “Has the TG-51 protocol resulted in less variability in reference dosimetry (beam output) determined by various cylindrical (cyl) and parallel-plate (PP) ion chambers than experienced with TG-21?” (better unification). This work responds to that question by presenting high precision (~0.2%) relative output-calibration results using both protocols for a wide range of ion-chambers (13 cylindrical and 8 parallel-plate). Both photon and electron beam results are provided for the two protocols at low (6 MV, 6 MeV) and high (18 MV, 16 MeV) energies. Both TG-51<sup>1</sup> and AAPM TG-39 report<sup>3</sup> (which speaks to the use of PP chambers in TG-21), describe calibration of PP chambers by comparison with a cylindrical ion-chamber (calibrated at an ADCL in a <sup>60</sup>Co beam) in a high-energy electron beam (called a “cross calibration” in TG-51 and labeled “calib in  $\bar{e}$  beam” here). Calibration of PP chambers is also allowed at an ADCL in a <sup>60</sup>Co beam. Therefore PP results are presented here using both ADCL calibration and calib in  $\bar{e}$  beam.

This study brings out several interesting and important conclusions. Cylindrical and PP chamber results are grouped separately. With cylindrical chambers, TG51 does show measurably better unification, but only in the low-energy photon beam. The unification (0.6% spread) obtained with TG51 for 13 different make and model of cylindrical chambers is remarkable. For other energies, modalities, and chamber type (cyl or PP); the spreads lay between 1.5% and 3%. The PP chambers with calib in  $\bar{e}$  beam have significantly smaller spread at the low-energy electron beam. The disparity between the median dose determined by the two types of chambers (cyl and PP) varies from ½% to 3%, being worst when the PP chambers with calib in  $\bar{e}$  beam are used for photon calibration (TG-21 only).

# Materials & Methods:

## Chambers:

21 different make and model of ionization chambers were used in these measurements. Both cylindrical (13) and parallel plate (8) chambers were used. The intent was to measure all of the most popular chambers, and a number of recently designed chambers. The chambers are listed in

**Table 1.** The table also lists important characteristics of the chambers.

**Table 1: Chamber ID and specification**

Chamber ID	Ion chamber		Volume cc	B-up cap	ID mm	Collector Mat'l / Dia [mm]	L / Gap [mm]	Wall / Front window		N <sub>g</sub> / N <sub>x</sub> [cGy/R]	K <sub>ecal</sub>	N <sub>D</sub> [10 <sup>-6</sup> Gy/C]	N <sub>X</sub> [10 <sup>-8</sup> R/C]
	Make	Model						Mat'l	[mm]				
<b>Cylindrical:</b>													
1	NEL	2571	0.6	3.87mm Delrin	6.3	Al / 1.0	22.5	Gr	0.360	0.854	0.903	45.30	46.90
2	PTW	23333	0.6	4.60 mm Acr	6.1	Al / 1.0	21.9	Acr/Gr	0.335/0.089	0.849	0.897	53.14	55.07
3	PTW	30001	0.6	4.60 mm Acr	6.1	Al / 1.1	23.0	Acr/Gr	0.335/0.090	0.849	0.897	52.77	54.86
4	PTW	30013	0.6	4.55 mm Acr	6.1	Al / 1.1	23.0	Acr/Gr	0.335/0.090	0.849	0.897	53.49	55.38
5	PTW	30004	0.6	4.60 mm Acr	6.1	Al / 1.0	23.0	Gr	0.425	0.854	0.906	50.46	52.35
6	PTW: CNMC version	30004.2	0.2	4.60 mm Acr	6.1	Al / 1.0	8.0	Gr	0.425	0.851	0.906	187.6	194.4
7	PTW	233641	0.3	3.00 mm Acr	5.5	Al / 1.5	16.3	Acr/Gr	0.750	0.850	0.898	97.42	100.6
8	Capintec	PR-06C	0.65	5.16 mm Polyst	6.4	C552 <sup>†</sup> / 1.6	23.0	C552 <sup>†</sup>	0.280	0.851	0.900	47.29	49.02
9	Capintec	PR-06G	0.65	5.16 mm Polyst	6.4	C552 <sup>†</sup> / 1.6	23.0	C552 <sup>†</sup>	0.280	0.851	0.900	50.15	52.17
10	Exr / Std.Im	A-12	0.65	2.80 mm C552 <sup>†</sup>	6.1	C552 <sup>†</sup> / 1.0	24.1	C552 <sup>†</sup>	0.500	0.866	0.906	50.29	51.90
11	Scanditronix/WellHofer	IC-70	0.65	3.90 mm Delrin	6.2	Al / 1.0	23.1	Gr	0.400	0.854	0.903	48.05	49.73
12	Scanditronix/WellHofer	FC65-P	0.65	3.90 mm Delrin	6.2	Al / 1.0	23.1	Delrin	0.400	0.850	0.897	48.66	50.35
13	Scanditronix/WellHofer	FC23-C	0.23	3.90 mm Delrin	6.2	C552 <sup>†</sup> / 1.0	8.8	C552 <sup>†</sup>	0.400	0.856	0.903	144.8	149.6
<b>Parallel Plate:</b>													
14	PTW Markus	*23343	0.06	3.2 mm Acr	5.3	Acr / 5.3	2.0	Polyeth/Gr	0.03	0.8590	0.905	546.7	550.7
15	PTW adv-Markus	*34045	0.02	3.2 mm Acr	5.0	Acr / 5	1.0	Polyeth/Gr	0.03	0.8564	0.896	1406	1412
16	PTW Roos	34001	0.35	3.2 mm Acr	15.6	Acr / 15	2.0	Acry/Gr	1.00	0.8547	0.901	83.02	83.67
17	Exr / Std.Im	P-11	0.62	4.0 mm polyst	20.0	Polyst-eq / 20	2.0	Polyst-eq/Gr	1.00	0.8480	0.888	58.76	58.59
18	Exr / Std.Im	*A-10	0.05	2.81 mm Aeq	5.4	C552 <sup>†</sup> / 5.4	2.0	Kapton/Gr	0.03	0.8699	0.939	605.7	623.9
19	Scanditronix/WellHofer	NACP-02	0.16	2.31 mm Graph	10.0	Rexolite / 10	2.0	Mylar/Gr	0.1/0.5	0.8450	0.885	173.4	172.3
20	Scanditronix/WellHofer	PPC-40	0.40	3.2 mm Acr	16.0	Acr / 16	2.0	Acr/Gr	1.00	0.8547	0.901	91.95	92.41
21	Scanditronix/WellHofer	PPC-05	0.05	2.04 mm Aeq	9.9	C552 <sup>†</sup> / 9.9	0.6	C552 <sup>†</sup>	1.00	0.8734	0.896	585.6	593.7

\* Have water-protective caps of acrylic thicknesses 0.85, 0.87 and 1.00 mm for PTW N23343, N34045, and Exradin A-10 respectively.

† Active volume's length for cylindricals, and gap for PPs.

‡ Air equivalent conducting plastic.

NOTE: There is an inconsistency between Chambers 16 and 20. Chamber 20 has both a larger volume and a larger N<sub>D</sub> and N<sub>X</sub> than Chamber 16.

Note: There is an inconsistency between chambers 16 and 20. Chamber 20 has both a larger volume and a larger N<sub>X</sub> and N<sub>D,w</sub>.

## Chamber Calibration:

All chambers were calibrated at the MD Anderson Cancer Center ADCL during the period over which these measurements were made. Both  $N_X$  for TG-21 and  $N_{D,w}$  for Tg-51 were assigned. The PP chambers were also calibrated by comparison with an NEL Model 2571 Farmer chamber in the 16 MeV electron beam during the actual data taking (calib in  $e^-$  beam).

## Electrometers:

Keithley Model 617 electrometers and a Keithley model 602 electrometer interfaced to a Fluke digital voltmeter were used. A software package was written to capture the electrometer readings, store and process the data. The electrometer was zeroed, start reading recorded, the accelerator run for typically 50 mu and the final accumulated charge recorded.

## Therapy Unit:

A Varian Clinac 2100CD at M.D. Anderson Cancer Center (MDACC) was employed. A nominal dose rate of 400 mu/min was used for each of 4 beams; 6 and 18 MV photons, and 6 and 16 MeV electrons. **Table 2** lists important characteristics of the four therapy beams.

**Table 2: Beam characteristics**

Beam	TMR <sub>20/10</sub> or $I_{50} / R_P$ [cm]	%dd(10) <sub>X</sub> or $R_{50}$ [cm]	Calibration depth* [cm]		fdd	
			TG21	TG51	TG21	TG51
Photons (6 MV)	0.674	66.3	5	10	0.868	0.663
Photons (18 MV)	0.785	81.4	7	10	0.920	0.806
Electrons (6 MeV)	2.6 / 3.4	2.6	1.45	$d_{ref} = 1.45$	0.999	1.000
Electrons (16 MeV)	6.4 / 8.0	6.5	3.80	$d_{ref} = 3.80$	0.994	0.992

\* axis of cylindrical, or inner surface of entrance window of parallel-plate chamber.

## **Monitors:**

At least one and usually two external ion chamber monitors were used to normalize the data. For photons, the monitors were located at 20 cm depth while for electrons they were located at 1.4 cm depth, near maximum ionization for both 6 and 16 MeV beams. For measurement of  $P_{ion}$  and  $P_{pol}$ , the monitor chamber was located at the same depth as the test chamber. The use of external monitor chambers reduced uncertainty due to machine fluctuations by a factor of 5 to 10, depending on the beam. All measurements were made in a 30cm x 30cm x 30cm water phantom using a horizontal beam, at 100 cm SSD. A field size of 15 cm x 15 cm provided sufficient margins for the monitors from the field edges for all beams. For additional redundancy, the first chamber (an NEL-2571 or Exradin A-12), measured at the start of the session, was re-measured at the end of the session. The difference never exceeded 0.2 %.

## **Depth measurement:**

Through the use of a pin-hole light source and scribe marks on the phantom, a precision micrometer drive and precision pointers, we believe that we achieved a reproducible depth determination from chamber to chamber of  $\cong 0.2\text{mm}$ .

## **Depth dose, beam quality, $P_{ion}$ and $P_{pol}$ :**

“Clinical” depth dose, and beam-quality specifiers [TMR<sub>20/10</sub>, %dd(10)<sub>x</sub>, and  $I_{50}$ ] were measured one time on each beam using a Farmer chamber for photons and a Farmer, and two parallel plate chambers for electrons. For  $P_{ion}$  and  $P_{pol}$ , an independent set of measurements was performed in a plastic phantom.

## **Measurement depth:**

For photons, TG-51 measurements were made at 10.0 cm depth, and for TG-21 were made at 5 and 7 cm depth for the 6 and 18 MV beams, respectively. For electrons, measurements for both protocols were made at  $d_{ref}$ .  $P_{ion}$  and  $P_{pol}$  measurements were made at 8 cm depth for photons and at  $d_{ref}$  for electrons.

## **NOTE:**

We considered TG-51 and TG-21 to be separate experiments. Our effort was to assure consistent results within a given protocol. In our evaluation we will not focus on the relative output indicated for TG-51 versus that for TG-21.

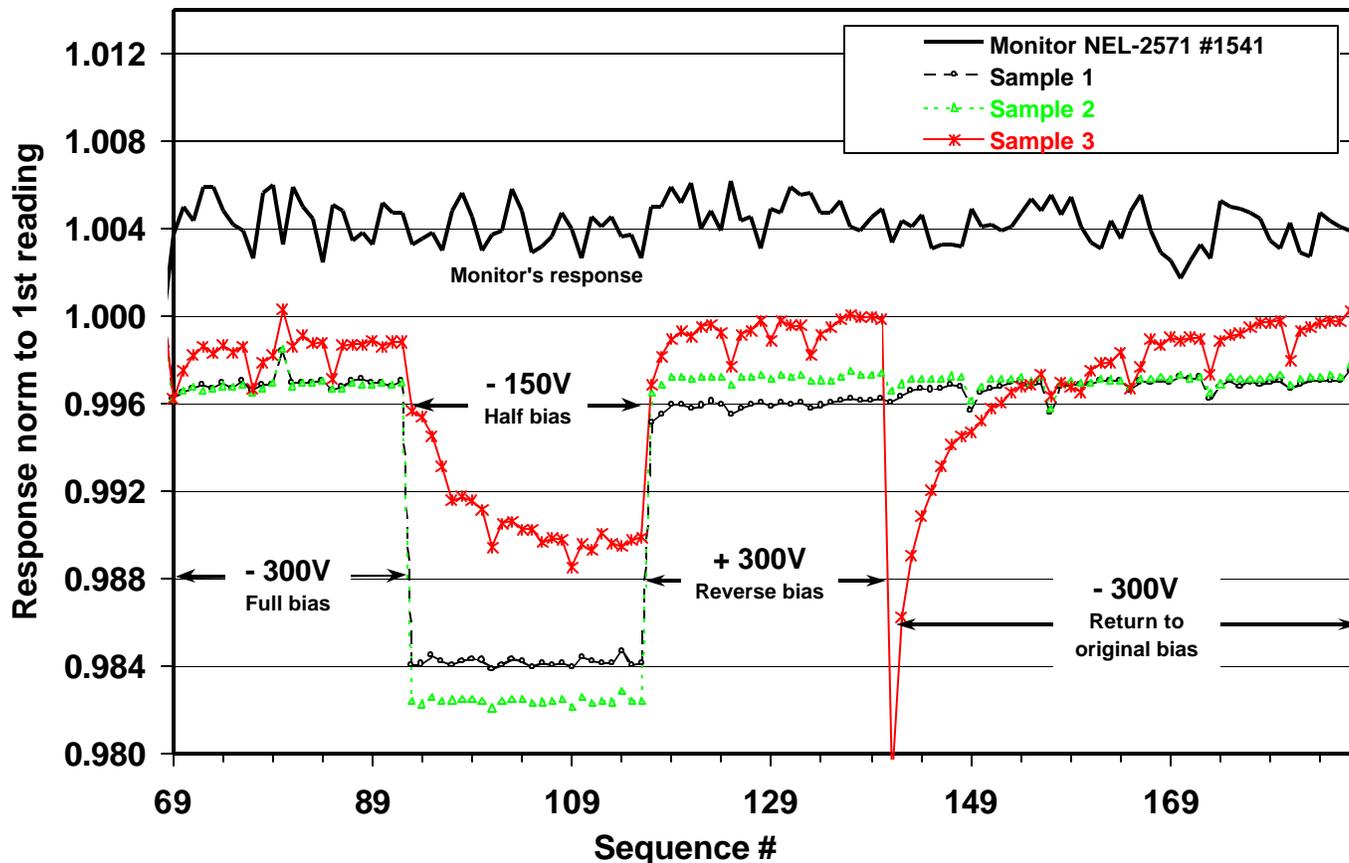
# **Results and Discussion:**

**Figure 1** illustrates typical data capture techniques. This figure shows data for determining  $P_{ion}$  and  $P_{pol}$  for 3 unidentified Farmer type chambers. Each point indicates the results of a 50 mu exposure. The quantity plotted is  $\Delta Q$ , normalized by the external monitor  $\Delta Q'$  (the black data in the figure), and normalized to unity for the first reading for that chamber. The therapy unit was cycled as rapidly as possible, until one electrometer neared saturation. After the ionization data were found satisfactorily stable, the set-up was changed for the next chamber. A few comments are worth mentioning:

- Our criteria for stability were non-trending data with a total spread of  $< 0.1\%$ . However, the measured data show substantially tighter results ( $\sim \leq 0.02\%$ ). We learned that the small spikes occurred if we failed to cycle the beam rapidly enough.

- Two of these chambers stabilized very quickly while one chamber took unusually long (~30 repeats of 50 mu) to stabilize. The plot shows behavior typical of the best and the worst behaving chambers.
- One chamber shows  $P_{ion}$  substantially nearer unity than the other two.
- For  $P_{ion}$  and  $P_{pol}$  measurements, the chambers were brought back to the original bias (-300V on the thimble) to assure that they returned to their original signal.

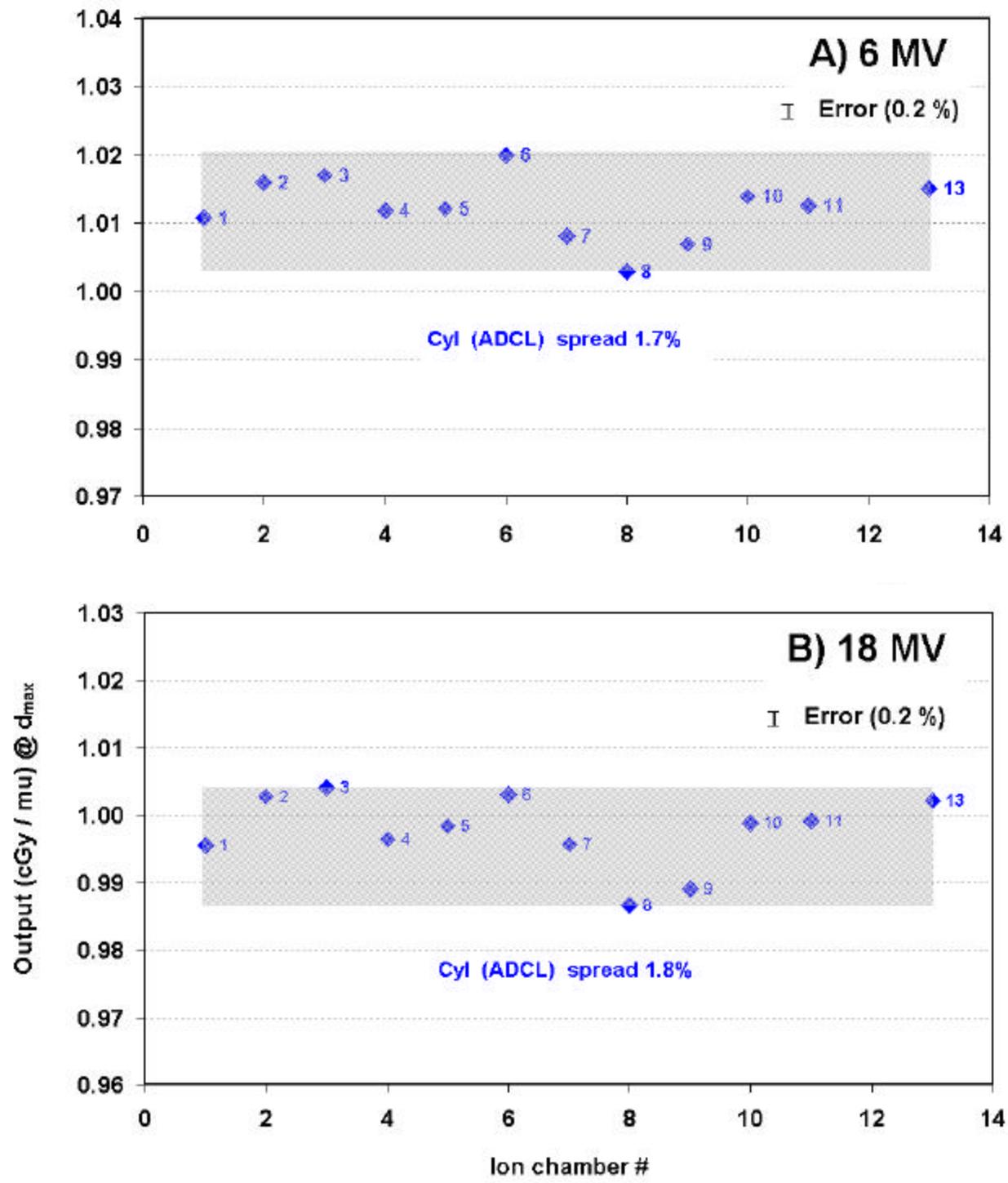
**Figure1: Sample of  $P_{ion}$  and  $P_{pol}$  data**  
16 MeV  $e^-$



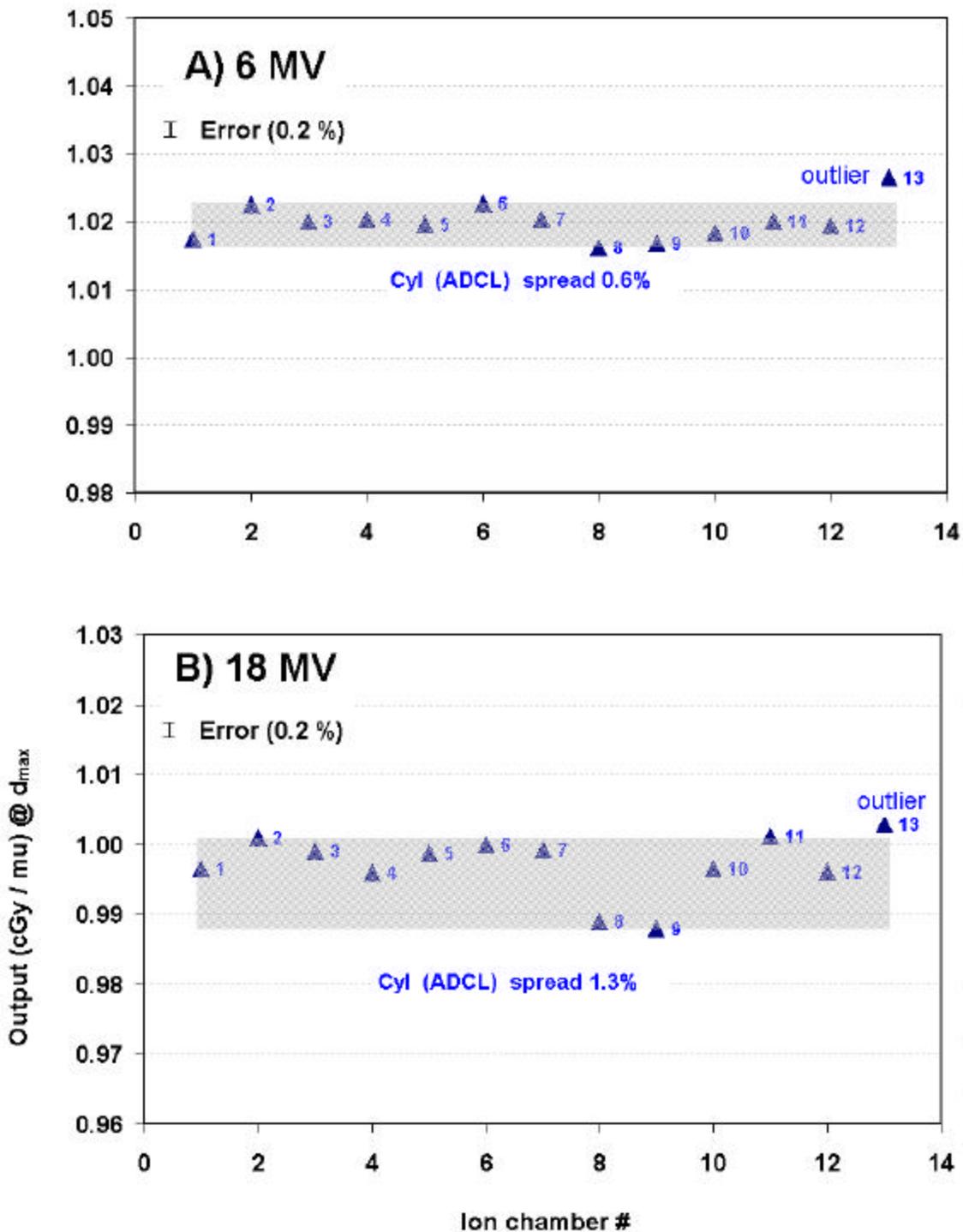
## Photons:

**Figures 2 A and B** show TG-21 output results for 6 and 18 MV photons, respectively with cylindrical chambers. This represents the most commonly used technique for calibration of photon beams. The corresponding TG-51 results are presented in **Figures 3 A and B**. At 6 MV x-rays, agreement of TG-51 results among the 13 cylindrical chambers is strikingly tight (0.6% spread with one outlier at 1%) but TG-21 results have nearly three times the spread (1.7%). At 18 MV, spread among the various cylindrical chambers is similar (~1 1/2 %) for the two protocols, showing only a slight improvement with TG-51.

**Fig 2: Photons TG-21  
cylindrical chambers**



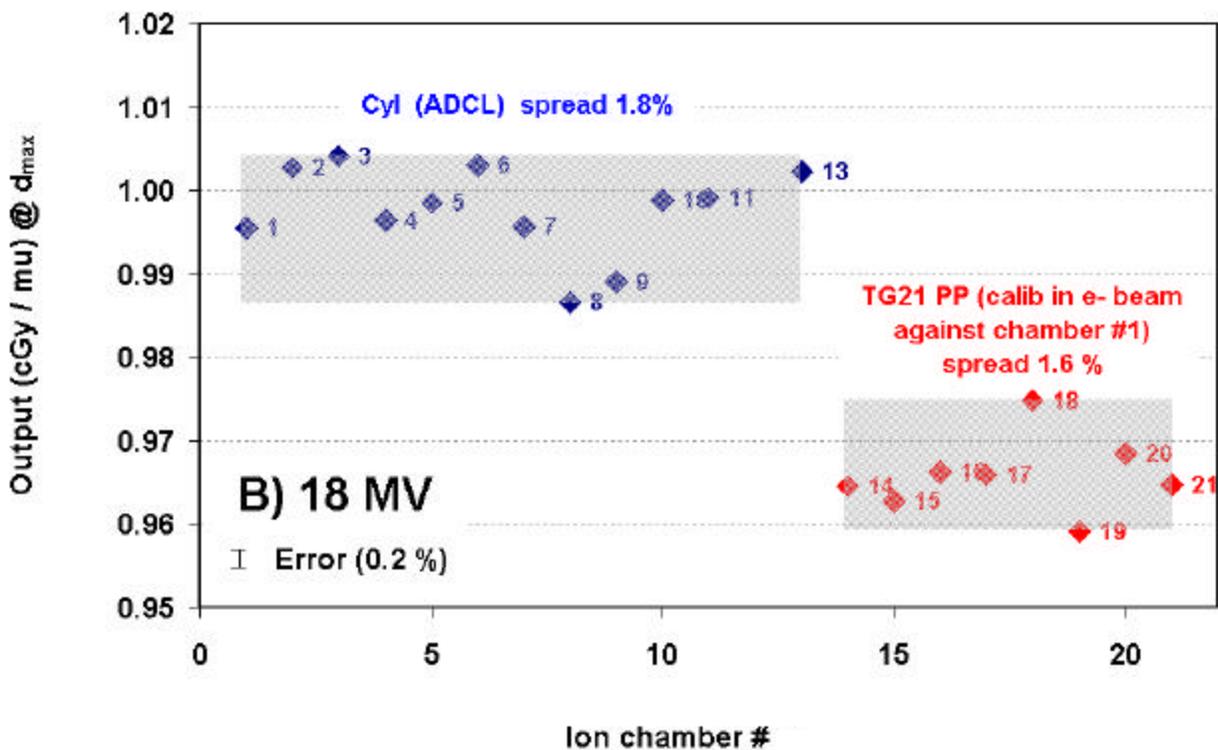
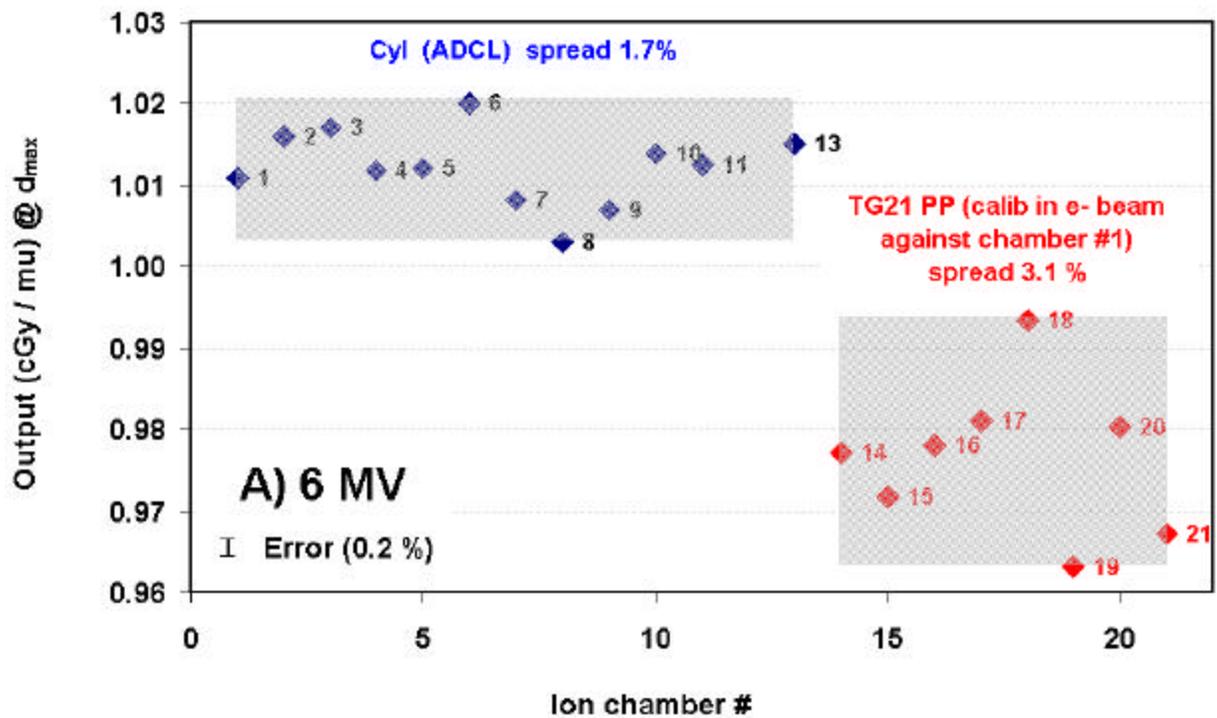
**Fig 3: Photons TG51  
cylindrical chambers**



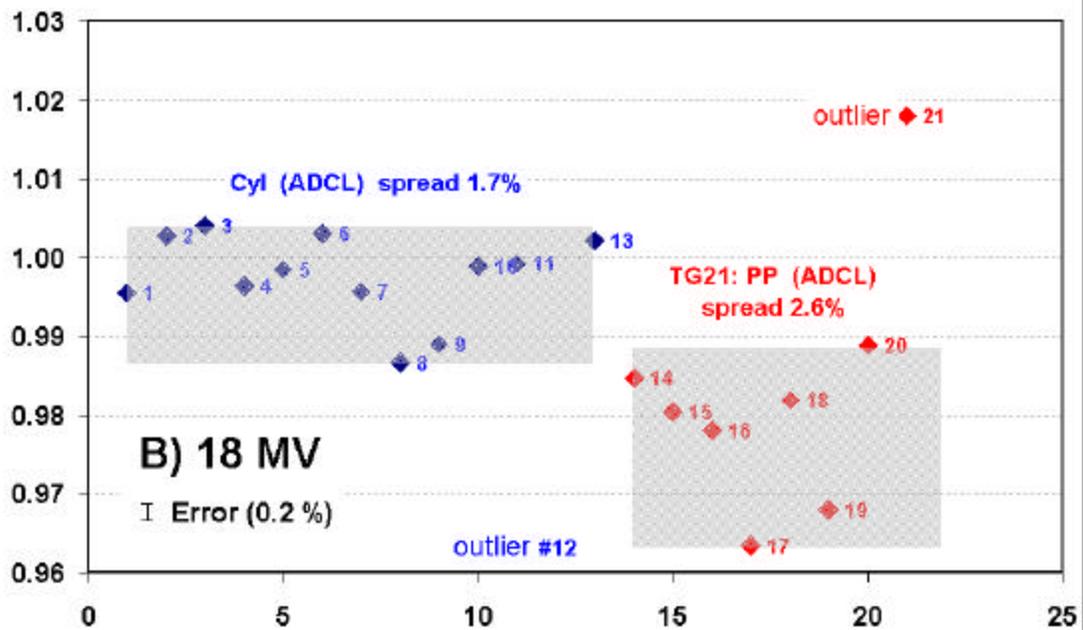
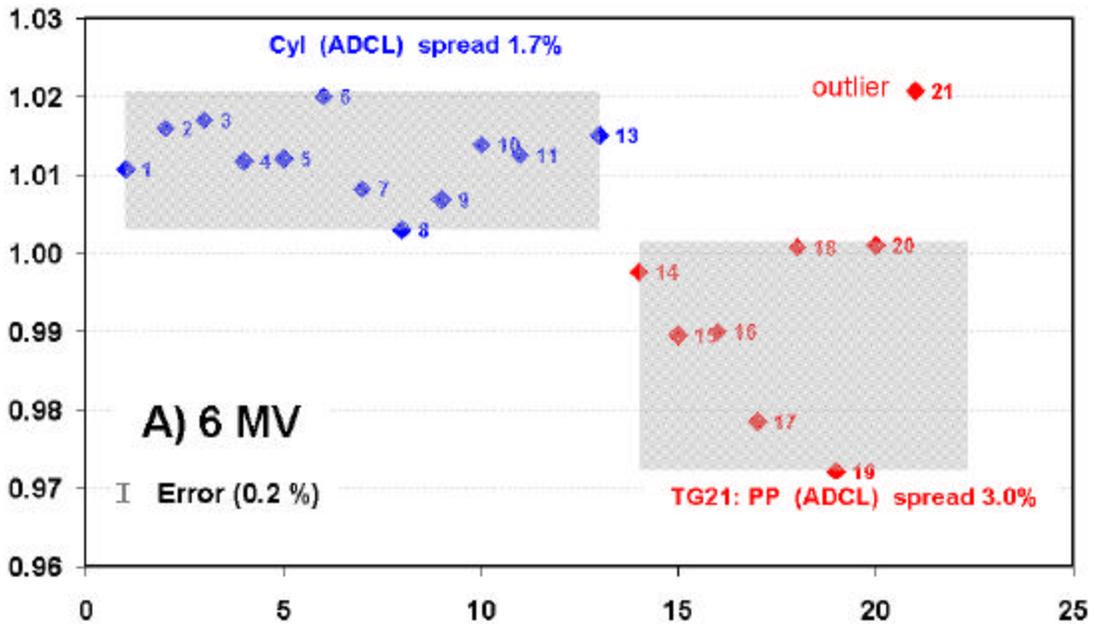
TG-21 allows calibration of photon beams with PP chambers, while TG-51 does not. For use of PP chambers with TG-21, the task group TG-39<sup>3</sup> describes two calibration methods, “ADCL” and “calib in e-beam”. Photon results with PP chambers are presented in Figures 4 and 5. PP chambers employing user’s calibration (calib in e-beam) are presented in **Figures 4 A and B**. The corresponding PP results employing ADCL calibrations are shown in **Figures 5 A and B**. The PP results deserve special comments:

- At both photon energies, in Figures 4 and 5, the average output measured with PP chambers with ADCL calibration is seen to be 2-2.5% lower than the average output determined with cylindrical chambers (TG-21 only). Output measured with PP chambers with “calib in an e<sup>-</sup> beam” is another 1% lower (3-3.5%).
- In figure 4 (calib in e<sup>-</sup> beam) at 18 MV, the spread in the PP chamber data is comparable to that for cylindrical chambers (~1.5%) while at 6 MV the spread among PP chambers (3.1%) is twice that for cylindrical chambers (1.7%). If chamber 16 is considered an outlier, the two are comparable..
- In figure 5 (ADCL) at both energies, the spread is larger for the PP chambers.

**Fig 4: Photons TG21**  
Cyl (ADCL) and PP (calib in e<sup>-</sup> beam)



**Fig 5: Photons TG-21**  
Cyl (ADCL) and PP (ADCL)

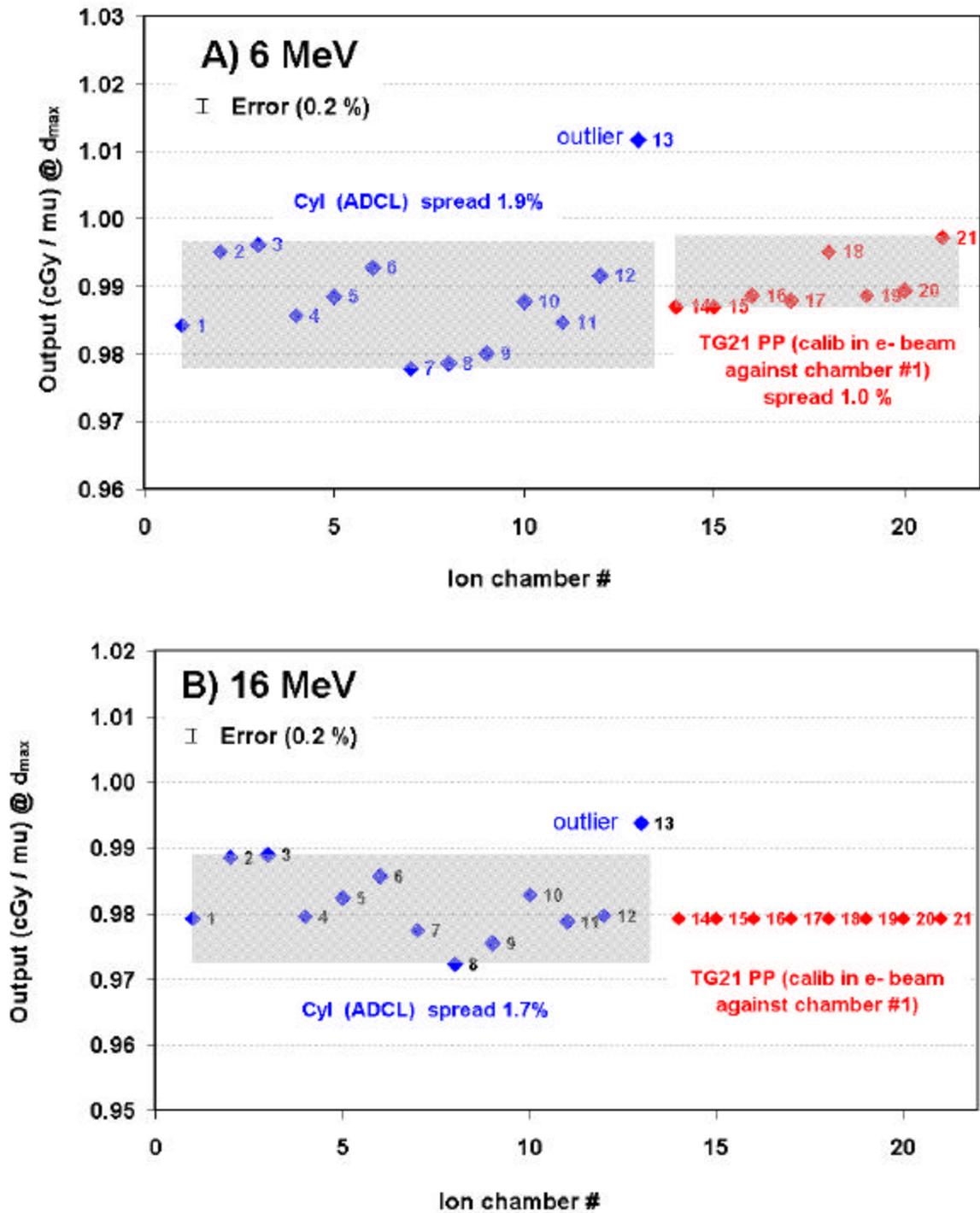


## Electrons:

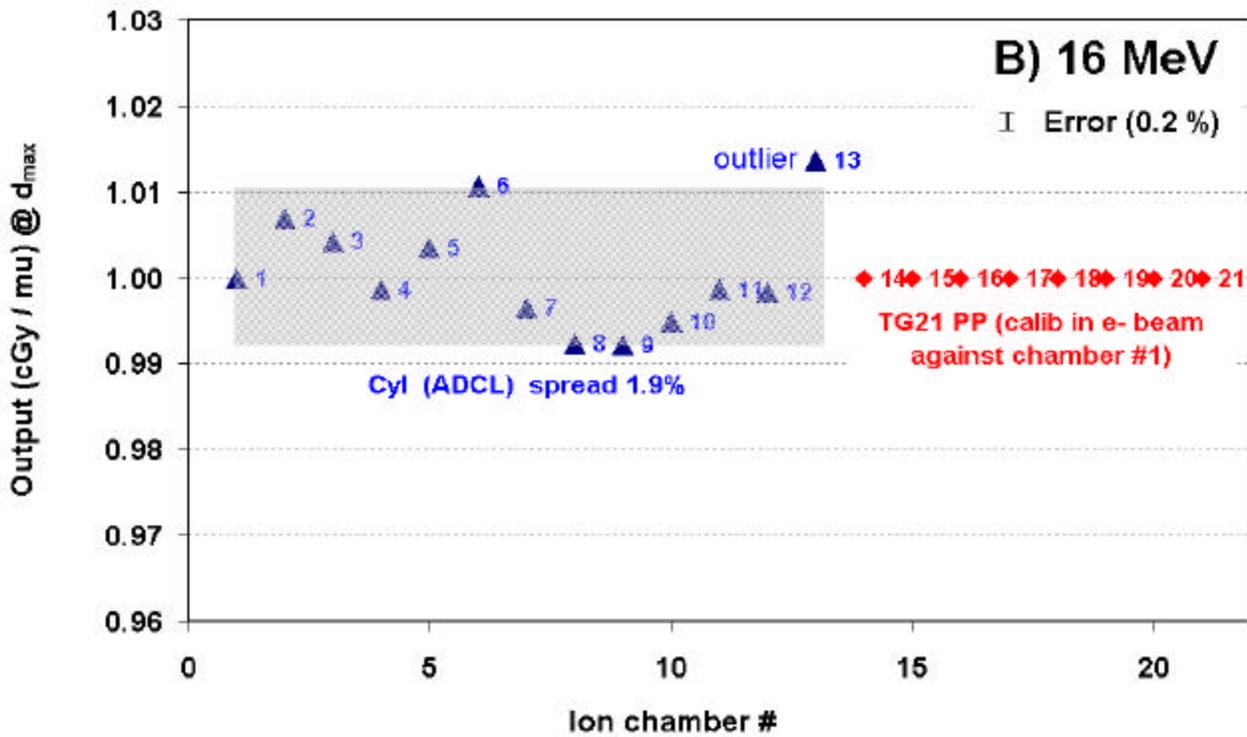
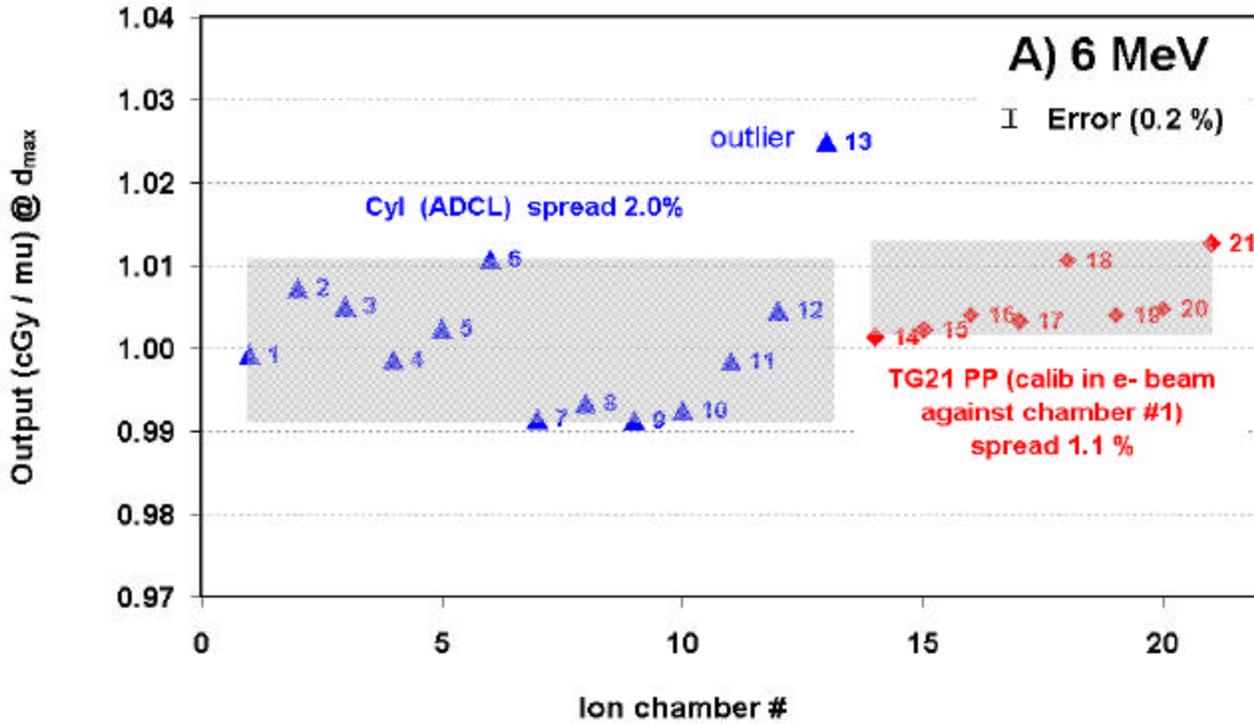
The relative dose at  $d_{\max}$  for 6 MeV electron beams determined using TG-21 for PP chambers using “calib in  $e^-$  beam” are presented in **Figures 6A and B**, respectively. The corresponding TG-51 results are shown in **Figures 7 A and B**. The results for cylindrical chambers with ADCL calibrations are included in all figures. Pertinent observations include:

- Since calibration in an  $e^-$  beam was performed against chamber #1 in the 16 MeV beam, the PP results at 16 MeV for either protocol agree, by definition, exactly with chamber #1.
- At 6 MeV the spread for PP chambers is about 1% for both protocols. Chambers 18 and 21 are notably outliers for both protocols. Both of these chambers are constructed of air equivalent conducting plastic (C552).
- To fully appreciate the total spread of the expected output with PP chambers, we must consider that these chambers could have been compared with any of the cylindrical chambers, and therefore the spread in the PP chambers at 6 MeV must be compounded with the spread in the cyl chamber data at 16 MeV.
- For both protocols, on average, the dose determined with cyl chambers at 6 MeV is about ½% lower than that with PP chambers. This is not inconsistent with the steepness of the peak at 6 MeV and the diameter of these chambers.
- The cylindrical chambers have a spread of ~2% for both protocols and beam energies.
- Cylindrical chamber #13 appears to be an outlier for both energies and both protocols. It is constructed of air equivalent plastic (C552), but so are chambers 8, 9, and 10.

**Fig 6: Electrons TG21**  
**Cyl (ADCL) and PP (calib in e-beam)**



**Fig 7: Electrons TG51**  
**Cyl (ADCL) and PP (calib in e- beam)**





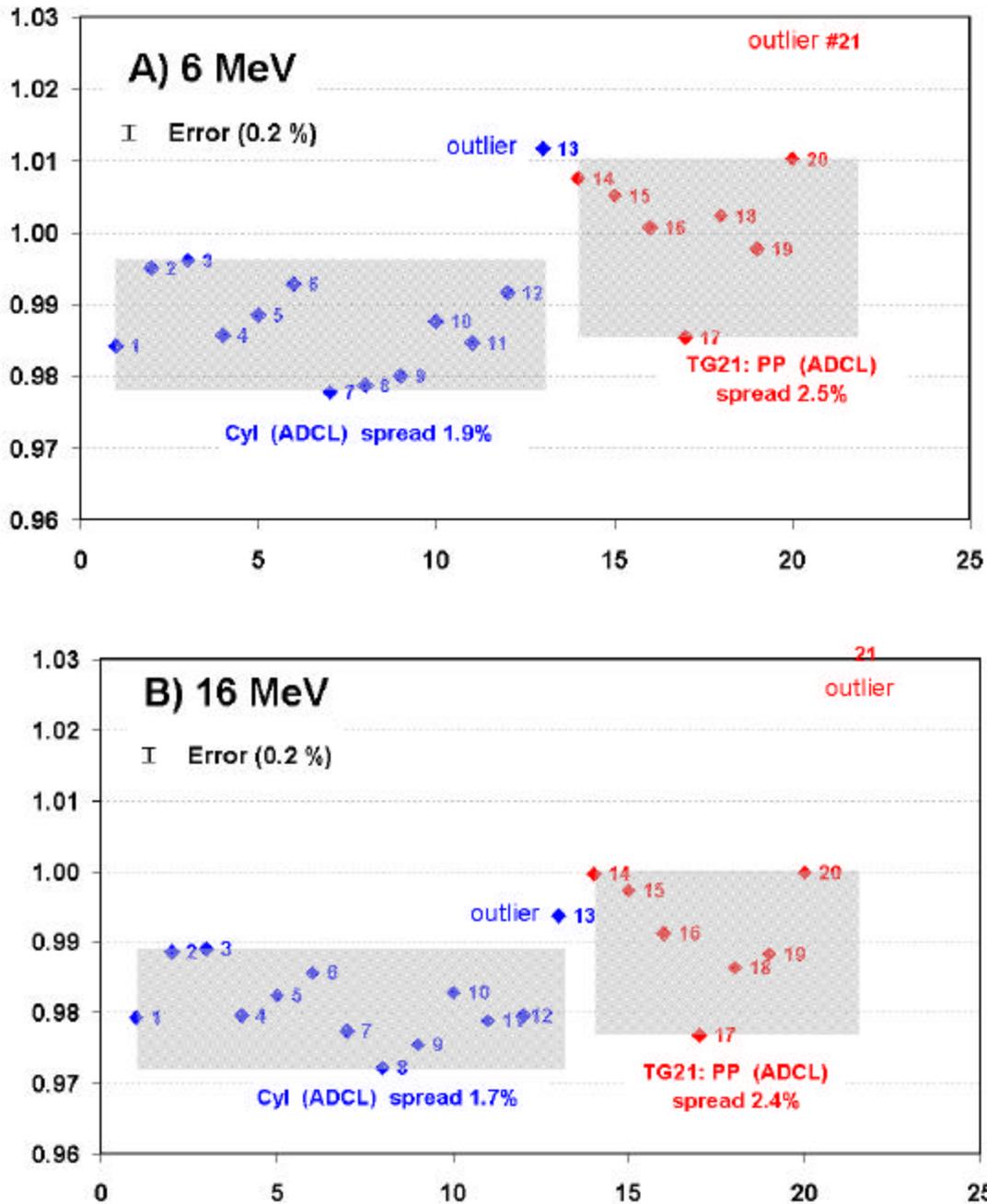
The TG-21 results for the 6 and 16 MeV electron beams for PP chambers using ADCL calibrations are presented in **Figures 8 A and B**, respectively. The corresponding TG-51 results are shown in **Figures 9 A and B**. The results for cylindrical chambers with ADCL calibrations are again included in all figures. Pertinent observations include:

- With ADCL calibration, PP results at both energies with either protocol show, on average, 1-1½ % higher output than that obtained with cylindrical chambers.

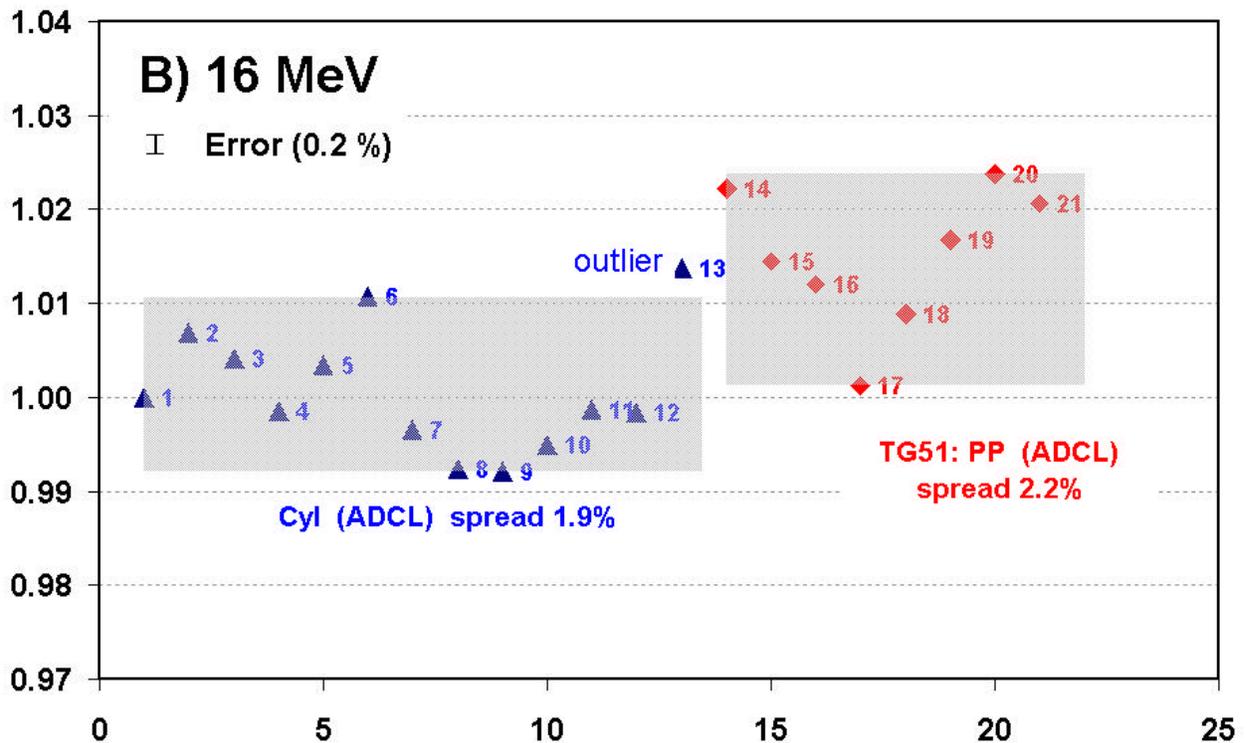
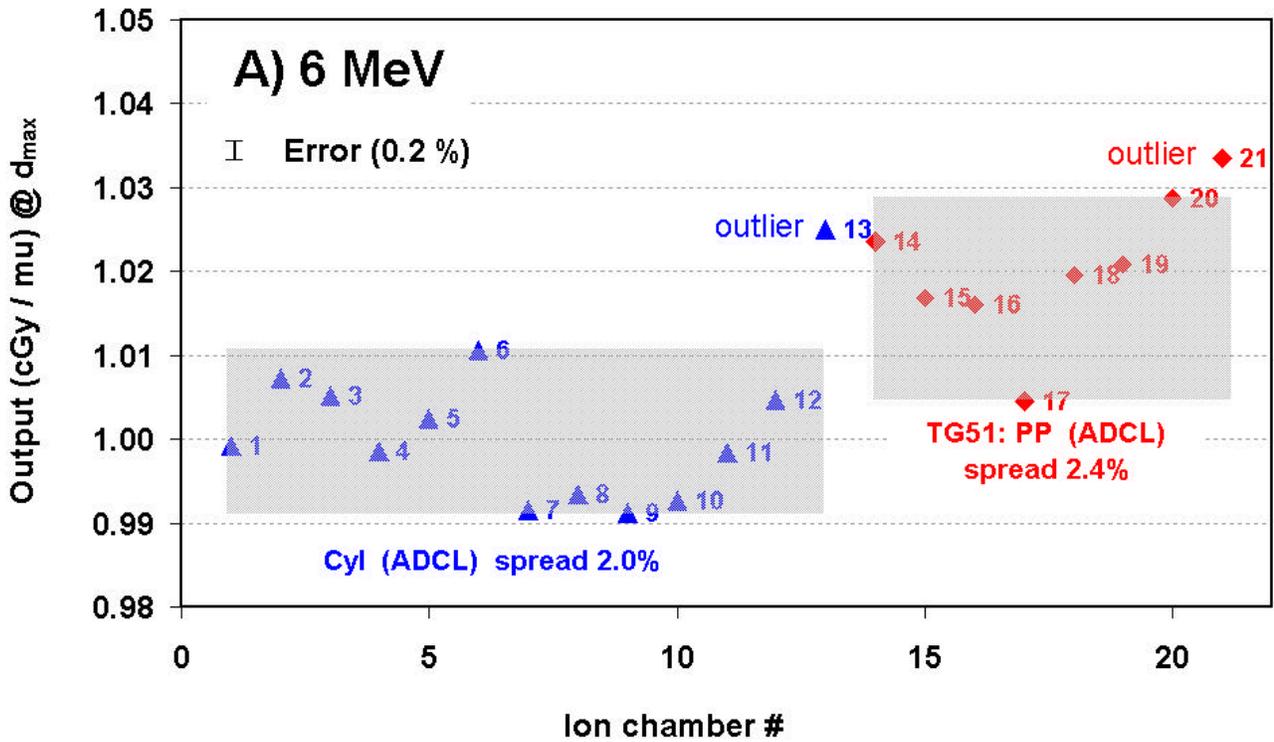
In both figures the spread in the data is ~ 2% for cylindrical chambers and ~ ½% higher for PP chambers except for 16 MeV using TG-21.

**Fig 8: Electrons TG21**  
**Cyl (ADCL) and PP (ADCL)**

21



**Fig 9: Electrons TG51**  
Cyl (ADCL) and PP (ADCL)



The process of “calib in  $e^-$  beam” determines the chamber calibration coefficient  $N_{gas}$  for TG-21 and the product  $N_{D,w} \cdot k_{ecal}$  for TG-51. For the process “ADCL”  $N_{gas}$  is determined by the product of  $N_X \cdot (N_{gas}/N_X)$  where  $N_X$  is obtained from an ADCL and  $N_{gas}/N_X$  is calculated from the equation in TG-21 or obtained from Gastorf et.al<sup>4</sup> or from TG-39<sup>3</sup>. For TG-51,  $N_{D,w}$  is obtained from an ADCL and  $k_{ecal}$  is obtained from the protocol. **Table 3** lists the values of  $N_{gas}$  and  $N_{D,w} \cdot k_{ecal}$  determined by “ADCL” and “calib in  $e^-$  beam” for the 8 parallel-plate chambers used in this study. The ratio of the two is also listed and represents the disparity between output determined by the two methods for individual chambers. The ratios vary from 0.997 – 1.024 with an apparent outlier at 1.055.

## Table 3:

Ratio, ADCL versus "calib in e- beam" for the determination of  $(N_{D,w} \cdot K_{ecal})$  &  $N_{gas}$  for TG-51 and TG-21 respectively.

Chamber ID	Ion chamber		$N_{D,w} \cdot K_{ecal}$			Ngas		
	Make	Model	ADCL	Calib in $e^-$ beam	ADCL / $e^-$ beam	ADCL	Calib in $e^-$ beam	ADCL / $e^-$ beam
<b>Parallel Plate:</b>								
14	PTW	*23343 Markus	495	484	<b>1.022</b>	473	463	<b>1.021</b>
15	PTW	*34045 adv-Markus	1260	1242	<b>1.014</b>	1209	1187	<b>1.018</b>
16	PTW	34001 Roos	74.8	73.9	<b>1.012</b>	71.5	70.6	<b>1.012</b>
17	Exr / Std.lm	P-11	52.2	52.1	<b>1.001</b>	49.7	49.8	<b>0.997</b>
18	Exr / Std.lm	*A-10	569	564	<b>1.009</b>	543	539	<b>1.007</b>
19	Scanditronix / WellHofer	NACP-02	153.5	150.9	<b>1.017</b>	145.6	144.3	<b>1.009</b>
20	Scanditronix / WellHofer	PPC-40	82.8	80.9	<b>1.024</b>	79.0	77.4	<b>1.021</b>
21	Scanditronix / WellHofer	PPC-05	525	514	<b>1.021</b>	519	491	<b>1.055</b>



## Table 4 summarizes the results.

The spread in the output determined is listed for all combinations of specified beam energy/modality, chamber type (cylindrical or parallel-plate) and calibration protocol (TG-21 or TG-51). The disparity between the parallel plate and cylindrical chambers is indicated as the ratio of the median output determined by the parallel-plate chambers versus the median output determined by the cylindrical chambers.

### Table 4: Summary

Figure #	Modality	Chamber class	PP calib techn	Protocol	Low energy beam		High energy beam	
					spread [%]	<PP>/<cyl>	spread [%]	<PP>/<cyl>
2-A, B	Photons	Cyl*	ADCL	TG-21	1.7	-	1.8	-
3-A, B			"	TG-51	0.6	-	1.5	-
4-A, B		PP*	in e <sup>-</sup> beam	TG-21	3.1	0.968	1.6	0.972
5-A, B			ADCL	TG-21	3.0	0.976	2.6	0.981
6-A, B	Electrons	Cyl*	in e <sup>-</sup> beam	TG-21	1.9	1.006	1.7	-
7-A, B		"	"	TG-51	2.0	1.006	1.9	-
8-A, B		"	ADCL	TG-21	1.9	1.012	1.7	1.006
9-A, B		"	"	TG-51	2.0	1.015	1.9	1.011
6-A, B		PP*	in e <sup>-</sup> beam	TG-21	1.0	see	-	see
7-A, B		"	"	TG-51	0.9	above	-	above
8-A, B		"	ADCL	TG-21	2.5		2.4	
9-A, B		"	"	TG-51	2.4		2.2	

\* Scanditronix's cylindrical: FC23-C (#13), and parallel-plate: PPC-05 (#21) are excluded in the spread analysis.

## Assumptions:

A number of chambers in this study were not in production when TG-21, TG-39, and TG-51 were written, so pertinent data for them was not included in the protocols. These pertinent data include  $N_{\text{gas}}/N_x$  for TG-21, and  $k_{\text{ecal}}$  and  $k_Q$  for TG-51. It was necessary for us to make some assumptions about the following chambers:

- #3-6 (PTW chambers with the new numbering system): We assumed that they were in fact equivalent to the chamber that PTW identifies as equivalent which is included in the protocols.
- #11 (cylindrical IC-70): This chamber has dimensions and materials very similar to the NEL 2571. We used those values.
  - #12 (cylindrical chamber FC 65-P): Both thimble and build-up cap are constructed of Delrin. However,  $L/\rho$  and  $\mu_{\text{en}}/\rho$  data for Delrin are not available in AAPM documentation, they are available only for a  $^{60}\text{Co}$  primary beam in Gastorf et.al.<sup>4</sup>.
    - We did not attempt to calculate  $P_{\text{wall}}$  and hence no photon TG-21 data are presented.
    - Since our calculated  $N_{\text{gas}}/N_x$ , using  $L/\rho$  and  $\mu_{\text{en}}/\rho$  from Gastorf et.al.<sup>4</sup>, for this chamber, is very close to that for chamber #3 (N30001), we used  $k_{\text{ecal}}$  and  $k_Q$  data for the later.
  - #13 (cylindrical FC23-C): This chamber has a C552 wall of thickness between that of chambers 9 & 10 (PR-06G and A12). Therefore,  $K_{\text{ecal}}$  was set equal to the average for chambers 9 & 10.
  - #15 (PP N34045 “adv markus”): Its  $k_{\text{ecal}}$  was taken from Rogers<sup>5</sup>.
  - #18 (PP A-10): For this presentation, the chamber was calibrated with a C552 buildup plate and  $N_{\text{gas}}/N_x$  calculated, using Schultz et.al.<sup>6</sup>, for a C552 wall. The chamber was also calibrated with a PMMA buildup plate, and  $N_{\text{gas}}/N_x$  calculated assuming all PMMA. The product ( $N_{\text{gas}}/N_x \cdot N_x$ ) for the two cases was dramatically different (>4%).
- #19 (PP NACP-02):
  - Its  $k_{\text{ecal}}$  was taken from Rogers<sup>5</sup>.
  - The body of this chamber is Rexolite (polystyrene like material) while the front window is thin mylar with 0.5mm graphite. We calibrated the chamber with both, a graphite and a polystyrene buildup slab and calculated  $N_{\text{gas}}/N_x$  for both conditions. The product ( $N_{\text{gas}}/N_x \cdot N_x$ ) for the two cases differed by 0.5%. We used the product for graphite. However, use of an  $N_{\text{gas}}/N_x$  value from TG-39 yielded a product 2% different.

## Source for $N_{\text{gas}}/N_x$ values:

Values of  $N_{\text{gas}}/N_x$  were taken from Gastorf et.al.<sup>4</sup> for cylindrical chambers and from TG-39<sup>3</sup> for PP chambers, if possible. The remainder were calculated using Schultz et.al.<sup>6</sup>.

## Unusual findings:

- $P_{\text{pol}}$  for one PP chamber # 18 was unusually high for electrons (2.3% for 6 MeV and 1.8% for 16 MeV). Other PP chambers showed no more than 0.9% correction.
- Several chambers took unusually long times to stabilize, particularly during measurements of  $P_{\text{ion}}$  and  $P_{\text{pol}}$ . The worst chamber drifted as much as 1% until settling.

# Postscript:

The RPC has carried chambers #1, 2, & 3, & recently #10, all of which are in the center of the distribution. One of the authors (WH) has always claimed that someone special looks after him.

# Conclusions:

## General conclusions :

- The results of this study quantify very nicely the combined uncertainty of certain aspects of our knowledge of radiation dosimetry physics; particularly as it pertains to our understanding of the influence of the physical components of ion chambers on Bragg-Gray cavity theory.
  - At this time the spreads among ion chambers are approximately the same for both TG-51 and TG-21 except for low energy photons where the spread for TG-51 (cylindrical chambers only) is approximately one third that for TG-21.
  - Parallel-plate chambers are less well understood than cylindrical chambers.
  - TG-51 improves dosimetry in a subtle way by disallowing PP chambers for photons and recommending “calib in e<sup>-</sup> beam” for PP chambers for electron reference dosimetry.
- The low energy photon beam (6MV) measured with cylindrical chambers is the only beam where TG-51 showed a significant improvement over TG-21 in the spread of the determined beam output.
- In all other cases, the cylindrical chamber spread was comparable for TG-21 and TG-51 (1½ - 2%).
- PP chambers had a larger spread than cyl chambers in all cases except for electron beams when PP chambers were calibrated in an electron beam.

## PP chambers :

- Electrons:
  - When “calib in e<sup>-</sup> beam” is used:
    - Calibration with all of the PP chambers shows a clear correlation at the lower energy electron beam (6 MeV) with the cylindrical chamber with which they were compared. This is true for both protocols.
    - The cyl chamber distribution is ~0.5% lower than PP distribution at 6 MeV for both protocols.
  - When ADCL calibration is used:
    - The scatter in the PP data is slightly larger than the cyl data for both energies and both protocols, with several notable outliers.
    - The cyl distribution is systematically 1 – 1½% lower than the PP distribution in all cases.
- Photons for TG-21 only:
  - The PP distribution is significantly shifted (lower) than the cyl distribution
    - 2% for ADCL calibration,
    - >3% when calib in e<sup>-</sup> beam is used.

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## References:

1. Task Group 51, Radiation Therapy Committee, American Association of Physicists in Medicine: "Protocol for clinical reference dosimetry of high-energy photon and electron beams", *Med. Phys.* **26**: 1847-1870 (1999)
2. Task Group 21, Radiation Therapy Committee, American Association of Physicists in Medicine. "A Protocol for the Determination of Absorbed Dose from High-energy Photon and Electron Beams", *Med. Phys.* **10**:741-771 (1983).
3. Task Group 39, "The calibration and use of plane-parallel ionization chambers for dosimetry of electron beams: An extension of the 1983 AAPM protocol report of AAPM Radiation Therapy Committee Task Group No. 39", *Med. Phys.* **21**:1251-1260 (1994).
4. "Cylindrical chamber dimensions and other data values", R. Gastorf, L. Humphries, and M. Rosenthal, *Med. Phys.* **13**:751-754 (1986).
5. "Calculations for plane-parallel ion chambers in  $^{60}\text{Co}$  beams using the EGSnrc Monte Carlo code", E. Mainegra-Hinz, I. Kawrakow, and D.W. O. Rogers, *Med. Phys.* **30**:179-189 (2003).
6. "Calculated response and wall correction factors for ionization chambers exposed to  $^{60}\text{Co}$  gamma-rays", Ravinder Nath and R. J. Schulz, *Med. Phys.* **8**:85-93 (1981).