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A review of the calibration of parallel-plate electron ionisation chambers at NPL for use with the IPEM 2003 Code of Practice

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A review of the calibration of parallel-plate electron ionisation chambers at NPL for use with the IPEM 2003 Code of Practice

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Division for the Quality of Life

ABSTRACT

In 2003 an electron dosimetry code of practice for radiotherapy written by the Institute of Physics and Engineering in Medicine was published. NPL has since calibrated many parallel plate ionisation chambers in terms of absorbed dose to water, for use with the code of practice. The results are summarised in this report.

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Approved on behalf of the Managing Director, NPL
by Dr Martyn Sené, Director, Division for the Quality of Life

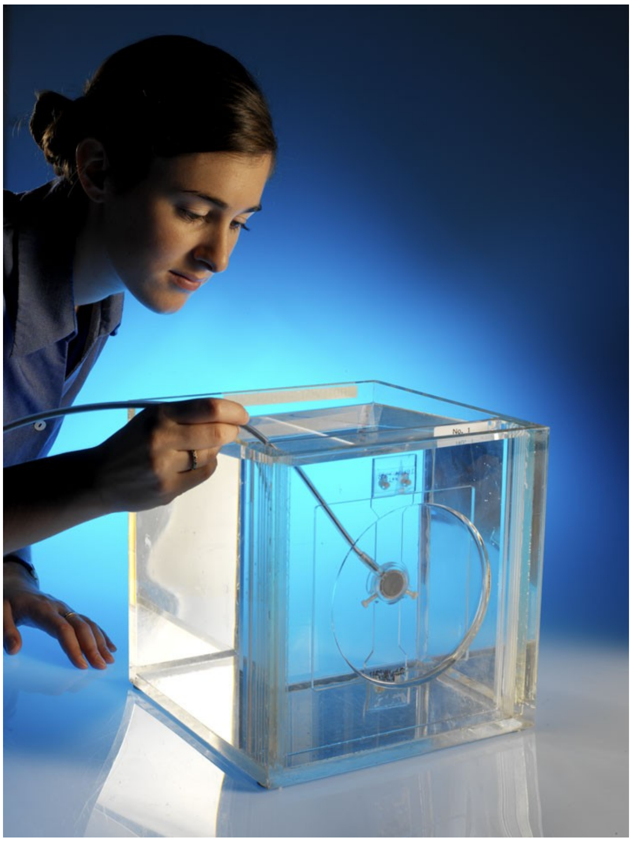
CONTENTS

1 Introduction

In 2003 the Institute of Physics published a code of practice (IPEM 2003, hereafter referred to as the Code of Practice) for electron dosimetry for radiotherapy beams. The code requires that a designated ionisation chamber be calibrated traceably to the electron absorbed dose to water standard at NPL. A number of trial calibrations of an electron chamber calibration service at NPL were carried out by McEwen *et al* (2001) prior to the service being offered on a routine basis from 2002.

The vast majority of the chambers sent to NPL for calibration have been either the NACP-designed parallel-plate chamber type 02 (Matsson *et al* 1981, NACP 1981) manufactured by Scanditronix[1], or the Roos-designed parallel-plate chamber type 34001 (Roos *et al* 1993) manufactured by PTW[2]. This report summarises the results of the calibration of the NACP-02 and PTW Roos chambers at NPL. It is intended that this report can be used as a reference for the radiotherapy user community when characterising field instruments.

Figure 1 The NPL water phantom used in the calibration service



[1] www.scanditronix-wellhofer.com

[2] www.ptw.de

2 NPL calibration

2.1 General

A 26 cm × 26 cm × 26 cm water phantom is used for the calibration at NPL (Figure 1).

The horizontal beams produced by the NPL electron linear accelerator (linac) are circular in cross-section with a beam diameter of 15 cm on the front face of the phantom; this is sufficient to provide electron scatter equilibrium on the central axis at the point of measurement.

The linac is normally operated at a pulse repetition frequency of 240 pulses per second with a pulse width of approximately 1 μs. For the chamber calibration factor measurements, the absorbed dose rate to water is approximately 2 Gy/min. The chamber is positioned 2 metres from an aluminium scattering plate. The thickness of the scatter plate is different for each energy, varying from 0.25 mm at nominal energy 4 MeV, to 3 mm at 19 MeV. All parallel-plate chamber measurements are performed with reference to a transmission monitor chamber.

2.2 Calibration procedure

A secondary standard chamber is calibrated by comparing its fully corrected response to the NPL reference chambers at each of the NPL beam qualities (section 2.4). The Code of Practice appendices A and C give details of this procedure. The calibrations are performed in batches.

During calibration, the secondary standard reading has to be corrected for the polarity effect and ion recombination. The correction factor f_{pol} to correct the chamber reading for the polarity effect is calculated from measurements performed with -100, +100 and again with -100 V applied to the chamber. During calibration at NPL, the polarising potential was applied to the chamber so that the collecting electrode was positive with respect to the polarising electrode. f_{pol} is calculated according to the Code of Practice paragraph A.3. This is done at each beam quality at NPL and the results are reported for information in the calibration certificate (section 4).

The Code of Practice paragraph A.4 describes various methods for assessing the ion recombination for chambers. At NPL, a full characterisation of the recombination correction is performed for every secondary standard chamber at one beam quality. A reading M is taken with a negative polarising voltage V applied to the chamber for V = 100, 75, 50, 30 and 100 volts again. A plot of $1/M$ against $1/V$ is used to ensure that the chamber is behaving linearly over the range of voltages applied. This is performed at three absorbed dose rates (approximately 2, 4 and 8 Gy/min) from which a general equation for recombination for each chamber can be derived (Code of Practice equation (A.5), section 5 of this report). The values of the equation parameters are reported in the calibration certificate.

2.3 Repeat calibration

The Code of Practice recommends that a designated chamber be calibrated every two years. To date, approximately 20 hospital chambers have been calibrated twice, with an average interval between calibrations of about two and a half years. The repeatability of the calibration results referred to in later sections refers to these chambers and several NPL chambers.

2.4 Beam qualities

Table 1 gives the NPL beam qualities in terms of $R_{50,D}$ (the depth at which the dose is 50% of that at the maximum for the depth-dose curve in water) in cm and the calculated reference depth z_{ref} in cm. The nominal energy E_{nom} is that set on the NPL accelerator and is given for reference purposes only. It is not to be taken as a measure of the beam quality.

Table 1 NPL beam qualities

E_{nom} MeV	4	6	8	10	12	16	19
$R_{50,D}$ cm	1.23	1.97	2.75	3.48	4.23	5.72	6.60
z_{ref} cm	0.64	1.08	1.55	1.99	2.44	3.33	3.86

The 4 MeV beam quality has not been available since 2006 due to stability issues with the NPL linac. The results at this quality prior to 2006 are presented in this report for completeness.

3 Absorbed dose to water calibration factors

3.1 Calibration factors for type NACP-02 chambers calibrated at NPL

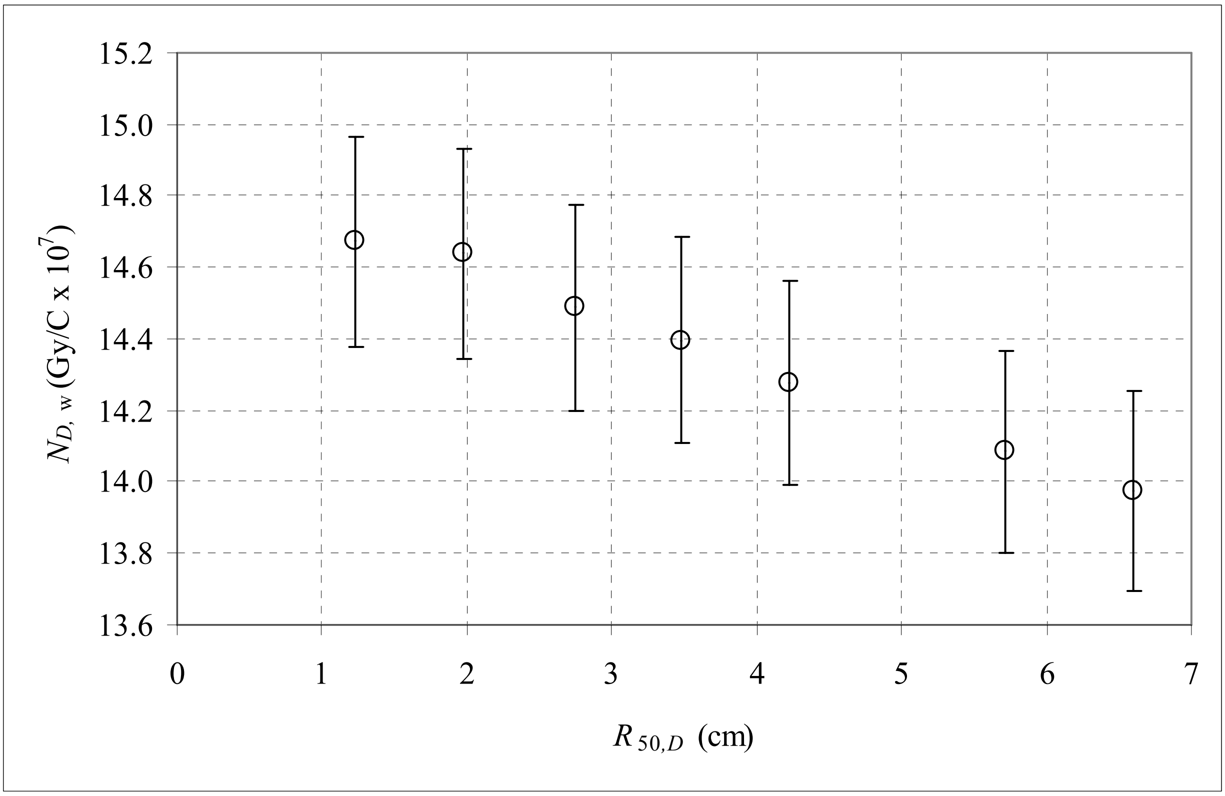
Table 2 gives the mean absorbed dose to water calibration factors in grays per coulomb (Gy/C) for approximately 50 type NACP-02 chambers calibrated between 2002 and 2007. The standard deviation and standard deviation of the mean (sdom) are also given. Figure 2 presents this data graphically. The error bars indicate one standard deviation.

The 'Repeatability of $N_{D,\mathrm{w}}$' in Table 2 refers to the mean difference between the second and first calibration result for a number of chambers.

Table 2 Mean $N_{D,\mathrm{w}}$ factors for NACP-02 chambers

E_{nom} MeV	4	6	8	10	12	16	19
$R_{50,D}$ cm	1.23	1.97	2.75	3.48	4.23	5.72	6.60
$N_{D,\mathrm{w}}$ Gy/C x10^7	14.67	14.62	14.47	14.38	14.26	14.07	13.96
σ	6.2%	6.0%	6.0%	5.9%	6.0%	5.9%	6.0%
sdom	0.9%	0.9%	0.9%	0.9%	0.9%	0.9%	0.9%
Repeatability of $N_{D,\mathrm{w}}$: second calibration relative to first							
Mean	+0.4%	+0.4%	+0.3%	+0.3%	+0.3%	+0.3%	+0.4%
σ	0.7%	0.4%	0.3%	0.4%	0.3%	0.3%	0.2%
sdom	0.3%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%

Figure 2 Mean $N_{D,\mathrm{w}}$ factors for NACP-02 chambers



3.2 Calibration factors for type PTW Roos chambers calibrated at NPL

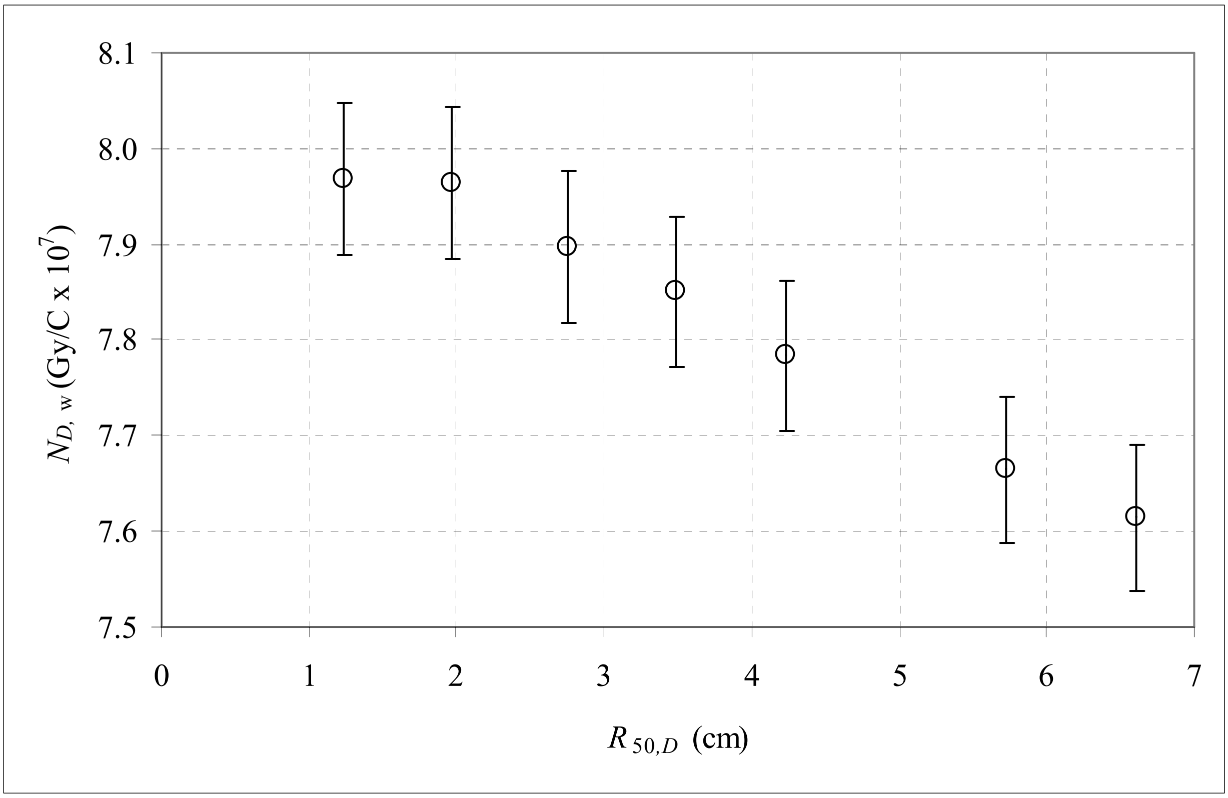
Table 3 gives the mean absorbed dose to water calibration factors in grays per coulomb (Gy/C) for approximately 30 type PTW Roos chambers calibrated between 2002 and 2007. The standard deviation and standard deviation of the mean (sdom) are also given. Figure 3 presents this data graphically. The error bars indicate one standard deviation.

The 'Repeatability of $N_{D,\mathrm{w}}$' in Table 3 refers to the mean difference between the second and first calibration result for a number of chambers.

Table 3 Mean $N_{D,\mathrm{w}}$ factors for PTW Roos chambers

E_{nom} MeV	4	6	8	10	12	16	19
$R_{50,D}$ cm	1.23	1.97	2.75	3.48	4.23	5.72	6.60
$N_{D,\mathrm{w}}$ Gy/C x10^7	7.97	7.95	7.88	7.83	7.77	7.65	7.60
σ	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%
sdom	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%
Repeatability of $N_{D,\mathrm{w}}$: second calibration relative to first							
Mean	-0.2%	+0.1%	+0.1%	+0.2%	+0.2%	+0.2%	+0.2%
σ	0.3%	0.3%	0.2%	0.2%	0.2%	0.3%	0.2%
sdom	0.2%	0.1%	0.1%	0.1%	0.1%	0.1%	0.0%

Figure 3 Mean $N_{D,\mathrm{w}}$ factors for PTW Roos chambers



3.3 Discussion of repeat calibration results

The repeat calibration results indicate a small but consistent difference across the range of qualities of 0.3-0.4% for type NACP-02 chambers and 0.1-0.2% for type PTW Roos chambers. In both cases, the standard deviation of the mean difference at each quality is comparable to the difference itself, indicating the relatively large variation in this measure. However, since all of the chambers were calibrated against the same transfer standard chambers there does seem to be a small but significant difference in the change of the response of type NACP-02 chambers compared to PTW Roos chambers. The mechanism for this change is not clear, since it is also not apparent from the check source measurements (see section 6).

4 Polarity effect correction factor f_{pol}

4.1 Correction factor f_{pol} for type NACP-02 chambers calibrated at NPL

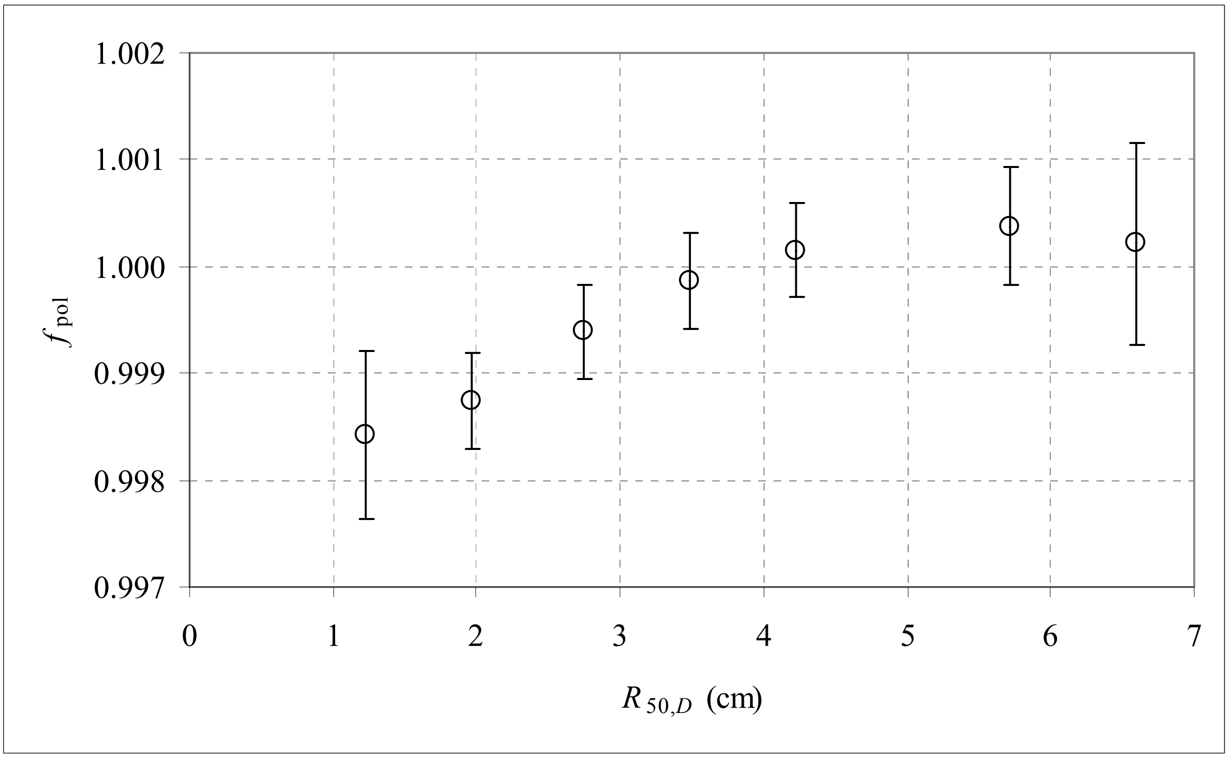
Table 4 gives the mean polarity effect correction factors f_{pol} for type NACP-02 chambers. The standard deviation and standard deviation of the mean (sdom) are also given. Figure 4 presents this data graphically. The error bars indicate one standard deviation.

The 'Repeatability' in Table 4 refers to the mean difference between values of f_{pol} derived during the second and first calibration for a number of chambers. It can be seen that the results agree to 0.1% or better.

Table 4 Mean polarity effect correction factors f_{pol} for type NACP-02 chambers

E_{nom} MeV	4	6	8	10	12	16	19
$R_{50,D}$ cm	1.23	1.97	2.75	3.48	4.23	5.72	6.60
f_{pol}	0.9984	0.9988	0.9995	0.9999	1.0002	1.0004	1.0002
σ	0.0008	0.0005	0.0004	0.0004	0.0004	0.0006	0.0010
sdom	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Repeatability							
Mean	-0.1%	+0.0%	+0.0%	+0.0%	+0.0%	+0.0%	+0.1%
σ	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%

Figure 4 Mean polarity effect correction factors f_{pol} for type NACP-02 chambers



4.2 Correction factor f_{pol} for type PTW Roos chambers calibrated at NPL

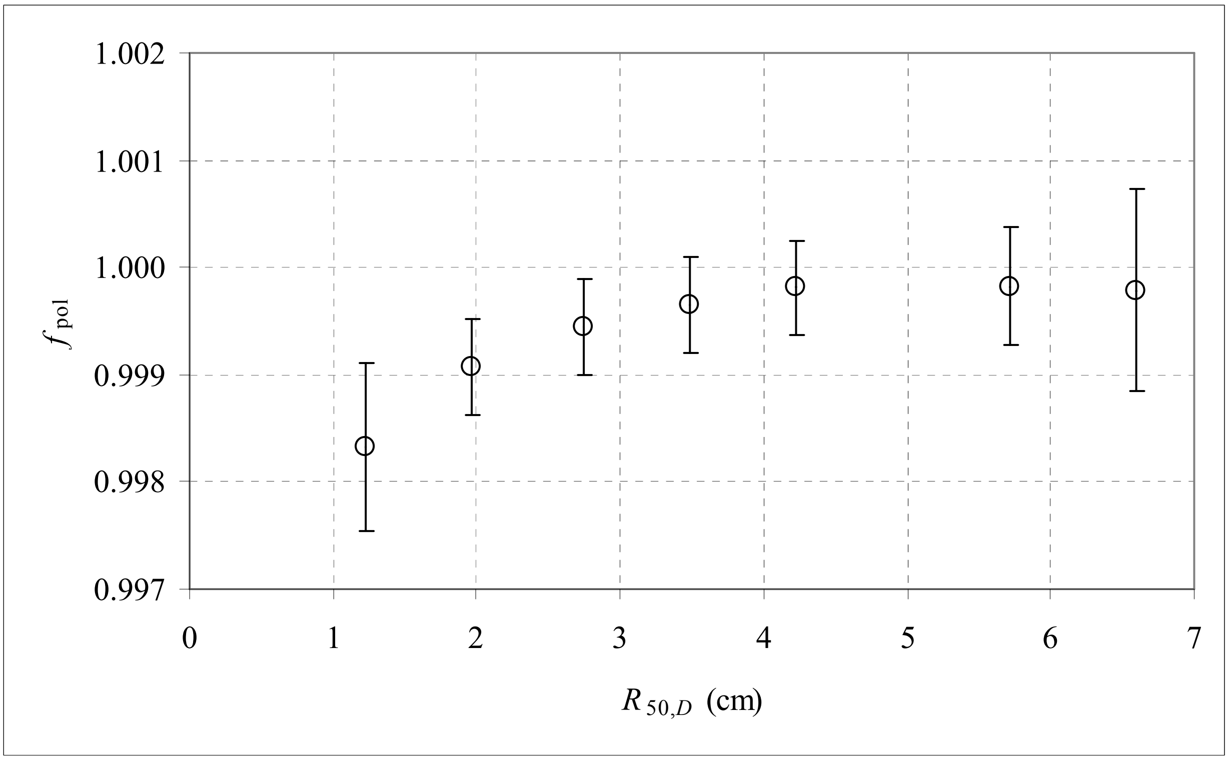
Table 5 gives the mean polarity effect correction factors f_{pol} for type PTW Roos chambers. The standard deviation and standard deviation of the mean (sdom) are also given. Figure 5 presents this data graphically. The error bars indicate one standard deviation.

The 'Repeatability' in Table 5 refers to the mean difference between values of f_{pol} derived during the second and first calibration for a number of chambers. It can be seen that the results agree to 0.1% or better.

Table 5 Mean polarity effect correction factors f_{pol} for type PTW Roos chambers

E_{nom} MeV	4	6	8	10	12	16	19
$R_{50,D}$ cm	1.23	1.97	2.75	3.48	4.23	5.72	6.60
f_{pol}	0.9983	0.9991	0.9995	0.9997	0.9998	0.9998	0.9997
σ	0.0005	0.0002	0.0002	0.0002	0.0002	0.0004	0.0008
sdom	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001
Repeatability							
Mean	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
σ	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%

Figure 5 Mean polarity effect correction factors f_{pol} for type PTW Roos chambers



5 Ion recombination correction factor f_{ion}

The general equation for the recombination correction factor f_{ion} is

$$f_{ion} = c + md$$

where d is the dose per pulse in cGy (equation (A.5) in the code of practice, page 2950, Bruggmoser *et al* 2006).

5.1 Values of f_{ion} for type NACP-02 chambers calibrated at NPL

Table 6 gives the mean values for c and m for type NACP-02 chambers. The standard deviation and standard deviation of the mean (sdom) are also given. For a typical dose rate of 2 Gy/min, values of f_{ion} are given for a range of dose per pulses, calculated from the known pulse repetition frequency (PRF). Figure 6 is a plot of calculated values of f_{ion} versus dose per pulse using the mean values of c and m. The dashed lines indicate the value of f_{ion} at one standard deviation from that obtained with the mean values of c and m.

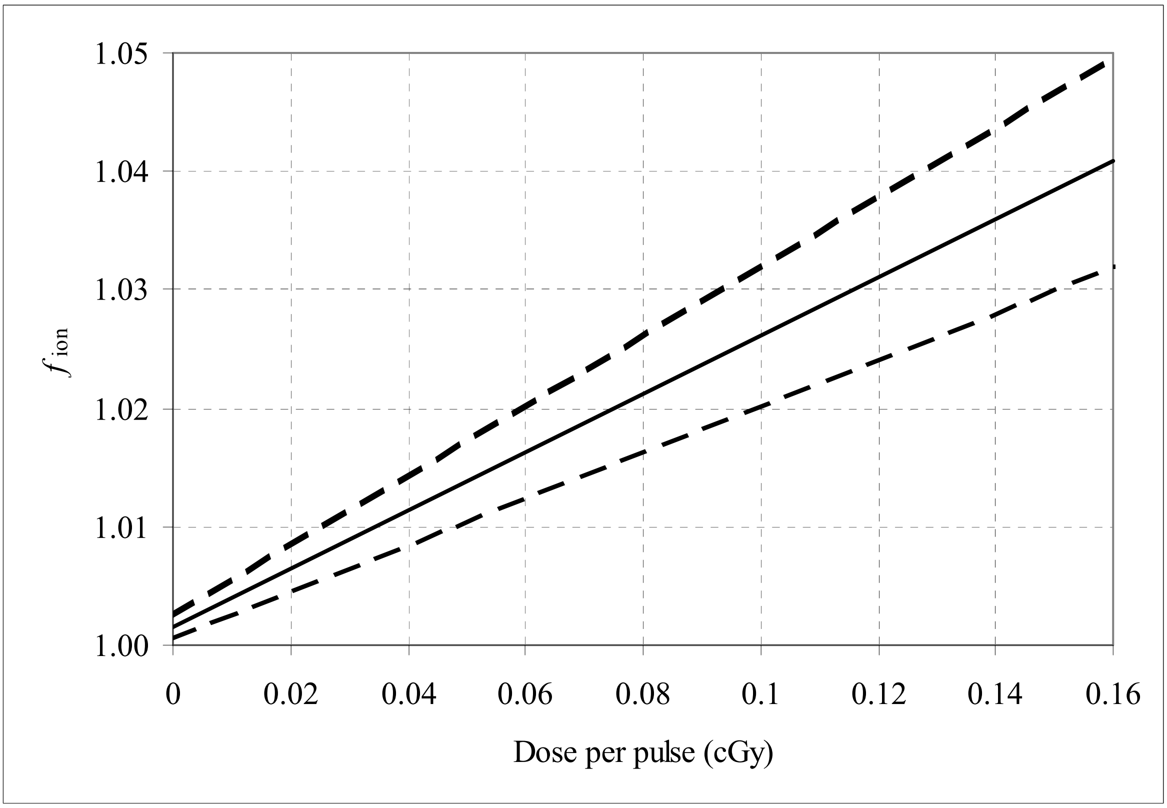
Table 6 Mean equation parameters for calculating f_{ion} for type NACP-02 chambers

-	c	m	Doserate Gy/min	PRF Hz	Dose per pulse cGy	f_{ion}
Mean	1.0015	0.2482	2	60	0.056	1.015
σ	0.0010	0.0495		120	0.028	1.008
sdom	0.0001	0.0075		240	0.014	1.005

5.2 Repeat recombination characterisation for type NACP-02 chambers calibrated at NPL

The recombination characterisation of those chambers calibrated a second time results in new values for c and m. The values obtained at NPL for f_{ion} during the second calibration were compared to those from the first calibration for a dose per pulse of 0.014 cGy. The mean difference was found to be less than 0.05%, with a similar sdom.

Figure 6 f_{ion} for type NACP-02 chambers



5.3 Values of f_{ion} for type PTW Roos chambers calibrated at NPL

Table **7** gives the mean values for c and m for type PTW Roos chambers calibrated at NPL. The standard deviation and standard deviation of the mean (sdom) are also given. For a typical dose rate of 2 Gy/min, values of f_{ion} are given for a range of dose per pulses, calculated from the known pulse repetition frequency (PRF). Figure 7 is a plot of calculated values of f_{ion} versus dose per pulse using the mean values of c and m. The dashed lines indicate the value of f_{ion} at one standard deviation from that obtained with the mean values of c and m.

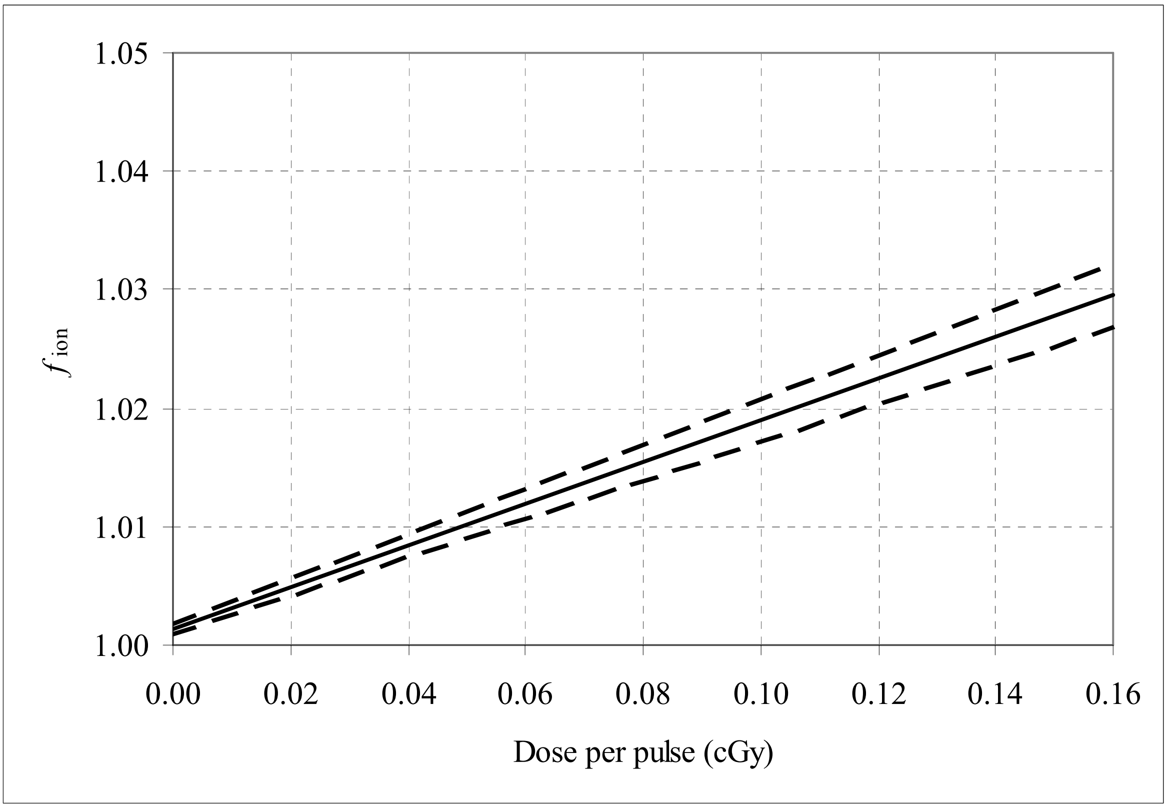
Table 7 Mean equation parameters for calculating f_{ion} for type PTW Roos chambers

-	c	m	Doserate Gy/min	PRF Hz	Dose per pulse cGy	f_{ion}
Mean	1.0013	0.1787	2	60	0.056	1.011
σ	0.0005	0.0129		120	0.028	1.006
sdom	0.0001	0.0025		240	0.014	1.004

5.4 Repeat recombination characterisation for type PTW Roos chambers calibrated at NPL

The recombination characterisation of those chambers calibrated a second time results in new values for c and m. The values obtained at NPL for f_{ion} during the second calibration were compared to those from the first calibration for a dose per pulse of 0.014 cGy. The mean difference was found to be less than 0.05%, with a similar sdom.

Figure 7 f_{ion} for type PTW Roos chambers



6 Check source measurements

6.1 Method

A PTW type 8921 strontium-90 check source is used at NPL to perform quality assurance measurements with the electron chambers and appropriate check source holder before and after in-beam calibrations. A commercial secondary standard electrometer is used to measure the response of a chamber to the check source in terms of charge collected in 100 seconds. This measurement is repeated several times and the calculated mean corrected to standard temperature and pressure and for the radioactive source decay to a convenient reference date.

6.2 Measurement history of NPL-owned chambers

The NPL-owned chambers have had check source measurements performed regularly for many years in some cases. Figure 8 and Figure 9 show the check source measurement results for NACP-02 serial number 3701 and PTW Roos serial number 0133 respectively corrected to a reference date and normalised to the mean result in each case. The dashed lines indicate one standard deviation from the normalised mean. A linear regression fit to the data for both chambers shows no significant trend.

Figure 8 Normalised check source measurements for NACP-02 serial number 3701

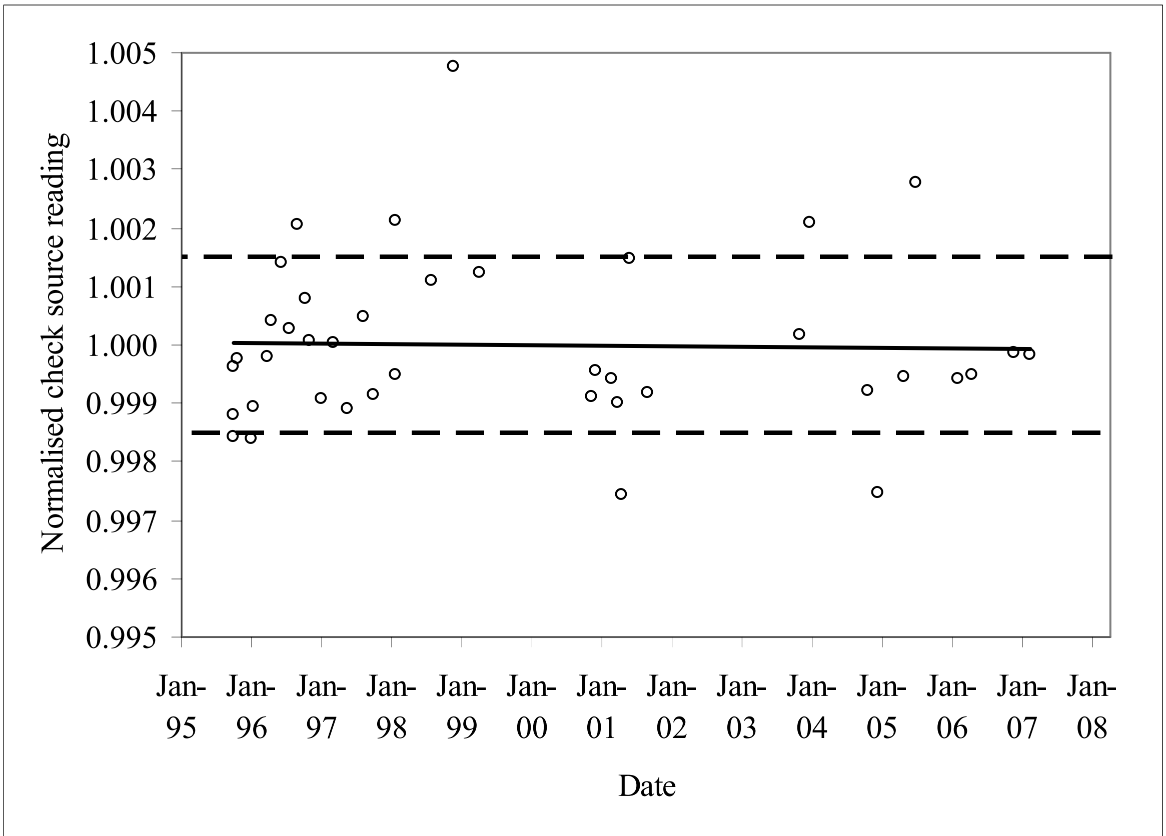
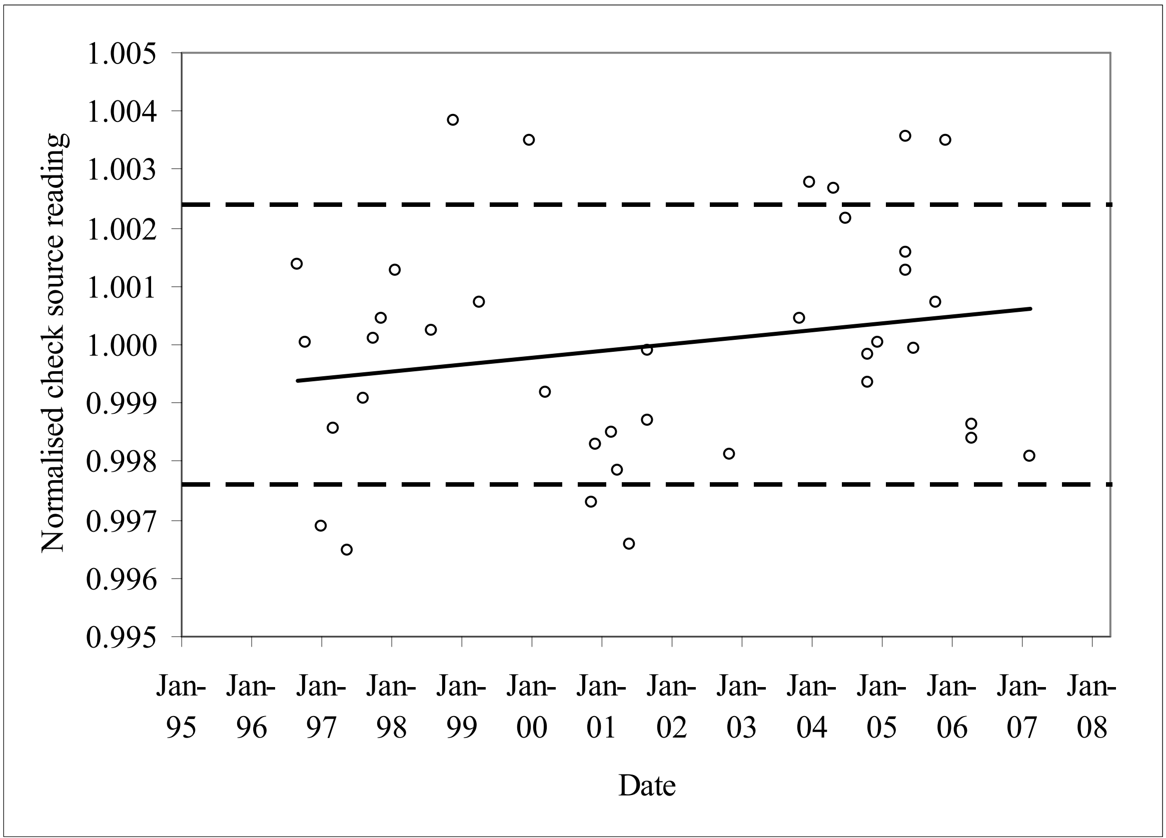


Figure 9 Normalised check source measurements for PTW Roos serial number 0133



6.3 Relationship between individual chamber sensitivity and check source measurement

For each chamber calibrated, the results of the absorbed dose to water calibration at one quality and the check source measurement were plotted in order to investigate the accuracy of predicting the quality response from the check source measurement. Figure 10 and Figure 11 show the absorbed dose to water sensitivity of the chamber at the $R_{50,D}$=3.48 cm (10 MeV nominal) quality plotted against the check source current measurement corrected to October the 1st 2002 for type NACP-02 and PTW Roos chambers respectively. A linear fit to the data is included in each case.

Figure 10 Sensitivity versus check source current for type NACP-02 chambers

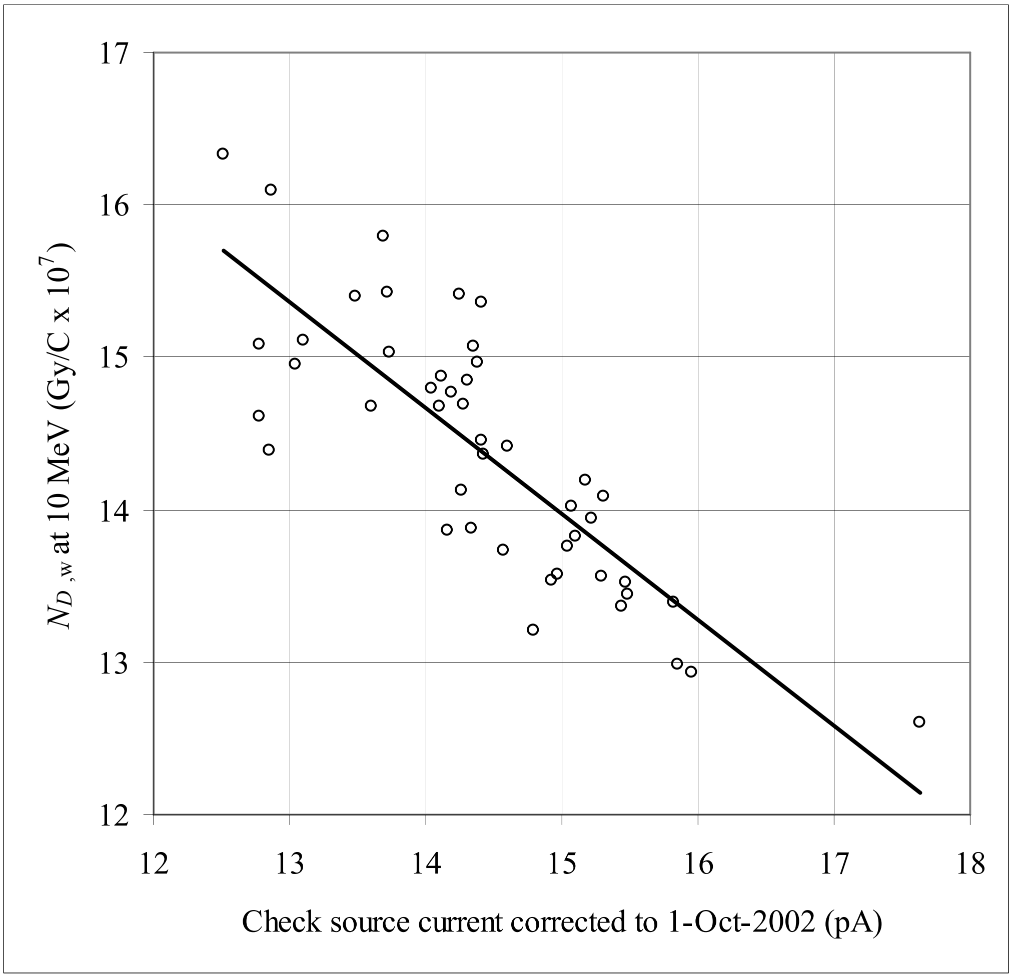
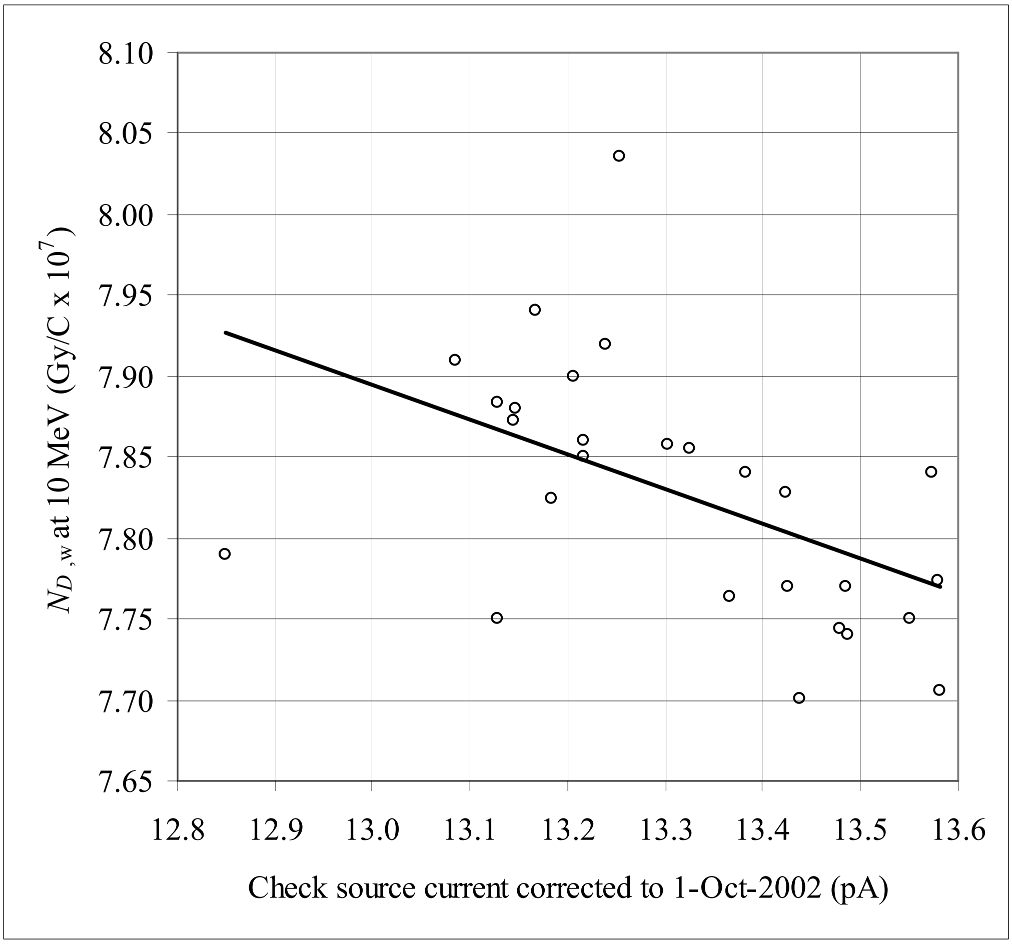


Figure 11 Sensitivity versus check source current for type PTW Roos chambers



6.4 Conclusions from check source measurement data

The repeatability of the check source measurements with type NACP-02 and PTW Roos chambers is consistent, typically within ± 0.3 % of the mean value, over several years. This conclusion is based on the results of measurements with several NPL-owned chambers and other chambers from the user community that have been calibrated more than once at NPL. The relative check source measurement performance of the NACP-02 and PTW Roos chambers cannot easily be compared because of the different design of the chambers and check source holders.

There is evidence of a correlation between the check source measurement result and the absorbed dose sensitivity of the chambers calibrated at NPL as might be expected but the absolute value obtained from the check source measurement with a particular chamber cannot be used to accurately predict its absorbed dose sensitivity.

7 Other types of chambers

7.1 Scanditronix-Wellhöfer chamber type PPC40

The Code of Practice did not include this Roos-type chamber as a designated chamber as at the time of writing the Code there were some waterproofing issues with some of the chambers. It is understood that these issues were addressed with a modified design in later chambers and indeed several of these chambers have been successfully calibrated in water at NPL and are being used clinically. The sensitivity, polarity and recombination characteristics of the type PPC40 chambers calibrated at NPL are within the normal range of the results reported for the PTW Roos chambers, but are not included here due to the limited data.

7.2 PTW Markus chamber

The Code of Practice did not include this chamber type as a designated chamber as it did not meet all the design and construction requirements. McEwen *et al* (2001) and Pearce *et al* (2006) show that Markus and Advanced Markus chambers respectively can exhibit properties undesirable in a reference chamber used for absolute dosimetry.

8 Acknowledgements

The authors would like to thank all of the past and present members of the Radiation Dosimetry Group at NPL who have contributed to the absorbed dose to water calibration service.

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