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CALIBRATION REPORT
on a therapy ionisation chamber for
^{60}Co GAMMA RAYS and MEGAVOLTAGE LINAC X-RAYS

Client ACDS
ARPANSA
619 Lower Plenty Road
Yallambie VIC 3085

Ionisation chamber PTW 30013, serial number 5448

Period of tests 4 May 2021 - 6 July 2021

Previous calibration April 2018 (ARPANSA Reference CAL00807/07)

Test by Max Hanlon, Andrew Cole
Report by Max Hanlon
Report date 12 July 2021

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Signed: ______________________ (Authorised Signatory) Date: 3 Aug 2021

Duncan Butler, Director, Primary Standards Dosimetry Laboratory
per C-M Larsson, CEO of ARPANSA

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The results of the tests, calibrations and/or measurements included in this document are traceable to Australian/national standards

NATA Accredited Laboratory Number: 14433

IRC-FORM-2100J (ARPANSA-FORM-1856) 23-Production

GENERAL COMMENTS

Chamber description – PTW 30013

- Farmer-type chamber with plastic-coated graphite walls of nominal thickness 0.057 g/cm².
- The nominal cavity volume is 0.6 cc (length 23 mm and radius 3.1 mm).
- The central electrode is aluminium.
- The buildup cap is PMMA.
- The chamber is waterproof.

Accessories Supplied

- Buildup cap.

Preliminary Inspection

- The ionisation chamber had no obvious damage or faults on receipt.

Calibration Coefficient

- The calibration coefficient is the number by which the charge from the chamber, in nC, must be multiplied to obtain the absorbed dose to water or air kerma. The calibration factor for the electrometer must also be taken into account when measuring the charge from the chamber.

Calibration Coefficient for Cobalt-60 Gamma Radiation in Air

- The calibration coefficient for the chamber for gamma rays in air from the ARPANSA ^{60}Co teletherapy source was derived from a comparison with the air kerma rate from the teletherapy source, as determined by the ARPANSA Carbon Cavity Chamber which is the Australian primary standard for ^{60}Co gamma rays.

Calibration Coefficient for Cobalt-60 Gamma Radiation in Water

- The chamber was calibrated with 100 cm from the source to the water surface and at 5 cm depth in water.
- The ionisation chamber, without its buildup cap, was placed in a water phantom of dimensions 30 cm x 30 cm x 30 cm. The radiation beam entered the phantom horizontally through a side window of thickness 3 mm. The centre of the chamber was placed 5 cm behind the front surface of the phantom, and this surface was placed 100 cm from the effective source centre.
- The calibration coefficient for the chamber, in terms of absorbed dose to water from gamma rays from the ARPANSA ^{60}Co teletherapy source, was derived from a comparison with the absorbed dose to water rate at the reference point in a water phantom. The absorbed dose to water rate was determined using a Monte Carlo calculation from measurements of absorbed dose to graphite using the ARPANSA Graphite Calorimeter, which is the Australian primary standard for absorbed dose.

Measured k_Q Factors for MV Photons in Water

- The ionisation chamber, without its buildup cap, was placed in a water phantom of dimensions 30 cm x 30 cm x 30 cm. The radiation beam entered the phantom horizontally through a side window of thickness 3 mm. The centre of the chamber was placed at a water equivalent depth of 10 cm with the phantom surface 100 cm from the effective source centre.

- ARPANSA maintains a number of secondary standard reference chambers which have been calibrated against the calorimeter. These are used to cross calibrate client chambers on the day of calibration.
- The absorbed dose to water rate at the reference point in the water phantom from MV photons produced by the ARPANSA Elekta Versa linear accelerator was determined using a Monte Carlo calculation from measurements of absorbed dose to graphite using the ARPANSA Graphite Calorimeter, which is the Australian primary standard for absorbed dose.

Recombination Correction Measurement

- In ^{60}Co and MV photon beams, the recombination correction was estimated using the two-voltage method[1] at an operating voltage of -400 V and a reduced voltage of -80 V Central Electrode Negative.

Table 1: Recombination corrections

Nominal beam energy	^{60}Co	6 MV	10 MV	18 MV
Beam quality ($TPR_{20,10}$)	0.569	0.684	0.733	0.779
Recombination correction, k_s	**1.0001**	**1.0034**	**1.0041**	**1.0047**
Approx. absorbed dose to water rate	2 mGy/s	54 mGy/s	53 mGy/s	70 mGy/s
Approximate dose per pulse	NA	0.14 mGy	0.26 mGy	0.35 mGy

- The formula used to obtain the correction in ^{60}Co was

$$k_{\text{s,Co-60}} = \frac{(V_1/V_2)^2 - 1}{(V_1/V_2)^2 - (M_1/M_2)} \tag{1}$$

where V_1 is -400 V, V_2 is -80 V, and M_1 and M_2 are the charges collected at V_1 and V_2 respectively.

- The formula used to obtain the recombination correction in pulsed accelerator beams was

$$k_s = a_0 + a_1\left(\frac{M_1}{M_2}\right) + a_2\left(\frac{M_1}{M_2}\right)^2 \tag{2}$$

The coefficients, a_i, were determined using Table 4.VII of IAEA TRS-398[1].

- The recombination corrections in Table 1 have been applied to the $N_{D,w}$ calibration coefficient and k_Q factors presented in this report.

Polarity Correction Measurement

- A dose measurement made at one polarity can be corrected to the average of the dose measurements made at opposite polarities using the polarity correction k_{pol} [1], where

$$k_{pol} = \frac{|M_+| + |M_-|}{2|M|} \tag{3}$$

- We define M and M_+ to be the charge when the voltage is the operating voltage (V_1), and M_- is the charge at -V_1.
- The chamber has been calibrated with the Central Electrode Negative (CEN). Setting '-400 V' set using the PC electrometer software results in 400 V CEN for the Sun Nuclear PC Electrometer electrometer.

Table 2: Polarity corrections

Nominal beam energy	^{60}Co	6 MV	10 MV	18 MV
Beam quality ($TPR_{20,10}$)	0.569	0.684	0.733	0.779
Polarity correction, k_{pol}	**1.0003**	**0.9997**	**0.9992**	**1.0004**
Approx. absorbed dose to water rate	2 mGy/s	54 mGy/s	53 mGy/s	70 mGy/s
Approximate dose per pulse	NA	0.14 mGy	0.26 mGy	0.35 mGy

– The polarity corrections in Table 2 have been applied to the $N_{D,w}$ calibration coefficient and k_Q factors presented in this report.

References

[1] Andreo, P., Burns, D. T., Hohlfeld, K., Huq, M. S., Kanai, T., Laitano, F., Smyth, V. and Vynckier, S., *Absorbed Dose Determination in External Beam Radiotherapy: An International Code of Practice for Dosimetry based on Standards of Absorbed Dose to Water*, IAEA Technical Report Series No. 398, IAEA, Vienna, 2000. (V.12, 2006).

Notes

– The ionisation chamber was tested in accordance with ARPANSA Standard Operational Procedures ARPANSA-SOP-0816 Version 7 and ARPANSA-SOP-0812 Version 5.

Air Kerma Calibration Certificate - ^{60}Co gamma-rays

Client	ACDS
Ionisation chamber	PTW 30013, serial number 5448
Polarising voltage	-400 V on the guard electrode
Collected charge polarity	Positive (Central Electrode Negative)
Reference point	On the central axis of the chamber in the plane described by the line on the buildup cap
Geometry	Chamber reference mark facing the radiation source Chamber stem vertically downwards, cable up Horizontal radiation beam Source-detector distance 100 cm 10 cm x 10 cm square beam
Buildup	PMMA buildup cap as supplied
Polarity and recombination	Corrections **not** applied
Reference conditions	20^{o}C, 101.325 kPa and 50% humidity
Measurement date(s)	10 May 2021 - 5 July 2021

Uncertainties are given at a confidence level of approximately 95% (k=2)

Table 3: ^{60}Co air kerma calibration coefficient

Radiation source	Effective photon energy	Air kerma rate	Air kerma calibration coefficient	Uncertainty
	keV	mGy/s	mGy/nC	%
^{60}Co	1250	2.4	49.48	1.0

NOTE: According to international recommendations such as those in IAEA Techdoc 1274, the air kerma result may be interpolated with a suitable kilovoltage X-ray air kerma calibration coefficient to obtain the coefficient at intermediate energies such as ^{192}Ir.

MAX H

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Absorbed Dose to Water ^{60}Co Calibration Certificate and MV Photon Beam Measured k_Q Factors

Client	ACDS
Ionisation chamber	PTW 30013, serial number 5448
Polarising voltage	-400 V on the guard electrode
Collected charge polarity	Positive (Central Electrode Negative)
Reference point	The geometrical centre of the cavity
Geometry	Mark on chamber stem facing the radiation source Horizontal radiation beam 10 cm x 10 cm square beam at phantom surface Source-surface distance 100 cm MV photon beam source-detector distance 110 cm ^{60}Co photon beam source-detector distance 105 cm
Buildup	The buildup cap was removed and the chamber placed directly in the water phantom (no sleeve)
Polarity and recombination	Corrections applied
Reference conditions	20°C, 101.325 kPa and 50% humidity
^{60}Co measurement dates	4 May 2021 - 25 June 2021
MV photon measurement dates	7 June 2021 - 6 July 2021

Uncertainties are given at a confidence level of approximately 95% (k=2)

Table 4: ^{60}Co absorbed dose to water calibration coefficient

Beam name	Beam quality, Q_0	Absorbed dose to water calibration coefficient[a] $N_{D,w}$	Uncertainty
	$TPR_{20,10}$	mGy/nC	%
^{60}Co	0.569	53.76	0.8

[a] The reference quality Q_o is ^{60}Co so $N_{D,w,Qo}$ is denoted by $N_{D,w}$

Table 5: MV photon beam measured k_Q factors

Beam name	Beam quality, Q	Measured k_Q[b]	Uncertainty
	$TPR_{20,10}$		%
6 MV	0.684	0.977	0.7
10 MV	0.733	0.965	0.8
18 MV	0.779	0.952	0.8

[b] The reference quality is ^{60}Co and hence $k_{Q,Qo}$ is denoted by k_Q

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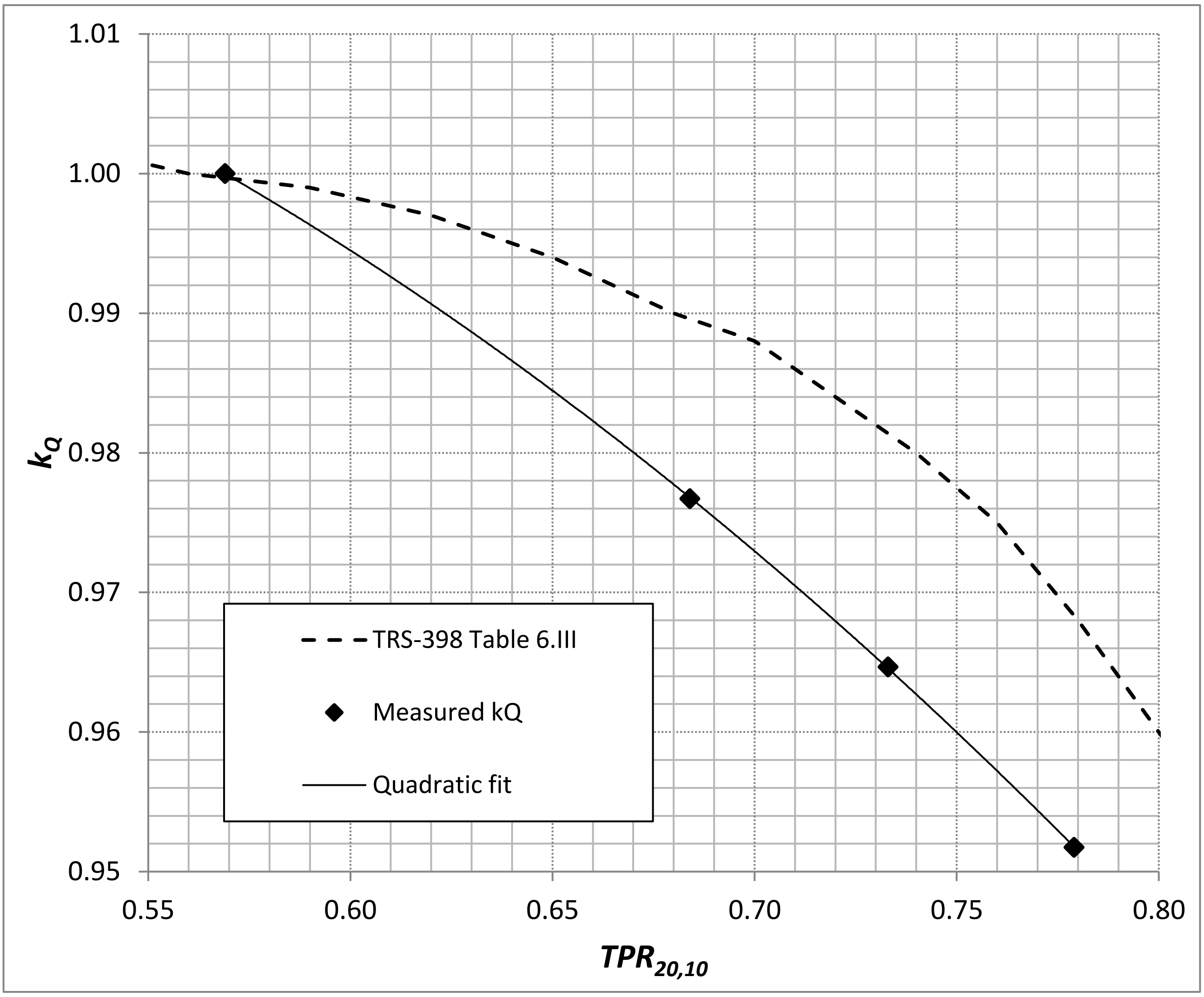

Figure 1: Measured k_Q factors for PTW 30013, serial number 5448

The ^{60}Co k_Q (1.00) and the three measured MV photon k_Q factors were fitted with a quadratic shown in Figure 1 of the form

$$k_Q = a\,(TPR_{20,10})^2 + b\,(TPR_{20,10}) + c \qquad (4)$$

where a = -0.2932, b = 0.1658, c = 1.0006

User calibration factors

– Equation 4 can be used to interpolate from k_Q factors at ARPANSA beam qualities to k_Q factors at user MV photon beam qualities. This interpolation coupled with possible spectral differences between different accelerators will add uncertainty to the user k_Q value. It is recommended that a value of 0.4% (k=2) be added in quadrature with the uncertainty in Table 5 to account for this added uncertainty.

Appendix 1

Use of the ARPANSA absorbed dose to water calibration coefficient with TRS-398

To use this calibration coefficient to determine absorbed dose to water with the chamber under reference conditions according to the IAEA TRS-398 protocol[1] for high energy photons:

$$D_{w,Q}(z_{ref}) = M_1 k_{TP} k_{elec} k_{pol} k_s N_{D,w} k_Q \tag{5}$$

where

$D_{w,Q}(z_{ref})$	is the absorbed dose to water in the linear accelerator photon beam at the reference depth, in the absence of the chamber;
Q	denotes the user's linear accelerator photon beam quality;
z_{ref}	is the reference depth (usually 10 cm) at which the centre of the chamber is placed and the absorbed dose in the absence of the chamber is determined;
M_1	is the response of the chamber when placed in the radiation beam at the reference depth as recorded by the electrometer;
k_{TP}	is the correction factor to convert the cavity air mass to reference conditions of temperature 20°C (293.15 K) and pressure 101.325 kPa;
k_{elec}	is the calibration factor or coefficient of the electrometer;
k_{pol}	is the polarity correction in the user beam Q, as determined by the user from measurements made at opposite voltages as described in IAEA TRS-
k_s	is the recombination correction in the user beam Q, as determined by the user from the two voltage method as described in IAEA TRS-398;
$N_{D,w}$	is the calibration coefficient at ^{60}Co, corrected for the effects of recombination and polarity at ^{60}Co (i.e. the average of the absolute value of the calibration coefficients obtained at opposite polarising voltages, when all the charge released in the chamber cavity is collected), as given in Table 4;
k_Q	is the beam quality correction factor for the user beam Q relative to ^{60}Co, determined by interpolation of ARPANSA measured k_Q factors (see Equation 4).