ELECTRON CALIBRATIONS: PARRALLEL PLATE CHAMBERS VS. CYLINDRICAL CHAMBERS

P. Balter, J.R. Lowenstein, and W.F. Hanson
Department of Radiation Physics
Section of Outreach Physics
U.T. M.D. Anderson Cancer Center
Houston, TX

THE UNIVERSITY OF TEXAS
MD ANDERSON
CANCER CENTER

THIS INVESTIGATION WAS SUPPORTED BY PHS GRANT CA10953 AWARDED BY THE NCI, DHHS.

ABSTRACT

The publication of TG-51 has reawakened the debate over to need the use parallel plate chambers for low energy electron calibrations. TG-51 recommends parallel plate chambers for beam energies below 10 MeV and requires them for 6 MeV or less. We have done comparisons between dose rates at d_{ref} as determined with a graphite farmer chamber and that determined by several common parallel plate chambers. We did this in electron beams ranging in energy from 5 to 20 MeV. We found no significant energy dependence over these energies. We also examined the differences in absolute dose determined using an ADCL calibration combined with the published k_{ecal} factor (TG-51 Method B) with that determined by acquiring $k_{ecal}N_{D,w}$ from cross comparison with a cylindrical chamber in a high energy electron beam (TG-51 Method A) and using this value for other energies. We found the differences in determined dose which range from 0.1% to 2.5%, depending on the model of parallel plate chamber and the beam energy used. The results of this work suggest a parallel plate chamber is not necessary for electron beam calibrations over an energy range of 5 – 20 MeV. Our data also suggests that determining $k_{ecal}N_{D,w}$ using Method A results in more consistent electron beam calibrations across all type of equipment than does Method B. The establishment of an absolute dose standard for electrons would reduce the uncertainty and/or equipment dependence on electron beam calibrations.

BACKGROUND

Choice of Chambers for Reference Dosimetry of electron beams

TG-21: References the NACP protocol (1981) and states that “plane-parallel chambers are preferred for electron beam dosimetry in the range of 5-10 MeV.” This is justified by the statement that “for low-energy electron beams they [replacement corrections] can be as large as 4% for Farmer-type chambers and can exceed 5% for chambers with internal diameters greater than 7 mm.” and “Because the uncertainty in the determination of any physical parameter is reduced as the magnitudes of correction factors are reduced, plane-parallel chambers are preferable to cylindrical chambers when used in the same dosimetry phantom.”

TG-51: “For electron beams with R_{50} <4.3 cm (incident energies of 10 MeV or less), well-guarded plane-parallel chambers are preferred and they may be used at higher energies. Plane-parallel chambers must be used for beams with R_{50} <2.6 cm (incident energies of 6 MeV or less).”

Determination of a Parallel Plate Chamber's Response to a Reference Beam

TG-21: Suggests that N_{gas} for a parallel plate chamber can be determined either from the product of a published N_{gas}/N_x ratio with an ADCL supplied N_x, or by cross calibration in a high energy electron beam.

TG-39: Clarifies the "chain of tracablity" for N_{gas} determined by cross calibration performed by an end user rather than a secondary standards laboratory. This report publishes a set of N_{gas}/N_x ratios for common chambers but suggests that cross calibration with a traceable cylindrical chamber in a high energy electron beam is the preferred method for determining N_{gas} and is still a "traceable" calibration.

TG-51: References work by Kosumen and states that "the ^{60}Co calibration factors of at least some plane-parallel chambers appear to be very sensitive to small features of their construction." This is used as a justification for recommendation that the product $k_{ecal}N_{D,w}$ should be determined by cross calibration with a cylindrical chamber in a high energy electron beam(Method A) rather than determined by the taking the product of the supplied

k_{ecal} value with an ADCL supplied $N_{D,w}$ value (Method B), although both methods are acceptable.

MATERIALS AND METHODS

Ion Chambers: (Physical Characteristics Summarized in Table 1)

- NEL2571 (Dose Standard for this Work)

  The NEL 2571(Nuclear enterprises, England) is a graphite walled 0.6 cc farmer type ionization chamber with an aluminum central electrode. This chamber was chosen as our comparison standard since it is a common chamber with a reputation for stability. In addition its simple graphite/Aluminum construction does not posses the uncertainties in composition present in plastic chambers. This chamber is not waterproof and PMMA water proofing, 1 mm thick over the active volume, was used throughout this work.

- PTW 34001 (Roos)

  The PTW 34001 chamber is a well-guarded waterproof polystyrene Parallel Plate chamber with a 2 mm plate separation, 1 mm entrance and exit windows.

- Welhoffer PC40 (Roos Type)

  The Welhoffer PC40 chamber is a well-guarded waterproof polystyrene Parallel Plate chamber with a 2 mm plate separation, 1 mm entrance and exit windows.

- Exradin P11

  The Exradin P11 is a well-guarded waterproof polystyrene Parallel Plate chamber with a 2 mm plate separation and a 1 mm entrance window, in contrast to the Roos Type chambers this chamber has a substantial exit wall (14 mm of polystyrene).

- PTW 23343 (Marcus)

  The PTW Marcus chamber is one of the most common parallel plate therapy chambers in the US. This is not a well-guarded chamber and has a replacement correction different from unity. This chamber has a thin mylar entrance window and a substantial PMMA body. Throughout this work this chamber was used with the manufacturer supplied 1 mm thick PMMA waterproofing.

Linear Accelerators:

- Varian Clinac 2100C:

  Kylstron powered linear accelerator with photon energies of 6 and 18 MeV and electron energies of 6, 9, 12, 16, and 20 MeV. Max rep rate in electron mode of 400 MU/min
- Varian Clinac 2100C/D:

  Kylstron powered linear accelerator with photon energies of 6 and 18 MeV and electron energies of 6, 9, 12, 16, and 20 MeV. Max rep rate in electron mode of 1000 MU/min

- Siemens Mevatron 6740:

  Magnatron powered linear accelerator with a single 6 MV photon beam and electron energies of 5, 7, 8, 9, and 12 MeV.

Phantoms

- Standard RPC Phantom:

  30 cm x 30 cm x 40 cm water phantom with an automated 1-D scanning mechanism allowing relative adjustment of the chamber depth with a precision superior to 0.5 mm. The accuracy of the depth setup with this phantom is on the order of than 1 mm for both cylindrical and parallel plate chambers. This tank is used with a vertical beam and there is no material between the surface of the water and the electron applicator.

- Electron Cross Comparison Tank:

  30 cm x 30 cm x 30 cm water phantom with a 1/8 inch PMMA thin widow for use with a horizontal beam. This tank was designed for cross comparisons in electron beams and has a system that allows chambers to be positioned with respect to a movable reference line. The precision of chamber set-up to the reference line is superior to 1 mm and the precision of setup to the reference line is also sub millimeter.

TG-51 PARAMETERS

All dose rates in this work were determined using the methods and data in AAPM TG-51 protocol.

- 15 cm x 15 cm field (cone) size defined at the phantom surface for all energies.
- 100 cm SSD.
- Waterproof chambers used bare in water
- Non-waterproof chambers used with 1 mm PMMA waterproofing over the active volume.
- All measurements done in traditional, wet, liquid, not solid, water.
- All measurements done with either no material or a 1/8" PMMA "thin window" between the surface of the phantom and the source.
- Beam energies (R_{50}) were determined using the NEL 2571 only. We looked at the difference in beam energies when determined using the Exradin P11, but found no measurable differences with those values determined using the cylindrical chamber even for low energy beams
- k'_{R50} values were determined for the NEL 2571 using the analytical expression for farmer type chambers. The k'_{R50} values for the PTW 34001 and the Welhoffer PPC40 chambers where

determined from the equation for the well guarded parallel plate chambers and the values for the PTW Marcus chamber where determined from figure 6 of TG-51.

TG-51 REVISITED

Several modifications of the protocol procedures were made to improve precision and/or efficiency.

1. No measurements were made with the center of the cylindrical chamber at d_{ref}.
2. Determinations made in the later part of this work did not include P_{pol} for energies $\geq$ 10 MeV.
3. P_{ion} was only determined once for each combination of chamber, accelerator and energy.

Justification by Numbers:

1. If we examine the dose specification equation in TG-51 on worksheet B: Electron Beams – Cylindrical Chambers (eq 1), and combine this with the definition of P_{gr} (eq 2) and M (eq 3) we see that M_{raw} at d_{ref} numerically cancels out (eq 4). The only introduced violation of the protocol is the difference in P_{pol} and P_{ion} when measured with the center of the chamber at $d_{ref}+0.5r_{cav}$ rather than at d_{ref}. There are no physical reasons to think this is a concern, or that these values should be determined at d_{ref} rather than $d_{ref}+0.5r_{cav}$.
2. For energies $\geq$ 10 MeV we found that the day to day variation in the measurement of P_{pol} was on the same order as P_{pol}. The polarity correction was found to vary as a function of beam energy and chamber type with its values tending towards unity as energy increases. At energies of 10 MeV or higher, for all chambers used in this work, P_{pol} was within measurement precision of unity.
3. The uncertainty in the determination of P_{ion} is on the same order as the correction. We carefully determined this correction factor once for each combination of chamber, energy and accelerator.

We then used these factors in further determinations using these same combinations of chamber and beam, reducing the noise in the data and greatly reducing the time required to acquire the data.

DISCUSSION

Energy Dependence

The initial goal of this work was to examine the relative energy response of cylindrical chambers to parallel plate chambers over a range of electron energies. The data presented in Table 2 suggest there is little if any difference in determined dose rate between a graphite cylindrical chamber and parallel plate chamber. The Exradin P11 can be interpreted to have an energy dependence, but it should be noted that the 5,7, and 8 MeV data which show this trend were all taken on the same day on the same machine after some delay between calibration with the NEL 2571. The 6 MeV point, which consists of the average of 3 determinations taken on different days, is a strong argument against this apparent energy dependence. Likewise the Welhoffer PC40 also shows some energy dependence but at less than the 0.5% level. The PTW 340001 may also be interpreted to have a small amount of energy dependence but at less than the 0.3% level. The PTW Marcus chamber shows no energy dependence. All of these determinations fall within measurement uncertainty of the mean, suggesting that any energy dependence is on the order of measurement uncertainty. The results of this work demonstrates that there will be little additional uncertainty introduced into electron calibrations by performing them with cylindrical chambers even at energies down to 5 MeV (R_{50} = 2.1).

Method A vs. Method B determination of $k_{ecal}N_{D,w}$

A second set of data acquired in this work is a comparison between TG-51's methods A and B for determining the reference electron beam response ($k_{ecal}N_{D,w}$) for Parallel Plate ionization chambers. Table 3 presents four ways of looking at the ratio between $k_{ecal}N_{D,w}$ determined from method A, cross comparison with a cylindrical chamber, and method B, calibration at an ADCL in a ^{60}Co beam. The values in this table can be interpreted as ratios of measured dose or as ratios of $k_{ecal}N_{D,w}$'s (equations 6a, 6b). The first two rows represent an average ratio of the $k_{ecal}N_{D,w}$ ratios across all energies, representing the statistical "best estimate," and the last two rows in the table represent comparisons in two different high energy electron beams, "representing method B explicitly." All four methods of evaluating the "goodness" of the $k_{ecal}N_{D,w}$ value are consistent at the 0.4% level. The maximum difference between the two methods of determining the chamber's dose response was 2.5%. It should be noted that these differences include a 0.7% (2σ) uncertainty in the ADCL's assignment of $N_{D,w}$. Table 4 presents statistics on the reproducibility of ADCL calibrations for the chambers used in this work. The top row of Table 4 represents the reproducibility of the ADCL's standard chamber evaluated against the decay of the ADCL's ^{60}Co source, the next two rows represent two NEL 2571's used in this work and the remainder of the rows represent the Parallel Plate chambers used. It should be noted that the precision of the calibration of the NEL 2571 was an order of magnitude better than that for the Parallel Plate chambers that had multiple calibrations. It is not clear if this is due to the stability

of the chambers or the difficulty in calibrating this type of chamber, but it is a strong argument against Parallel Plate chambers being used as dose standards.

RESULTS

There is no measurable energy dependence in the ratio of dose as determined with a parallel plate chamber vs. that determined by a cylindrical chamber.

Dose rate in electron beams, based on ADCL calibrations of Plane Parallel chambers, are a function of the chamber type at the 2.5% level.

CONCLUSIONS

The use of parallel plate chambers does not improve the determination of refe$_r$ence dose in electron beams with nominal energies from 5 to 20 MeV.

Method A, cross calibration of Parallel Plate chambers in a high energy electron beam, is preferable to method B, calibration by an ADCL, for the determination of $k_{ecal}N_{D,w}$.

A primary standard for absorbed dose from high-energy electron beams needs to be established.

$$D_w^Q = M \cdot P_{gr}^Q \cdot k_{R50}^{'} \cdot k_{ecal} \cdot N_{D,w}^{^{60}Co}$$

Equation 1: TG-51 equation for reference dose from an electron beam.

$$P_{gr}^Q = \frac{M_{raw}^{d_{ref}+0.5r_{cav}}}{M_{raw}^{d_{ref}}}$$

Equation 2: gradient correction, note the notation has been modified from that used in the TG51 protocol to avoid misinterpretation

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

Equation 3: The definition for corrected meter reading

$$D_w^Q = P_{ion} \cdot P_{TP} \cdot P_{elec} \cdot P_{pol} \cdot M_{raw}^{d_{ref}} \cdot \frac{M_{raw}^{d_{ref}+0.5r_{cav}}}{M_{raw}^{d_{ref}}} \cdot k_{R50}^{'} \cdot k_{ecal} \cdot N_{D,w}^{^{60}Co}$$

Equation 4: Equations 1-3 combined, it should be noted that the raw meter reading at d_{ref} numerically cancels out and thus was not measured for this work.

$$(k_{ecal} N_{D,w}^{^{60}Co})^{\text{PP Method A}} = \frac{(D_w / MU)^{cyl} MU}{(Mk'_{R50})^{PP}}$$

Equation 5: Equation for determining $k_{ecal}N_{D,w}$ using method A.

$$\frac{(k_{ecal} N_{D,w}^{^{60}Co})^{PP\ method\ B}}{(k_{ecal} N_{D,w}^{^{60}Co})^{PP\ method\ A}} = \frac{(k_{ecal} N_{D,w}^{^{60}Co})^{PP\ method\ B}}{\frac{(D_w / MU)^{cyl} MU}{(Mk'_{R50})^{PP}}} = \frac{(k_{ecal} N_{D,w}^{^{60}Co})^{PP\ method\ B} \cdot (Mk'_{R50})^{PP}}{(D_w / MU)^{cyl} MU}$$

Equation 6a: The equation for the ratio's of $k_{ecal}N_{D,w}$ determined with method A over those determined with method B presented in Table 2.

$$\frac{(k_{ecal} N_{D,w}^{^{60}Co})^{PP\ method\ B}}{(k_{ecal} N_{D,w}^{^{60}Co})^{PP\ method\ A}} = \frac{(D_W / MU)^{PP\ (k_{ecal}N_{D,w}\text{ determined using method B})}}{(D_w / MU)^{cyl} MU}$$

Equation 6b: We note the numerator in equation 6.a is the equation for the dose at d_{ref} if Method B is used to determine $k_{ecal}N_{D,w}$ so Table 2 can also be interpreted as the dose determined based on a Method A determined $k_{ecal}N_{D,w}$ over that determined based on a Method B determination.

Chamber	Wall Material	Electrode	Volume (cm^3)	Diameter of Collecting Volume (mm)	Thickness of exit window (mm)
NEL 2571	Graphite	Aluminum	0.6	-	-
PTW T34001 (Roos)	PMMA	PMMA, graphite coated	0.35	15.6	1.0
PTW N23343 (Marcus)	PE	PMMA, graphite coated	0.055	6.0	0.03
Welhoffer PC40 (Roos Type)	PMMA	PMMA, graphite coated	0.40	16.0	1.0
Exradin P11	D400 (polystyrene equivalent)	Conducting Plastic	0.62	17.4	1.0

Table 1: Physics characteristics of chambers used in this work. Note the NEL 2571 is a cylindrical chamber all others are parallel plate.

	P11	PTW Roos	Welhoffer Roos	Marcus
5	1.008 (n=1)			
6	1.002 ± 0.1% (n=3)	1.000 (n=1)	0.996 ± 0.3% (n=2)	1.002 (n=1)
7	1.009 (n=1)			
8	1.006 (n=1)			
9	1.003 ± 0.1%(n=2)	0.998 (n=1)	0.996 (n=1)	1.000 (n=1)
12	1.000 ± 0.1%(n=3)	0.997 ± 0.2% (n=2)	0.996 (n=1)	1.004 ± 0.1% (n=3)
16	1.003 ± 0.2%(n=3)	0.998 ± 0.2 % (n=2)	1.001 ± 0.0% (n=2)	1.001 ± 0.2% (n=2)
20	1.000 ± 0.1%(n=4)	1.000 (n=1)	1.000 ± 0.1% (n=2)	1.000 (n=1)

Table 2: Ratios of relative dose at d_{ref} determined with various Parallel Plate chambers to that determined by an NEL 2571. The data have been normalized to the ratio at 20 MeV to separate out energy dependence from absolute calibration.

	Exradin P11	PTW 34001(Roos)	Welhoffer PC40	PTW 23343 (Marcus)
Average of all data	1.003 ± 0.3% (n=18)	1.020 ± 0.2% (n=7)	1.023 ± 0.3% (n=8)	1.022 ± 0.2% (n=8)
Average of all energies by energy	1.005 ± 0.3% (n=8)	1.020 ± 0.1% (n=5)	1.022 ± 0.2% (n=5)	1.021 ± 0.1% (n=5)
16 MeV data only	1.004± 0.2% (n=3)	1.020± 0.2% (n=2)	1.025± 0.3% (n=2)	1.020± 0.2% (n=2)
20 MeV data only	1.001± 0.1% (n=4)	1.021 (n=1)	1.025± 0.0% (n=2)	1.020 (n=1)

Table 3: Ratios of $k_{ecal}N_{D,w}$ values determined from Method B(ADCL calibration) to those determined with Method A(cross calibration). This data is also the ratio of dose at d_{ref} determined with each chamber vs. that determined with an NEL 2571(see equations 6a and 6b). The top row is an average over all data points, the second row is averages of the means for each energy which over represents some data points on energies that have a limited number of data points. The third and forth row represent two possible energies for the TG-51 method-A, determination of $k_{ecal}N_{D,w}$.

Chamber	Std Dev	N	Max/Min	Evaluation Period
NEL2571 (ADCL Std.)	0.1 %	70	1.007	2 years
NEL2571(1)	0.03 %	2	1.000	1 year
NEL2571(2)	0.02 %	2	1.000	3 months
PTW N34001 (Roos)	-	1	-	-
PTW N23343 (Marcus)	-	1	-	-
Welhoffer PC40	0.3%	5	1.008	1 year
Exradin P11	0.5%	3	1.009	1 year

Table 4: Calibration statistics of various chambers. Note the NEL 2571(ADCL std.) is a NIST traceable chamber used as the M.D. Anderson's ADCL primary Absorbed-Dose-To-Water standard. The calibration of this chamber is compared to the decay of the ADCL's ^{60}Co calibration source and all other chambers are compared to this chamber. For any given chamber the average value of all ADCL calibrations was used as the $N_{D,w}$ value in this work.

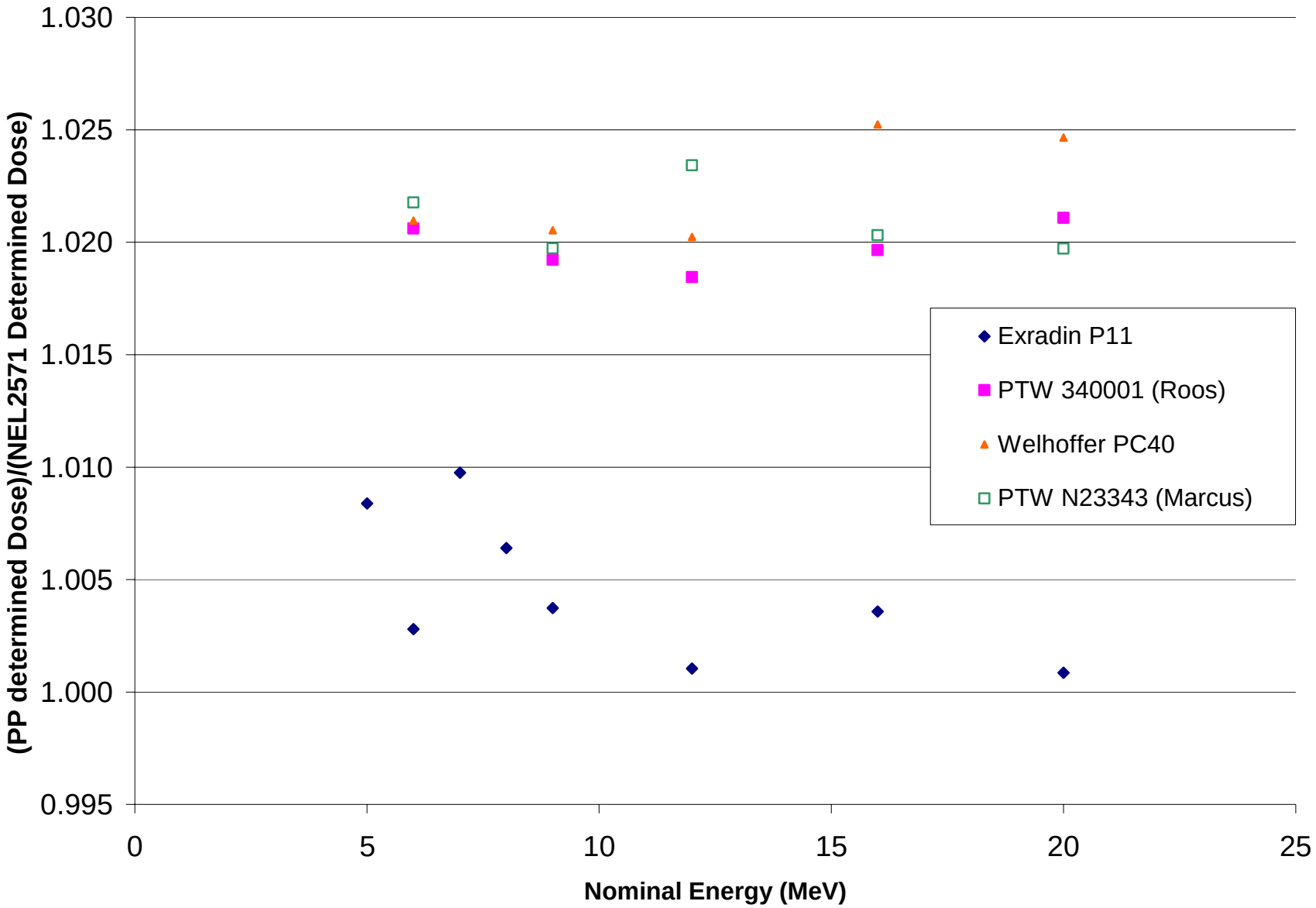

Figure 2: Scatter-gram of showing ratios of dose at d_{ref} as determined with cylindrical vs. Parallel Plate chambers. It should be noted that the chamber dependence is much larger than the energy dependence. It should also be noted that the total spread is only 2.5%.

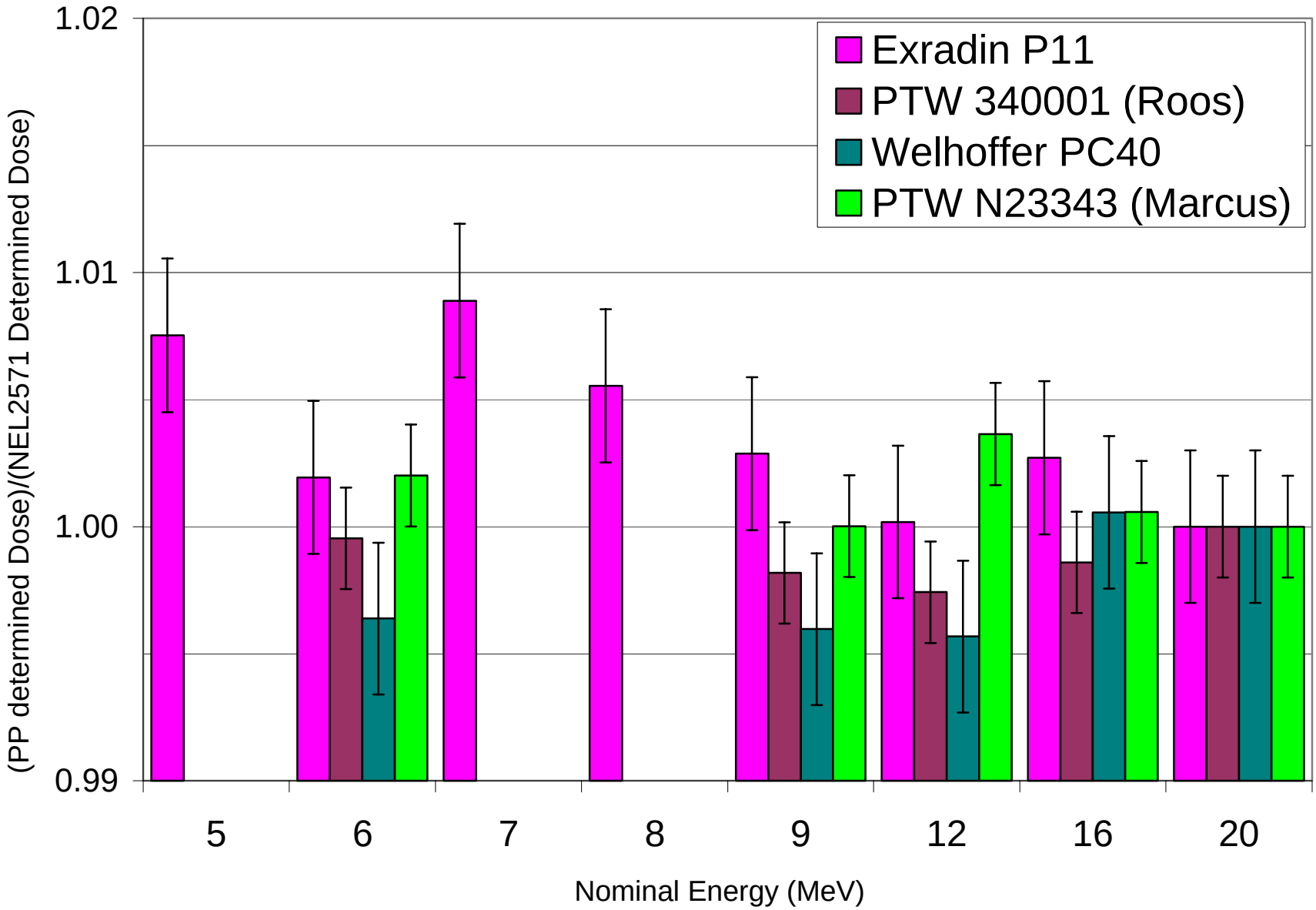

Figure 1: Ratio of relative dose at d_{ref} determined with various Parallel Plate chambers to that determined by an NEL 2571. The data have been normalized to the ratio at 20 MeV to separate out energy dependence from absolute calibration. Error bars represent measured ± 1σ values for determinations with multiple data points and represent ± 0.25% (a composite estimate) for single determinations. (see Table 2 for numerical values)