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Characterization of a SNC350p parallel-plate ionization chamber for electron beam reference dosimetry

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1 OUTLINE OF INVESTIGATION

Measurements and Monte Carlo calculations were carried to characterize the SNC350p ion chamber for use in electron beam reference dosimetry. The purpose of this investigation was to determine the equivalence of this ion chamber type to detectors of the same basic design presently manufactured and for which there are published data for use in reference dosimetry protocols.

2 MEASUREMENT PROCEDURE

2.1 Ion recombination

The procedure as described by McEwen (2010) was used to determine the ion recombination correction, P_{ion}, in linac photon beams. It has been shown that there is no dependence of P_{ion} on either the beam energy (Burns and McEwen, 1998) or modality (Muir *et al*, 2012a).

2.2 Polarity correction

The procedure as described by Muir *et al* (2014) was used to determine the polarity correction in linac electron beams. This has been shown (Muir *et al*, 2012b) to yield results consistent with those obtained using the procedure as described in the AAPM TG-51 protocol (1999).

2.3 Energy dependence

The procedure as described by Muir et al (2014) was used to determine the relative energy dependence of the chamber investigated here compared to a NRC reference ionization chamber. This has been shown (Muir *et al*, 2012b) to yield results with those obtained using the procedure as described by McEwen *et al* (2001) and the IPEM electron beam code of practice (Thwaites *et al*, 2003).

2.4 Measurement equipment

All measurements for both reference and user chambers were made using the NRC computer-controlled charge measurement system.

Table 1. Equipment and parameters used in experimental investigation

Parameter	Setting	Comment
Electrometer	Keithley 6517A	
Serial Number	1030518	
Bias	-100 V	A positive value for the bias indicates that a positive potential was applied to the rear (collecting) electrode of the ionization chamber.
Function	Charge	
Range	20 nC	
Chamber	SNC350p	
Serial Number	ENG-001	

2.5 Meter reading at calibration

Calibration irradiations yielded readings of approximately 2 nC. The leakage or drift in the absence of radiation was found to be < 45 fA. The correction P_{leak} (see below) which takes this into account was taken as 1.000.

2.5 Corrected meter reading

As described in the Addendum to the AAPM's TG-51 protocol (McEwen *et al*, 2014) the fully corrected ion chamber reading is given by:

$$M = M_{raw}\, P_{TP}\, P_{leak}\, P_{ion}\, P_{pol}\, P_{elec}\, P_{rp}$$

Where

M_{raw} is the uncorrected meter reading as read directly from the instrument.

P_{TP} is the correction factor for air density, required when the temperature and pressure of the air in the cavity of the ionization chamber differ from the reference values of 22 ºC and 101.325 kPa (760.0 mm of Hg). Also the air in the ionization chamber is assumed to be moist (relative humidity in the range of 10% to 70%).

P_{leak} is the correction factor to take into account any leakage or drift of the instrument readings in the absence of the radiation to be measured. The factor P_{leak} may be calculated from:

$$P_{leak} = 1\text{-}Bt/\, M_{raw}$$

where t is the time required to accumulate the reading M_{raw} and B is the leakage rate.

P_{ion} is the correction factor to take into account the incomplete collection of charge from an ionization chamber.

P_{pol} is the correction factor used to take into account that, in general, changing the sign of the charge being collected results in a change in its absolute value.

P_{elec} is the correction factor to account of the difference between the indicated reading of charge/current of the electrometer and the delivered charge.

P_{rp} is the correction factor to take account for radial variation in the intensity profile of the radiation field over the sensitive volume of the ionization chamber. For the calibration procedure, which involves a comparison with reference chambers, this is a differential effect – if the chambers are the same dimension then P_{rp} = 1.000. For chambers of different dimensions P_{rp} is obtained from 2-D beam profiles obtained at the reference depth.

For this investigation the same electrometer and radiation field were used for both reference and user chambers and therefore only the first four correction factors were applied to the raw ion chamber reading.

2.6 Uncertainties

The overall uncertainty assumes a normal distribution and is the sum in quadrature of the uncertainty of the measurement standard and the instrument being calibrated. The individual components and the combined total are given in Table 2. Multiplying the overall uncertainty presented here by a coverage factor of k = 2 would give a confidence level of approximately 95%.

Table 2. Uncertainty budget for measurement of relative energy dependence

Component	**Standard uncertainty**
Ratio of ion chamber readings (user/reference)	0.08 %
Positioning of chamber in water phantom	0.06 %
Ion recombination correction	0.03 %
Polarity correction	0.07 %
Combined uncertainty	**0.13 %**

3 CALCULATION PROCEDURE

Monte Carlo calculations were carried out for the SNC350p ion chamber in order to obtain the k_Q beam quality conversion factor for high energy electron beams.

3.1 Calculation method

The k_Q calculation method follows closely the approach of Muir and Rogers (2013). For each beam quality we compute the dose to: 1) the air in the cavity of the SNC350p chamber at the point of measurement inside the water phantom; and 2) the water disk at the point of measurement inside the water phantom.

The ratio of the dose to air and the dose to water is computed, and this ratio divided by that in a Co-60 beam yields the beam quality conversion factor k_Q. See Muir and Rogers (2013) for more details.

3.2 Software

The EGSnrc code by Kawrakow *et al* (2013) was used to perform the Monte Carlo simulations of the ion chamber, using the **`egs_chamber`** user code by Wulff *et al* (2008), which is recognized as the most accurate and efficient simulation tool for ion chamber response.

3.3 Ion chamber model

The SNC350p ion chamber geometry was modelled using the egs++ geometry class library (which is part of EGSnrc). The physical dimensions of the chamber components were obtained from CAD drawings provided by SunNuclear in electronic format. Material specifications were provided by SunNuclear. The chemical composition of the conductive DAG coating was taken from Buckley *et al* (2003).

The chamber was modelled as a simple stack of cylindrically symmetric layers, thus omitting such details as the cable connection assembly and small nooks, holes and recesses. The ion chamber model is further inscribed in a 30 cm x 30 cm x 30 cm water phantom.

To calculate dose to water directly, we use a 0.05 cm thick water disk, with a radius of 0.5 cm, inscribed in the same water phantom.

3.4 Point of measurement

The point of measurement of the chamber is taken as the inside front face of the air cavity. The point of measurement for the water disk is taken as the middle of the disk. For Co-60 simulations the point of measurement is positioned at 5 cm below the water surface, and for electron beam simulation it is positioned at a reference depth $d_{ref} = 0.6R_{50} - 0.1$ (cm).

3.5 Incident particles

Incident photon and electron energy spectra for a number or beam qualities were obtained in electronic format directly from Muir; see Table II in Muir and Rogers (2013). The particle source is positioned 100 cm SSD, and is collimated in a 10 cm x 10 cm square field at the surface of the phantom.

3.6 Sensitivity analysis

We conducted a sensitivity analysis to test the robustness of the calculated k_Q factors against modifications of the EGSnrc model of the SNC350p ion chamber. No significant change in the value of k_Q was noted for the following modifications:

- Replacing all DAG coatings with PMMA
- Modifying the density corrections for PMMA and DAG
- Including an air gap below the bottom DAG electrode (thickness of the polymid finger)
- Including a cylindrical void in the chamber body to model the stem assembly cavity
- Changing the Monte Carlo range rejection medium from PMMA to AIR

4 RESULTS

4.1 Chamber settling

Measurement setup: 10 MV photon beam
Dose per pulse varied in range: 0.025 cGy per pulse

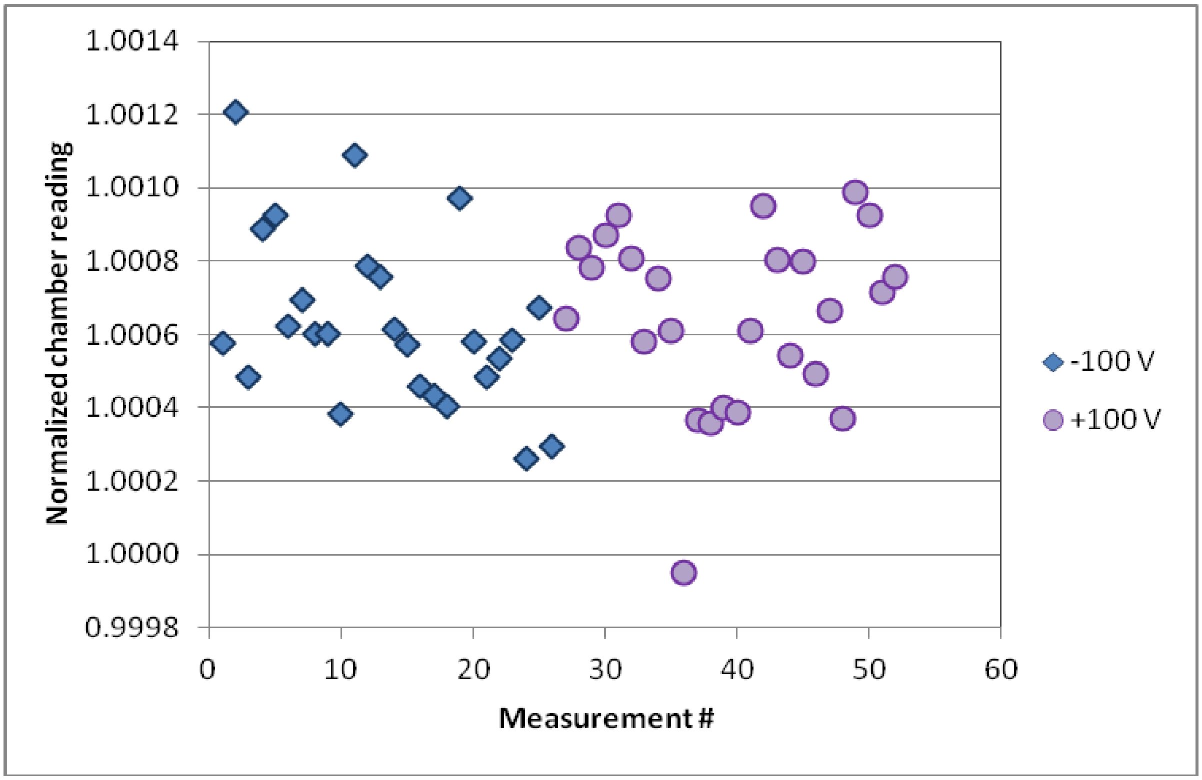

Figure 1. The effect on the chamber reading when a change of polarizing voltage is applied. Each measurement corresponds to an intergration time of 15 s. For well-behaved chambers one expectes a small effect immediately after the change (< 0.5 %) and a rapid equilibration (within five minutes). The chamber investigated shows no significant settling behaviour.

4.2 Ion recombination

Measurement setup: 6 MV, 10 MV photon beams
Dose per pulse varied in range: 0.01-0.08 cGy per pulse

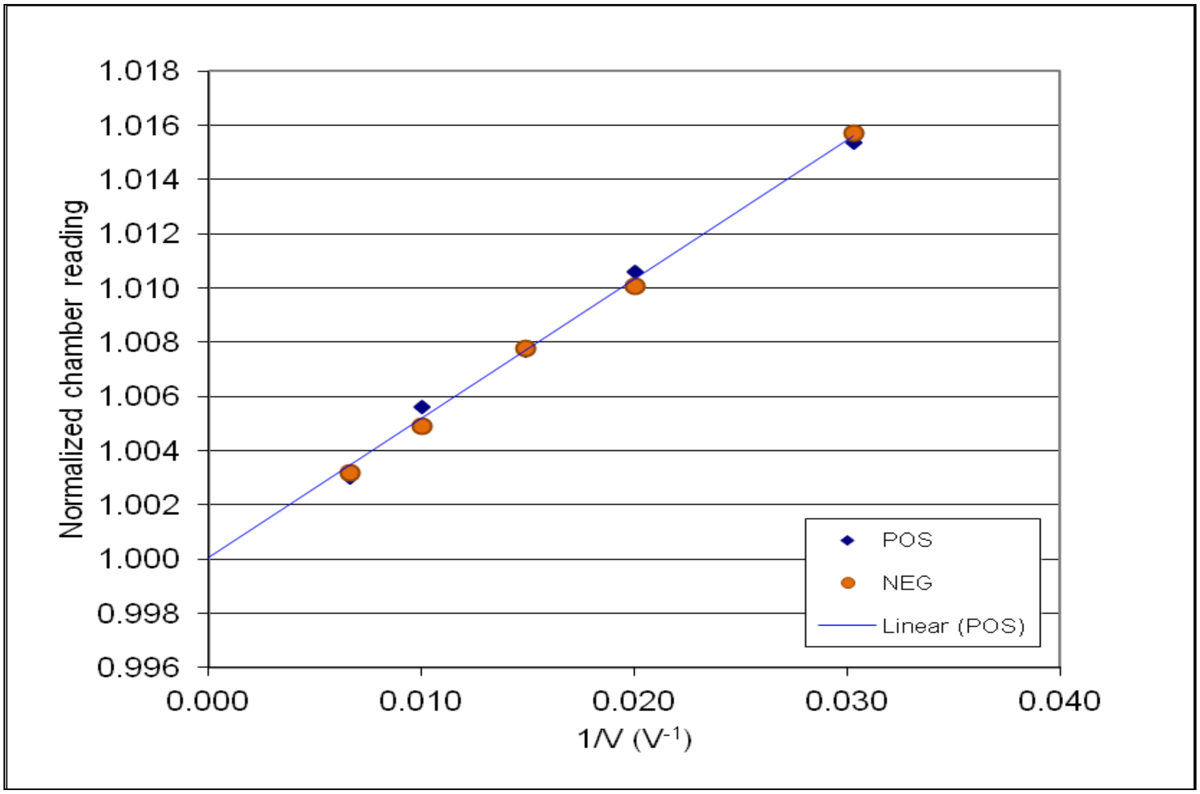

Figure 2: Typical Jaffé plot. Standard uncertainty on each point is estimated to be <0.04% (size of symbol). For a well-behaved chamber one expects a linear relationship between 1/V and 1/Reading and no difference in response whether collecting positive or negative charge. Good agreement between polarities and no nonlinearity was observed up to 150 V (the maximum polarizing voltage recommended by NRC for parallel-plate chambers).

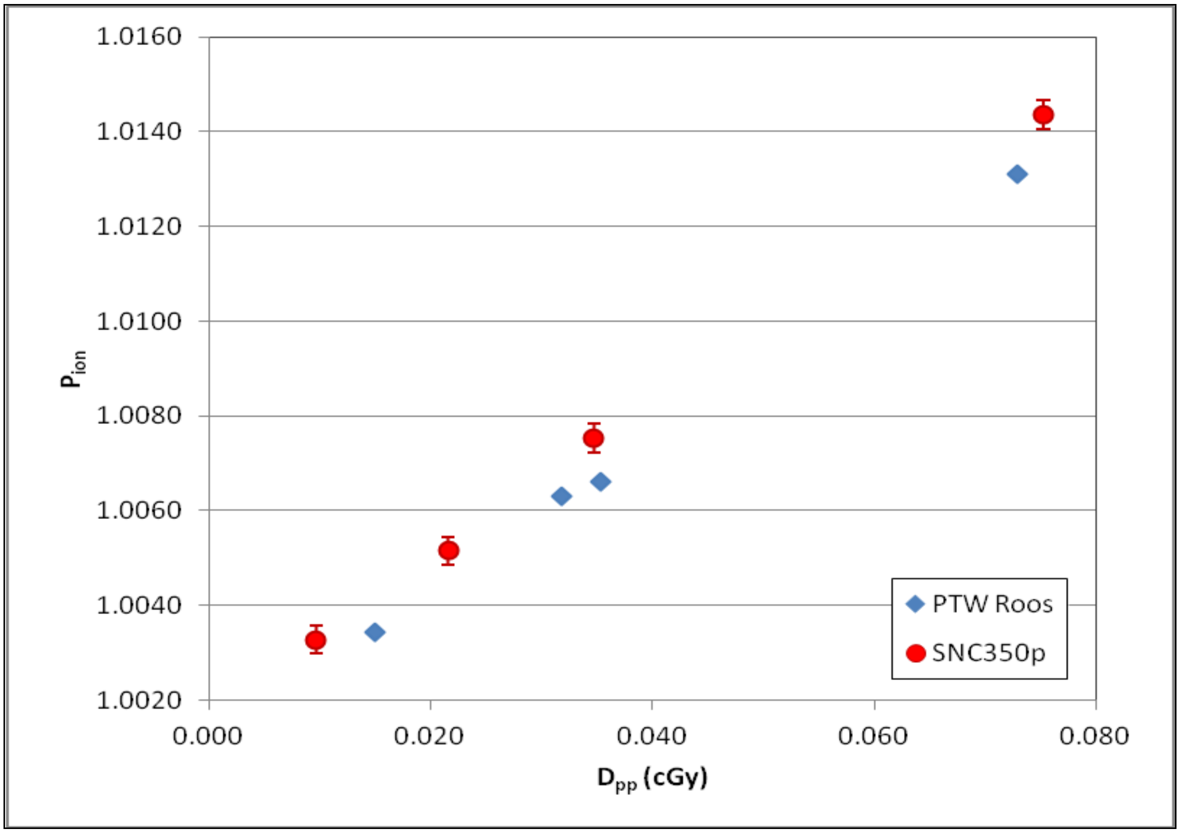

Figure 3: Variation in the ion recombination correction as a function of dose per pulse for a polarizing voltage of **100 V**. The standard uncertainty on each point is estimated to be 0.03 %. One expects a linear relation with an intercept in the typical range 1.0005-1.0015. Response of SNC chamber is very similar to PTW Roos chamber (same gradient, similar intercept).

Following the notation of McEwen *et al* (2014) the ion recombination correction is expressed as:

$$P_{\text{ion}} = 1 + C_{\text{init}} + C_{\text{gen}} D_{\text{pp}}$$

where C_{init} is the component of the ion recombination correction factor to take account of initial recombination and C_{gen} is the coefficient of general (volume) recombination. The product of C_{gen} and the dose per pulse, D_{pp}, is the component of the ion recombination correction factor to take account of general recombination. For the SNC350p chamber the relevant data is given in Table 3.

Table 3. Recombination correction parameters for SNC350p chamber S/N ENG-001

C_{init}	C_{gen} (cGy^{-1})
1.0016	0.00136

4.2 Polarity correction

Measurement setup: 8, 12, 18 MeV electron beams.
Field size is 10x10 cm at phantom surface, SSD = 1 m.
Mean energy at point of measurement varied by adjusting measurement depth.

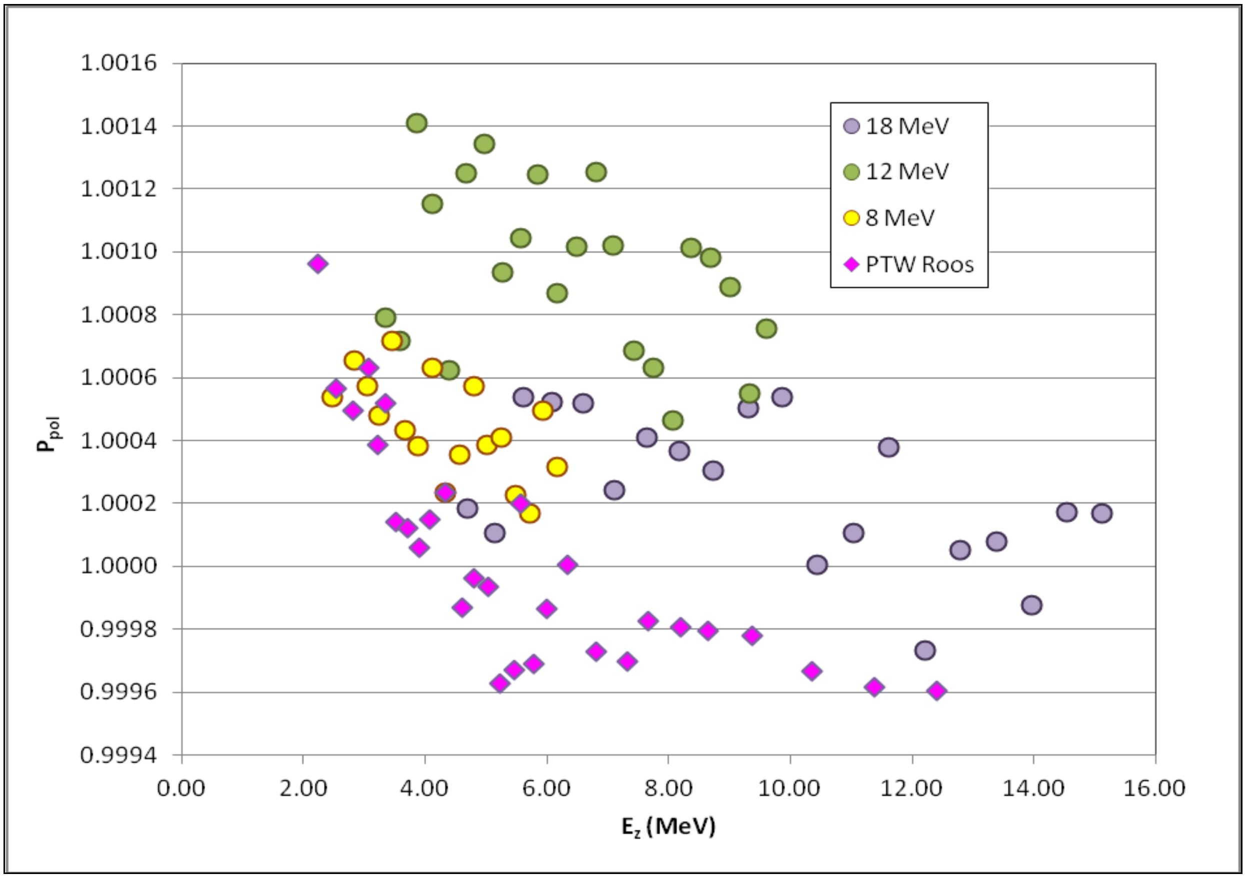

Figure 4: Variation in polarity correction (collecting **positive** charge) with mean energy at the point of measurement, obtained using three different incident beams. Standard uncertainty on each point is estimated to be less than 0.03%. Polarity correction is small, as expected from basic design but appears to be slightly different from the PTW Roos chamber. This may be due to detailed constructional differences.

4.3 Relative energy dependence - experimental

Measurement setup: 8, 12, 18 MeV electron beams.
Field size is 10x10 cm at phantom surface, SSD = 1 m.
Mean energy at point of measurement varied by adjusting measurement depth.
Reference chamber: PTW Roos #559

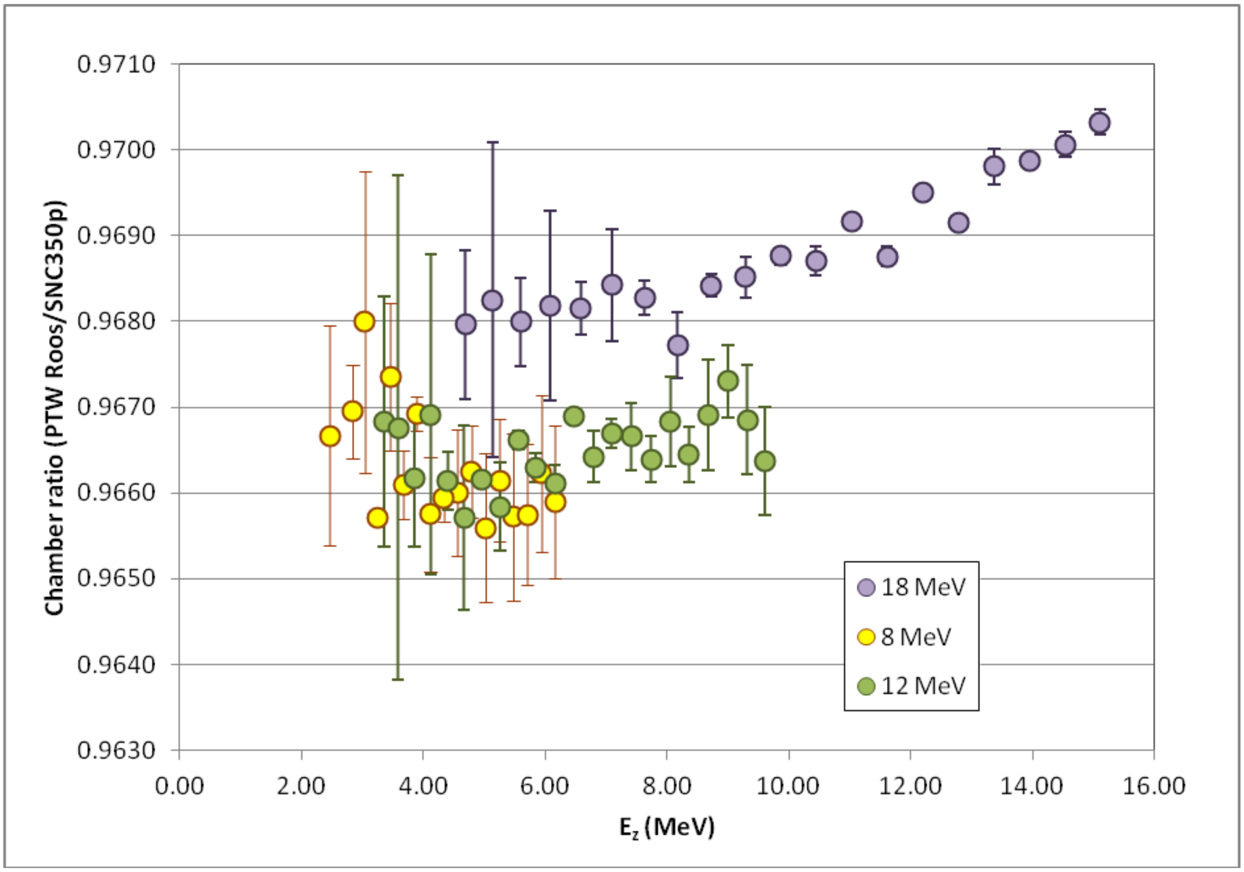

Figure 5: Response of SNC350p chamber relative to PTW Roos chamber as a function of the mean energy at the point of measurement. The Type A (statistical) standard uncertainty shown is dominated by the effects of dose gradients as the chamber is scanned through the water phantom (and therefore largest for the lowest energy beam). The total variation in the relative energy dependence is less than 0.5% and for the energy range relevant for absolute calibration (E_z< 10 MeV) the variation is of the order of 0.25% with no significant dependence on energy. The apparent dependence of the relative chamber response on the incident beam is believed to be due to small day-to-day variations in chamber response and is not considered significant. The difference in the absolute chamber ratio from unity is due to the ~ 3 % difference in absolute volumes of the SNC and PTW chambers.

4.4 Energy dependence – MC calculations

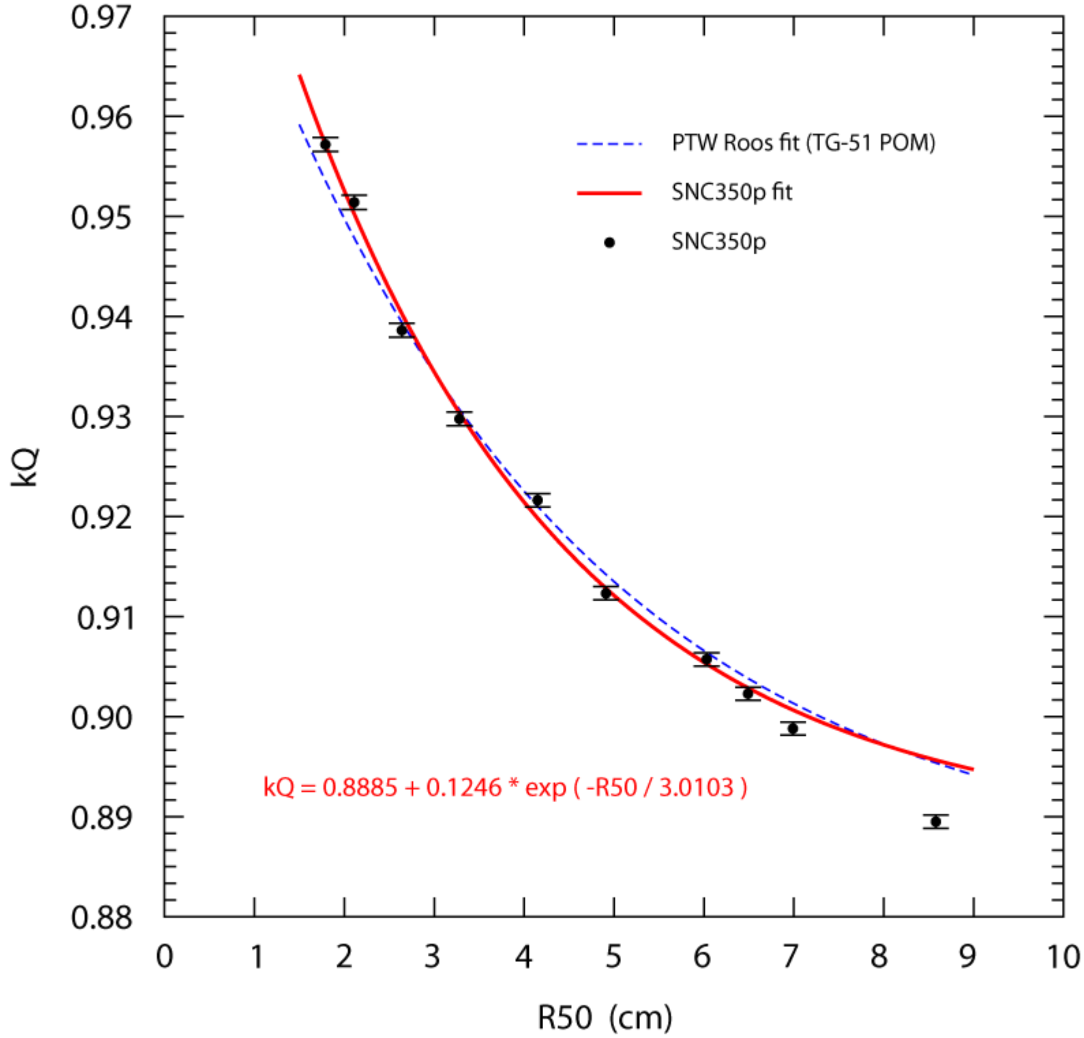

Figure 6: The k_Q values of the SNC350p ion chamber obtained by Monte Carlo calculation for 10 electron beam qualities, as specified by R_{50}. The black data points are the simulation results. Statistical uncertainties are obtained directly from the simulation sampling and are of the order of 0.1%. The red curve is an exponential fit of the data, discarding points above $R_{50} = 6.5$ cm due to the lack of contaminant photons in electron spectrum simulations, as explained in Muir and Rogers (2013). The dashed blue curve is a similar fit for the PTW Roos chamber, as calculated using the TG-51 protocol and as reported in Muir and Rogers (2013).

5 SUMMARY

The measured energy dependence of the SNC350p ionization chamber is found to be the same as that of a PTW Roos chamber within the estimated standard uncertainty of 0.13 %. Applying the specification of a reference-class ion chamber, as defined by McEwen *et al* (2014), the chamber investigated (S/N ENG-001) meets the requirements for chamber settling, leakage, ion recombination and polarity.

The calculated Monte Carlo k_Q factors for the SNC350p ion chamber are consistent with those computed for the PTW Roos ion chamber, using the same calculation method. The exponential fits for k_Q lie within 0.5% of one another over the investigated R_{50} range, from about 1 cm to 9 cm.

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