



Australian Government

**Australian Radiation Protection
and Nuclear Safety Agency**



TRS-398 Revision 1: Changes and Recommendations

Brendan Healy, Duncan Butler, Chris Oliver

Online webinar 23 May 2024

Overview

Dosimetry: implications of TRS-398 Revision 1 for

MV photons

MV electrons

kV photons

Protons

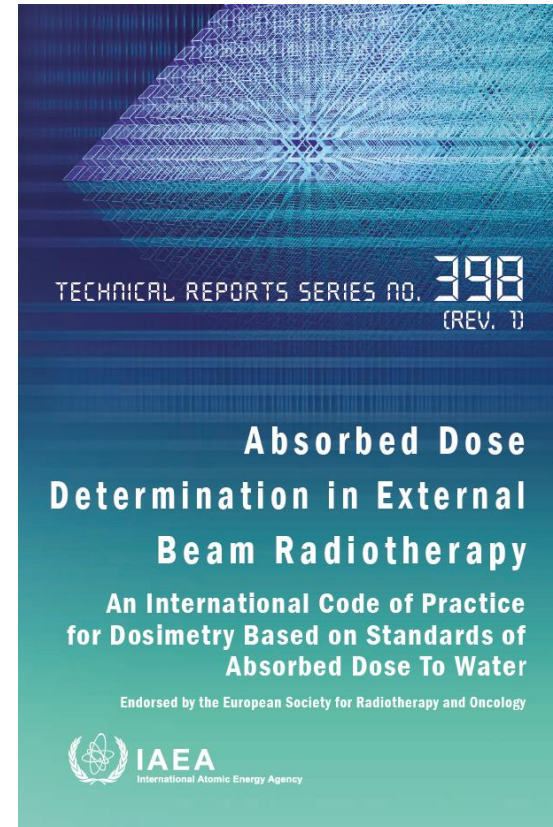
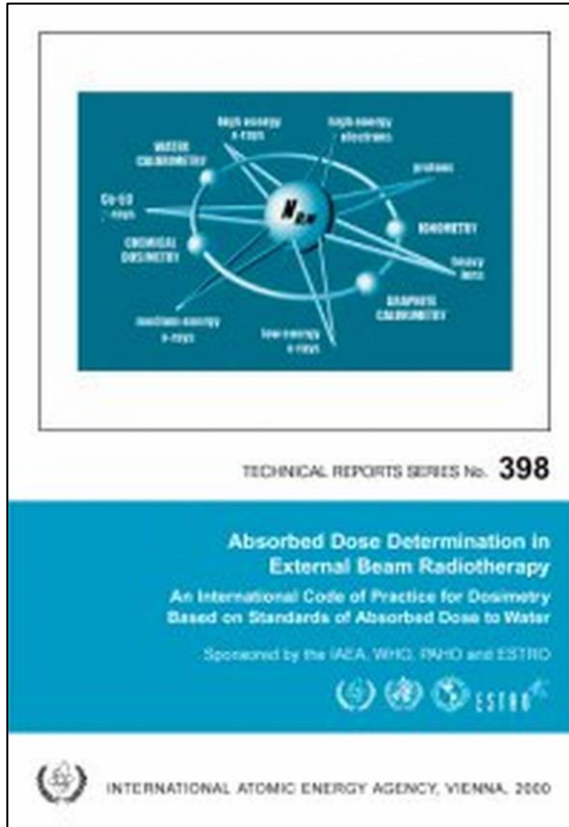
} Brendan

} Duncan

and

ACPSEM-ROSIG/ARPANSA recommendations

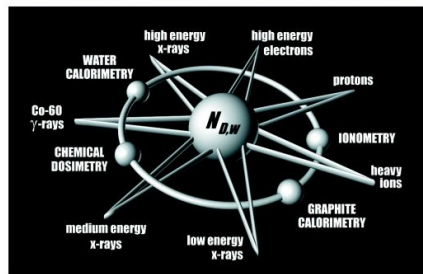
IAEA TRS-398



IAEA TRS-398

IAEA TRS-398

***Absorbed Dose Determination in
External Beam Radiotherapy:
An International Code of Practice for Dosimetry
based on Standards of Absorbed Dose to Water***

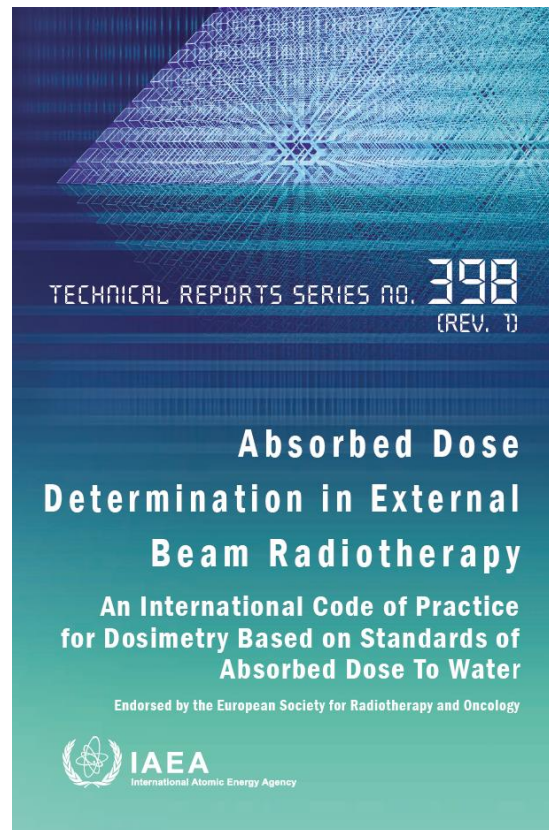


Pedro Andreo, Dosimetry and Medical Radiation Physics Section, IAEA
David T Burns, Bureau International des Poids et Mesures (BIPM)
Klaus Hohlfield, Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany
M Saiful Huq, Thomas Jefferson University, Philadelphia, USA
Tatsuo Kanai, National Institute of Radiological Sciences (NIRS), Chiba, Japan
Fedele Lattano, Ente per le Nuove Tecnologie L'Energia e L'Ambiente (ENEA), Rome, Italy
Vere Smyth, National Radiation Laboratory (NRL), Christchurch, New Zealand
Stefaan Vynckier, Catholic University of Louvain (UCL), Brussels, Belgium

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INTERNATIONAL ATOMIC ENERGY AGENCY **IAEA**
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March
2024

PDF updates
issued online
– most
recent v12 in
2006

Why update?

- Add new ionisation chambers (and delete old and inappropriate chambers)
- New data (ICRU Report 90 published in 2016)
- New MC methods to calculate k_Q
- Feedback from 20 years of clinical use
- New technology (FFF beams, scanned protons)
- Lack of kV D_w standards has continued

Overall changes

- Minimal (note: still TRS-398 – number preserved)
- Same structure:

Chapter 3: Formalism
Chapter 4: Implementation
Chapter 5: ^{60}Co
Chapter 6: MV photons
Chapter 7: MV electrons
Chapter 8: Low energy kV photons
Chapter 9: Medium energy kV photons
Chapter 10: Protons
Chapter 11: Light ions

Explanations common
to all chapters

Stand-alone chapters

MV photons – special techniques

- Added considerations for FFF beams (e.g. volume averaging)
- No addition for special techniques (e.g. CyberKnife, MR linacs)

Still go to TRS-483 for small fields and reference dosimetry for Tomotherapy and CyberKnife

MV photons – volume averaging

New section in Revision 1:

4.4.3.5. Volume averaging correction (in flattening filter free beams)

The aim of reference dosimetry is the determination of the absorbed dose to water at the reference point in the water phantom in the absence of the detector. However, the signal obtained from an ionization chamber is proportional to the

...

agreement. For this reason, the simplest model for the weighting function is chosen, which assumes a line shaped (1-D) detector of cavity length L as follows:

$$w(x,y) = \begin{cases} 1 & \text{for } x=0, -L/2 \leq y \leq L/2 \\ 0 & \text{otherwise} \end{cases} \quad (20)$$

The volume averaging correction factor is then calculated as follows:

$$k_{\text{vol}} = \frac{L}{\int_{-L/2}^{L/2} \text{OAR}(0,y) dy} \quad (21)$$

Here it is assumed that the 1-D detector with length L is aligned along the y direction with its centre at the origin $(x, y) = (0, 0)$ so that the integration over the dose profile in the y direction, $\text{OAR}(0, y)$, extends from $-L/2$ to $L/2$.

Table of generic values (page 68):

TABLE 11. GENERIC VALUES FOR THE **VOLUME AVERAGING** CORRECTION FACTOR IN FLATTERING FILTER FREE BEAMS OF CLINICAL ACCELERATORS

Cavity length, L (cm)	Beam quality index, $\text{TPR}_{20,10}$					
	0.6	0.63	0.66	0.69	0.72	0.75
0.5	1.000	1.000	1.000	1.000	1.000	1.000
1.0	1.000	1.000	1.000	1.001	1.001	1.001
1.5	1.000	1.001	1.001	1.001	1.002	1.002
2.0	1.000	1.001	1.002	1.002	1.003	1.004
2.5	1.001	1.002	1.003	1.004	1.005	1.006

MV photons – FFF beam quality

Advice on beam quality measurement for FFF beams:

6.3.2. Measurement of beam quality index

The experimental set-up for measuring $\text{TPR}_{20,10}$ is shown in Fig. 7. The reference conditions of measurements are given in Table 14.

Although the definition of $\text{TPR}_{20,10}$ is strictly made in terms of ratios of absorbed dose, the use of ionization ratios provides acceptable accuracy because of the slow variation with depth of the water–air stopping power ratios and the assumed constancy of perturbation factors beyond the depth of dose maximum. The influence of recombination effects at the two depths should be investigated and taken into account if there is a variation with depth.

For FFF beams, corrections for volume averaging due to radial non-uniformity (see Section 4.4.3.5) and for the reduced equivalent square field size (see Ref. [12]) can be neglected [147, 153].

TRS-398 Revision 1 / TRS-483 for FFF beams

- An additional correction to the stopping powers for FFF beams is included in TRS-483 and neglected in TRS-398 Revision 1
- Beam quality measurement $\text{TPR}_{20,10}$ slightly different (adjust field size for FFF beams in TRS-483, not in TRS-398 Revision 1)
- Volume averaging included in k_Q in TRS-483
- Up to 0.5% difference between Revision 1 and TRS-483 at 10 FFF

Example: Varian and Elekta 6 FFF and 10 FFF beams

	Varian 6 FFF		Varian 10 FFF		Elekta 6 FFF		Elekta 10 FFF	
	TRS-398 R1	TRS-483	TRS-398 R1	TRS-483	TRS-398 R1	TRS-483	TRS-398 R1	TRS-483
$TPR_{20,10}$	0.631	0.634	0.706	0.710	0.678	0.681	0.723	0.727
PDD%	63.2%	63.2%	70.7%	70.7%	100.0%	100.0%	100.0%	100.0%
k_Q	0.9882	0.9876	0.972	0.9706	0.9785	0.9779	0.9675	0.96649
k_{SPR}	1.000	0.999	1.000	0.996	1.000	0.9973	1.000	0.9955
k_{vol}	1.0016	1.0020	1.0037	1.0047	1.0030	1.0037	1.0043	1.0052
Product*	0.9898	0.9886	0.9752	0.9715	0.9814	0.9789	0.9717	0.9672
Difference	0.12%		0.38%		0.26%		0.46%	

*Ion chamber readings, k_s , k_{pol} etc the same in each case, so not included

PS: TRS-398 Revision 1 only covers up to 10 FFF.

Summary of differences for FFF beam dosimetry

	Differences TRS-398 Revision 1 / TRS-483			
Factor	Varian 6 FFF	Varian 10 FFF	Elekta 6 FFF	Elekta 10 FFF
k_Q	0.06%	0.10%	0.06%	0.11%
k_{SPR}	0.10%	0.37%	0.27%	0.45%
k_{vol}	-0.04%	-0.09%	-0.07%	-0.09%
Total	0.12%	0.38%	0.26%	0.46%



PS: TRS-398 Revision 1 only covers up to 10 FFF.

MV photons - k_Q

- New “consensus” k_Q values

PAPER

Determination of consensus k_Q values for megavoltage photon beams for the update of IAEA TRS-398

P Andreo¹, D T Burns², R P Kapsch³, M McEwen⁴, S Vatnitsky⁵, C E Andersen⁶, F Ballester⁷, J Borbinha⁸, F Delaunay⁹, P Francescon¹⁰, M D Hanlon¹¹, L Mirzakhania¹², B Muir⁴, J Ojala¹³, C P Oliver¹¹, M Pimpinella¹⁴, M Pinto¹⁴, L A de Prez¹⁵, J Seuntjens¹², L Sommier⁹, P Teles⁸, J Tikkanen¹⁶, J Vijande⁷ and K Zink¹⁷

¹ Karolinska University Hospital and Karolinska Institutet, Stockholm, Sweden

² International Bureau of Weights and Measures (BIPM), Paris, France

³ Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany

⁴ National Research Council of Canada (NRCC), Ottawa, Canada

⁵ MedAustron, Wiener Neustadt, Austria

⁶ Technical University of Denmark (DTU), Roskilde, Denmark

⁷ IRIMED Joint Research Unit (IIS La Fe - University of Valencia), Valencia, Spain

⁸ Centro de Ciências e Tecnologias Nucleares, IST-UL, Bobadela, Portugal

⁹ CEA, LIST, Laboratoire National Henri Becquerel (LNE-LNHB), Gif-sur-Yvette, France

¹⁰ San Bortolo Hospital, Vicenza, Italy

¹¹ Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), Yallambie, Australia

¹² McGill University, Montreal, Canada

¹³ Tampere University Hospital (Tays), Tampere, Finland

¹⁴ National Institute for Ionising Radiation Metrology (ENEA), Rome, Italy

¹⁵ VSL–Dutch Metrology Institute, Delft, The Netherlands

¹⁶ Radiation and Nuclear Safety Authority (STUK), Helsinki, Finland

¹⁷ Technische Hochschule Mittelhessen (THM), Giessen, Germany

E-mail: pedro.andreo@ki.se

Parameterised data:
only need to look up a and b

$$k_Q(\text{TPR}_{20,10}) = \frac{1 + \exp\left(\frac{a - 0.57}{b}\right)}{1 + \exp\left(\frac{a - \text{TPR}_{20,10}}{b}\right)},$$

Data are also in tables – use either

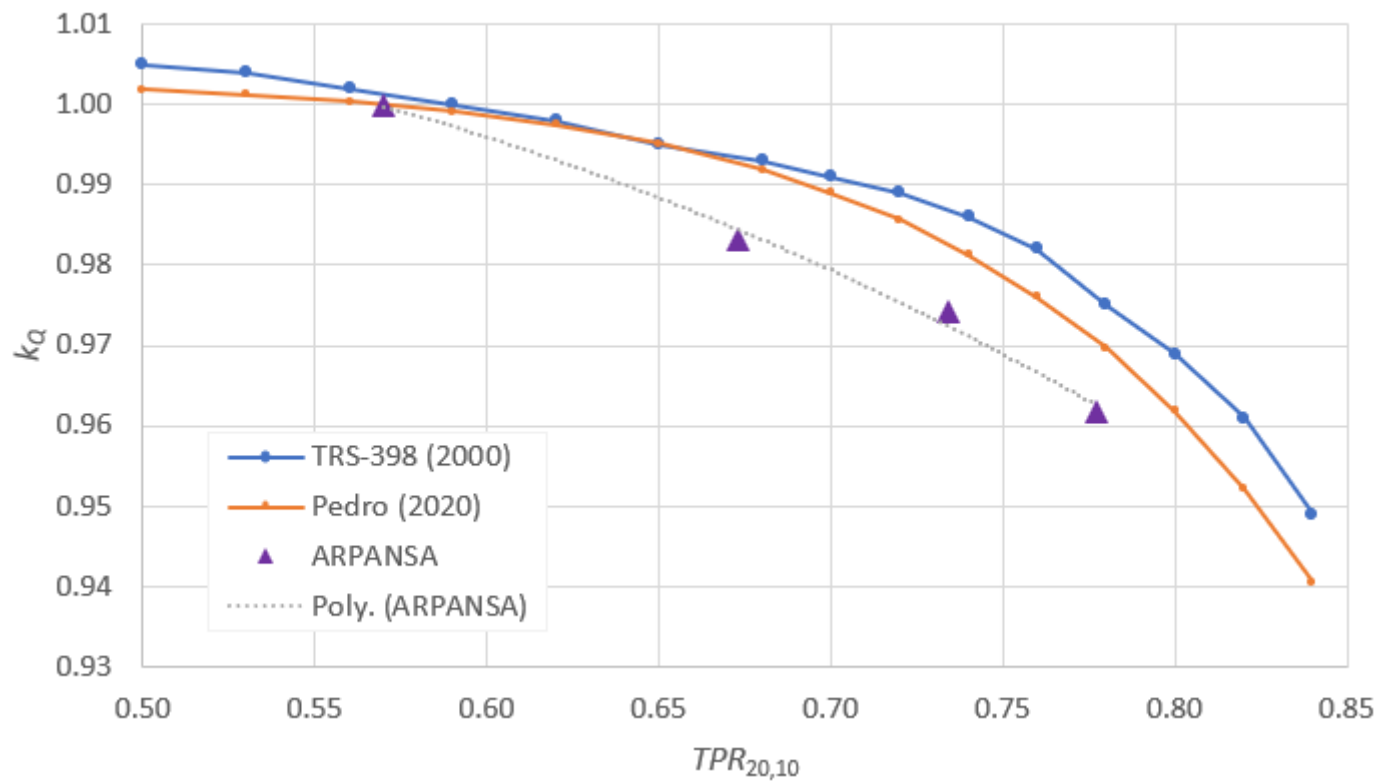
MV photons - k_Q

TABLE 16. CALCULATED VALUES^a OF k_Q FOR HIGH ENERGY PHOTON BEAMS FOR VARIOUS CYLINDRICAL IONIZATION CHAMBERS AS A FUNCTION OF THE BEAM QUALITY INDEX $TPR_{20,10}$ (see Eq. (34)) (cont.)

Ionization chamber type	Beam quality index, $TPR_{20,10}$											
	0.56	0.59	0.62	0.65	0.68	0.70	0.72	0.74	0.76	0.78	0.80	0.82
PTW 30010 Farmer	1.0005	0.9989	0.9967	0.9938	0.9901	0.9869	0.9832	0.9787	0.9734	0.9671	0.9595	0.9506
PTW 30011 Farmer	1.0005	0.9989	0.9969	0.9942	0.9906	0.9875	0.9838	0.9793	0.9739	0.9674	0.9595	0.9501
PTW 30012 Farmer	1.0004	0.9990	0.9970	0.9944	0.9910	0.9881	0.9846	0.9804	0.9754	0.9694	0.9622	0.9536
PTW 30013 Farmer	1.0007	0.9984	0.9956	0.9920	0.9876	0.9840	0.9800	0.9753	0.9699	0.9636	0.9565	0.9484
PTW 31010 Semiflex	1.0008	0.9982	0.9952	0.9914	0.9869	0.9835	0.9795	0.9750	0.9700	0.9643	0.9579	0.9507
PTW 31013 Semiflex	1.0007	0.9985	0.9958	0.9924	0.9882	0.9848	0.9810	0.9765	0.9714	0.9655	0.9588	0.9511
PTW 31016 PinPoint 3D ^b	1.0006	0.9987	0.9962	0.9930	0.9888	0.9853	0.9812	0.9762	0.9703	0.9632	0.9549	0.9451

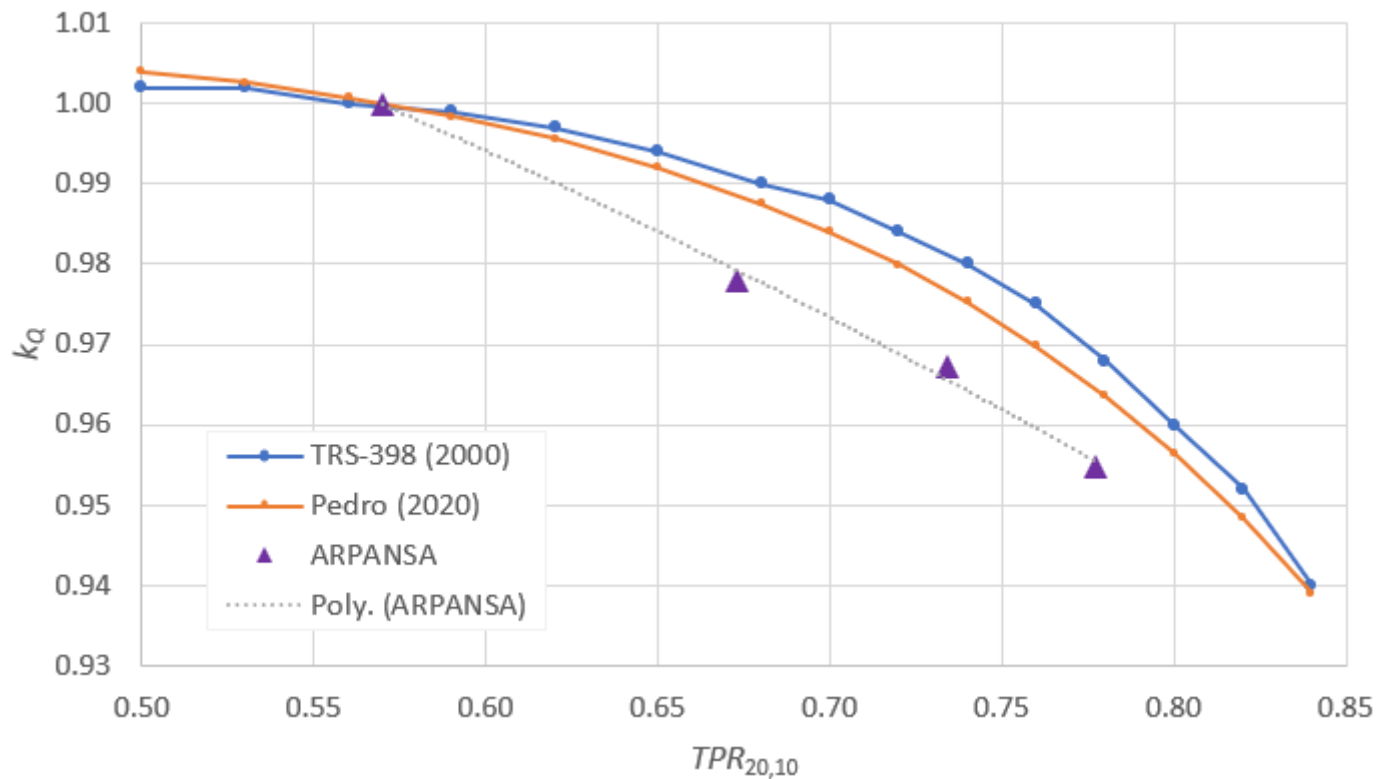
MV photon k_Q factors

2571

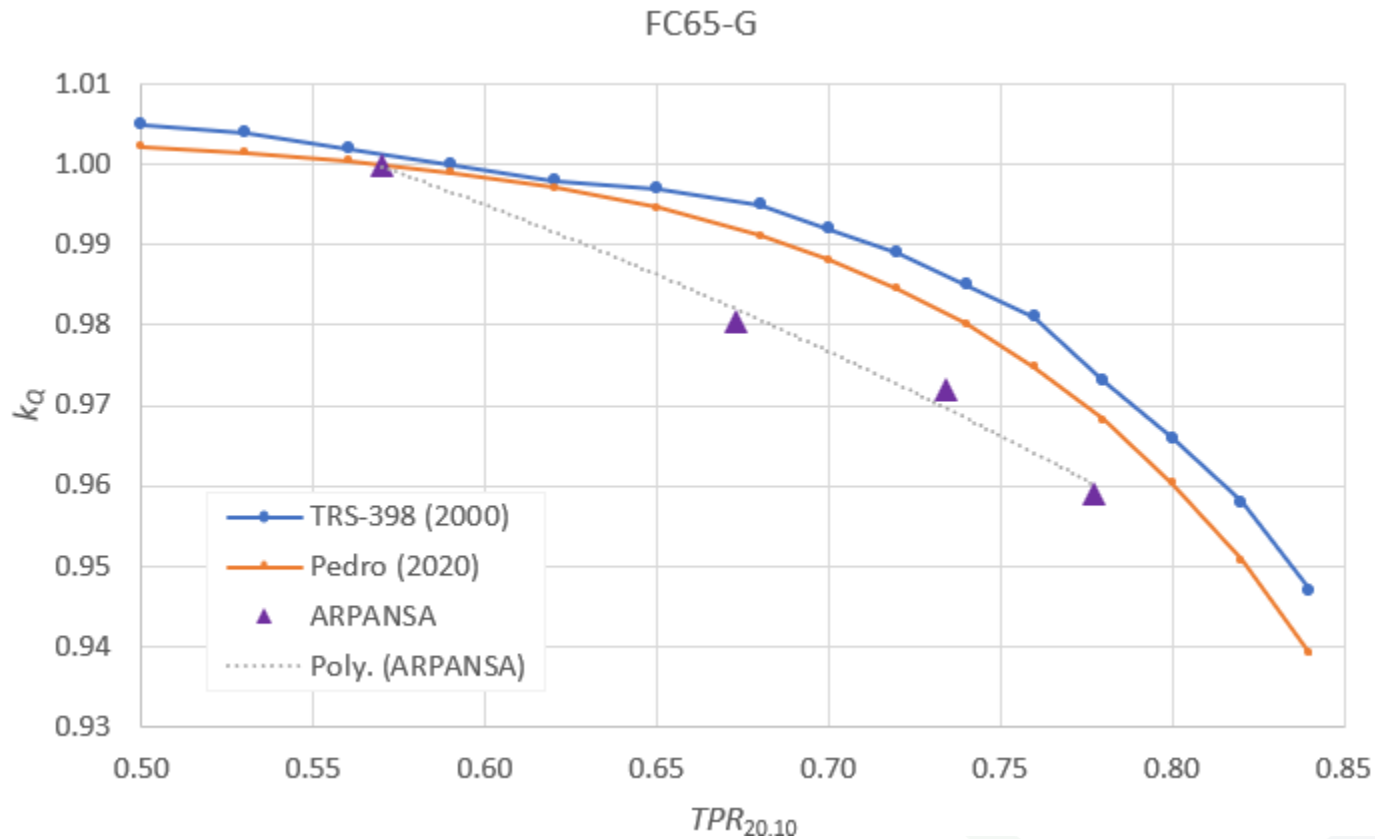


MV photon k_Q factors

30013



MV photon k_Q factors

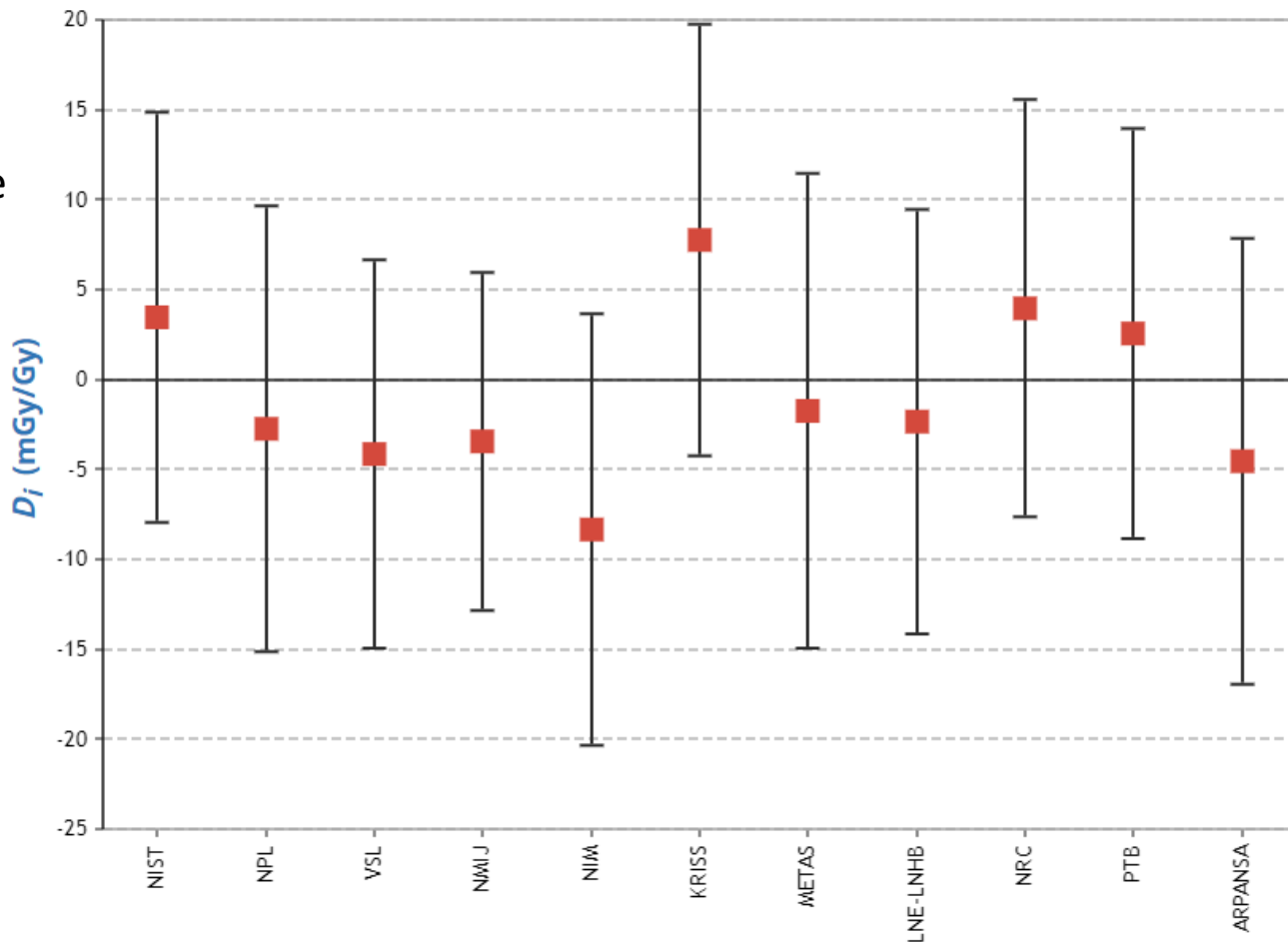


Absorbed dose to water; TPR_{20,10} [0.63 ; 0.71]

Aside: Measured factors are lower than consensus by ~1% why is this okay?

Key comparison results for absorbed dose to water in 6X beams

ARPANSA 0.5% below reference value (the BIPM result = 0 on graph)



MV photons - uncertainties

Original

TABLE 6.IV. ESTIMATED RELATIVE STANDARD UNCERTAINTY ^a OF $D_{w,Q}$ AT THE REFERENCE DEPTH IN WATER AND FOR A HIGH-ENERGY PHOTON BEAM, BASED ON A CHAMBER CALIBRATION IN ⁶⁰Co GAMMA RADIATION

Physical quantity or procedure	Relative standard uncertainty (%)
<i>Step 1: Standards Laboratory^b</i>	
$N_{D,w}$ calibration of secondary standard at PSDL	0.5
Long term stability of secondary standard	0.1
$N_{D,w}$ calibration of the user dosimeter at the standard laboratory	0.4
Combined uncertainty of Step 1	0.6
<i>Step 2: User high-energy photon beam</i>	
Long-term stability of user dosimeter	0.3
Establishment of reference conditions	0.4
Dosimeter reading M_Q relative to beam monitor	0.6
Correction for influence quantities k_i	0.4
Beam quality correction k_Q (calculated values)	1.0 ^c
Combined uncertainty of Step 2	1.4
Combined standard uncertainty of $D_{w,Q}$ (Steps 1 + 2)	1.5

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TABLE 17. ESTIMATED RELATIVE STANDARD UNCERTAINTY^a OF $D_{w,Q}$ AT THE REFERENCE DEPTH IN WATER AND FOR A HIGH ENERGY PHOTON BEAM, BASED ON A CHAMBER CALIBRATION IN ⁶⁰Co GAMMA RADIATION

Physical quantity or procedure	Relative standard uncertainty (%)
<i>Step 1: standards laboratory^b</i>	
$N_{D,w}$ calibration of secondary standard at PSDL	0.5
Long term stability of secondary standard	0.1
$N_{D,w}$ calibration of the user dosimeter at the standards laboratory	0.4
Combined uncertainty of step 1	0.6
<i>Step 2: user's high energy photon beam</i>	
Long term stability of user dosimeter	0.2
Establishment of reference conditions	0.3
Dosimeter reading M_Q relative to beam monitor	0.3 ^c
Correction for influence quantities k_i	0.3
Beam quality factor, k_Q [100]	0.6 ^d
Combined uncertainty of step 2	0.8
Combined standard uncertainty of $D_{w,Q}$ (steps 1 and 2)	1.0

Use of intermediate $k_{Q,Q_{int}}$ for MV photons

- If for example have $N_{D,w,6X}$ and need $N_{D,w,18X}$

$$k_{Q,Q_o} = \frac{N_{D,w,Q}}{N_{D,w,Q_o}} = \frac{N_{D,w,Q}}{N_{D,w,Q_{int}}} \frac{N_{D,w,Q_{int}}}{N_{D,w,Q_o}} = \frac{k_{Q,Q_{int}}}{k_{Q_o,Q_{int}}}$$

- Not required in Australian/NZ (ARPANSA gives 4 points – better to interpolate)

MV electrons

- Clearer advice on cross-calibration (sections 3.2.1 and 3.2.2 on use of Q_{int})
- Updated k_Q factors (for thimble and plane-parallel)
- Limited to $R_{50} \leq 10 \text{ g/cm}^2$ (previously 20 g/cm^2)
= Reduction from 50 MeV max to 25 MeV max
- Farmer-type chamber allowed down to $R_{50} = 3 \text{ g/cm}^2$ (previously 4 g/cm^2) (can use down to 8 MeV instead of 10 MeV)
- Plastic phantoms not allowed

MV electrons

“For beam qualities $R_{50} > 3 \text{ g/cm}^2$ ($E_0 > 8 \text{ MeV}$), cylindrical chambers may be used. This represents a reduction in the energy limit for this chamber type and reflects the investigation by Muir and McEwen [163].”

New k_Q factors for MV electrons

Parameterised:

$$k_{Q,pp} = a + be^{-\frac{R_{50,D}}{c}}$$

$$k_{Q,cyl} = a + bR_{50,D}^{-c}$$

- Great for programming and spreadsheets.
- Also still in tables.

MV electrons

Original

TABLE 7.III. CALCULATED VALUES FOR k_Q FOR ELECTRON BEAMS, FOR VARIOUS CHAMBER TYPES CALIBRATED IN ^{60}Co GAMMA RADIATION, AS A FUNCTION OF BEAM QUALITY R_{50}

(The data are derived using values for stopping-power ratios and perturbation factors as given in Appendix B.)

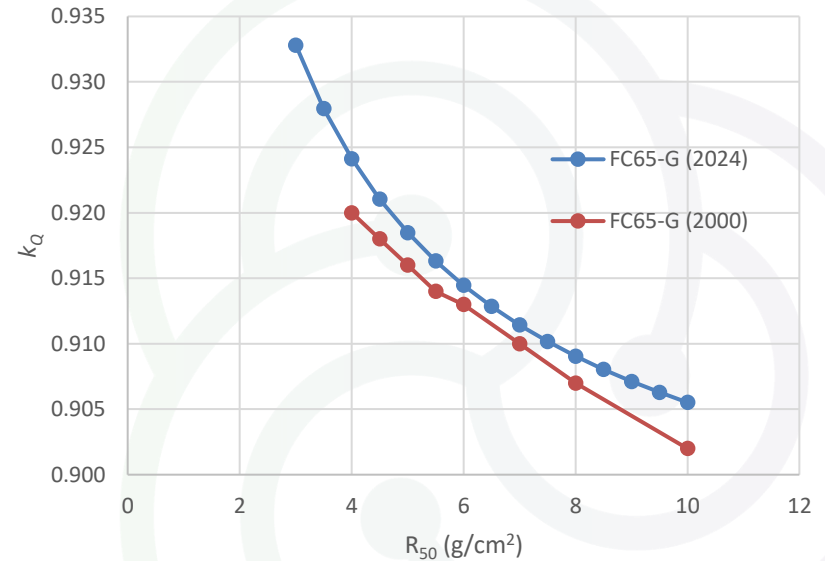
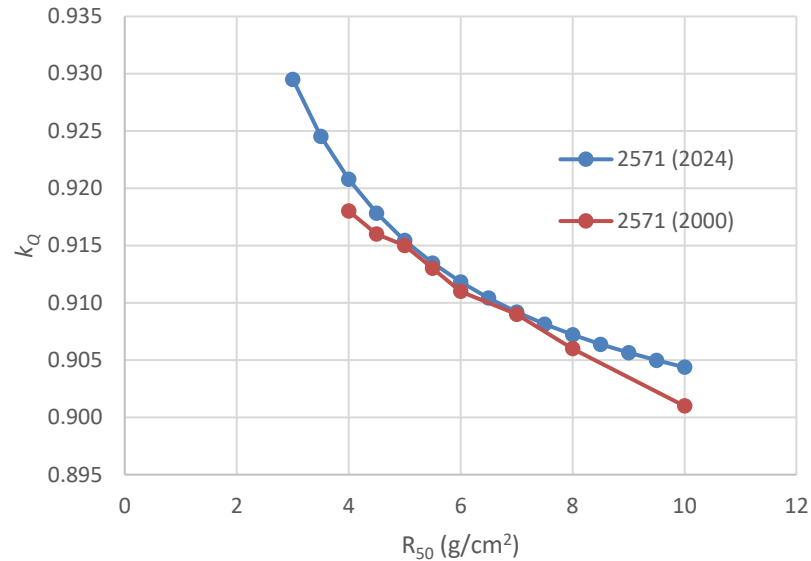
Ionization chamber type ^a	Beam quality R_{50} (g cm ⁻²)																
	1.0	1.4	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	7.0	8.0	10.0	13.0	16.0	20.0
PTW 30006/30013 Farmer	-	-	-	-	-	-	0.911	0.909	0.907	0.906	0.904	0.901	0.898	0.893	0.885	0.878	0.868

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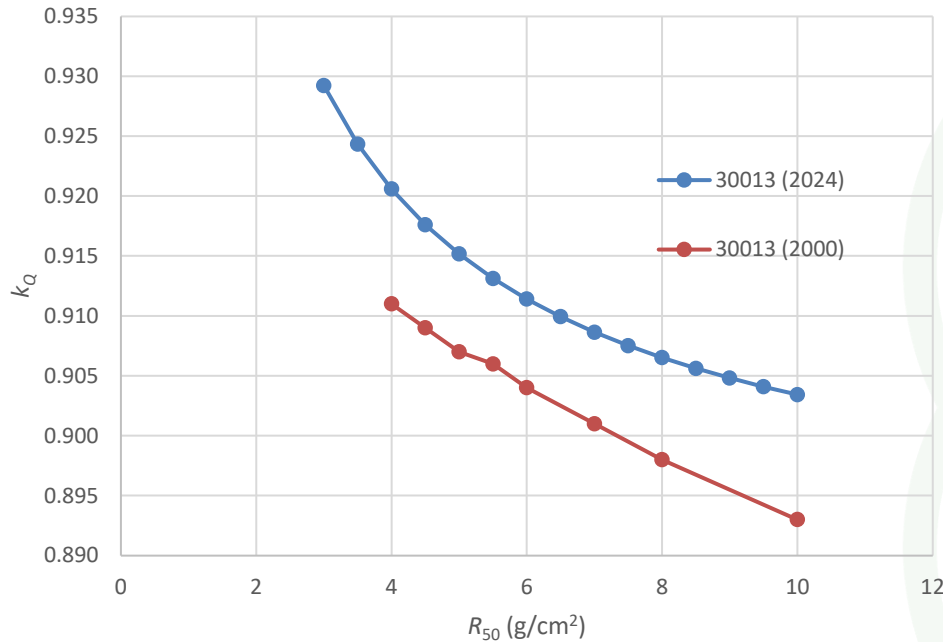
TABLE 20. CALCULATED k_Q VALUES^a FOR ELECTRON BEAMS, FOR VARIOUS CHAMBER TYPES CALIBRATED IN ^{60}Co GAMMA RADIATION, AS A FUNCTION OF BEAM QUALITY INDEX R_{50}

Ionization chamber type ^b	Beam quality index, R_{50} (g/cm ²)													
	1.0 ^c	1.4	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	7.0	8.0	10.0
PTW 34001 Roos	0.9743	0.9645	0.9518	0.9428	0.9349	0.9281	0.9222	0.9171	0.9127	0.9088	0.9055	0.9001	0.8960	0.8907
IBA NACP-02	0.9679	0.9580	0.9451	0.9360	0.9281	0.9214	0.9155	0.9104	0.9061	0.9023	0.8990	0.8938	0.8899	0.8848
NE 2571					0.9297	0.9248	0.9210	0.9181	0.9157	0.9137	0.9121	0.9095	0.9075	0.9047
IBA FC65-G					0.9328	0.9279	0.9241	0.9210	0.9184	0.9163	0.9144	0.9114	0.9090	0.9055
Exradin A12					0.9353	0.9304	0.9264	0.9232	0.9205	0.9182	0.9163	0.9130	0.9104	0.9066
Exradin A19					0.9320	0.9273	0.9236	0.9205	0.9178	0.9156	0.9136	0.9103	0.9077	0.9036
PTW 30013					0.9300	0.9247	0.9210	0.9180	0.9155	0.9135	0.9118	0.9090	0.9068	0.9037
PTW 30012					0.9384	0.9331	0.9290	0.9257	0.9230	0.9207	0.9187	0.9156	0.9131	0.9094

MV electrons - thimble chamber k_Q

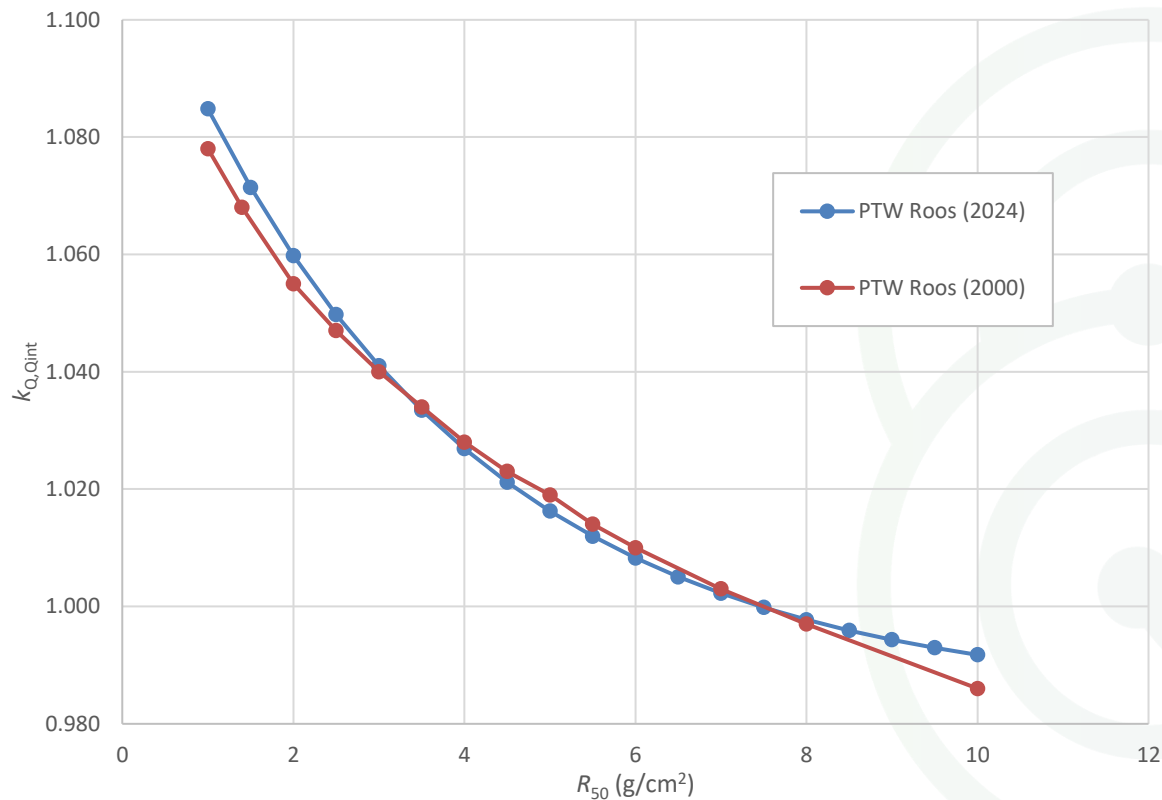


MV electrons - thimble chamber k_Q



R_{50} (cm)	Difference to TRS-398 (2006) %
4.0	1.1
4.5	0.9
5.0	0.9
5.5	0.8
6.0	0.8
6.5	
7.0	0.8
7.5	
8.0	0.9
8.5	
9.0	
9.5	
10.0	1.2

MV electrons - Roos chamber k_Q



MV electrons

For PTW 30013 there can be up to 1.4% change in clinic D_w

Scenario:

- ~0.8% shift in k_Q if reference chamber is PTW 30013
- Cross-calibrate Roos in high energy electron beam, shift carries through
- $k_{Q,Qint}$ for Roos changes by ~0.6% for low energy beams (4 MeV and 6 MeV)

		% difference Rev 1 - 1st Ed			
		30013	Roos	Roos	
E	R50	kQ	kQ,Qint	kQcross,Qint	sum
6	2.36	0.9%	0.3%	0.2%	1.4%
9	3.61	0.9%	0.0%	0.2%	1.0%
12	4.98	0.9%	-0.3%	0.2%	0.8%
16	6.59	0.9%	-0.1%	0.2%	0.9%

Shift for ARPANSA electron cross-calibration certificates

Reference chamber make and model	TRS-398 v12 (2006) k_Q		TRS-398 Revision 1 k_Q		Correction factor for k_Q and $N_{D,w}$	
	15E $R_{50} = 5.89$ cm	18E $R_{50} = 7.13$ cm	15E $R_{50} = 5.89$ cm	18E $R_{50} = 7.13$ cm	15E $R_{50} = 5.89$ cm	18E $R_{50} = 7.13$ cm
PTW 30013	0.9043	0.9006	0.9118	0.9083	1.0083	1.0086
IBA FC65-G	0.9131	0.9096	0.9148	0.9111	1.0019	1.0016
NE 2571	0.9112	0.9087	0.9122	0.9089	1.0010	1.0002

MV electrons – R_{50}

Original

TABLE 7.1 REFERENCE CONDITIONS FOR THE DETERMINATION OF ELECTRON BEAM QUALITY (R_{50})

Influence quantity	Reference value or reference characteristics
Phantom material	for $R_{50} \geq 4 \text{ g cm}^{-2}$, water. For $R_{50} < 4 \text{ g cm}^{-2}$, <u>water or plastic</u>
Chamber type	for $R_{50} \geq 4 \text{ g cm}^{-2}$, plane-parallel or cylindrical. For $R_{50} < 4 \text{ g cm}^{-2}$, <u>plane parallel</u>
Reference point of chamber	for plane-parallel chambers, on the inner surface of the window at its centre. For cylindrical chambers, on the central axis at the centre of the cavity volume
Position of reference point of chamber	for plane-parallel chambers, at the point of interest. For cylindrical chambers, $0.5 r_{\text{cyl}}$ deeper than the point of interest
SSD	100 cm
Field size at phantom surface	for $R_{50} \leq 7 \text{ g cm}^{-2}$, at least $10 \text{ cm} \times 10 \text{ cm}$. For $R_{50} > 7 \text{ g cm}^{-2}$, at least $20 \text{ cm} \times 20 \text{ cm}$ ^a

^a A field size smaller than $20 \text{ cm} \times 20 \text{ cm}$ may be used provided that R_{50} does not change by more than around 0.1 g cm^{-2} from the value measured for a $20 \text{ cm} \times 20 \text{ cm}$ field.

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TABLE 18. REFERENCE CONDITIONS FOR THE DETERMINATION OF THE ELECTRON BEAM QUALITY INDEX (R_{50})

Influence quantity	Reference value or reference characteristic
Phantom material	<u>Water</u>
Chamber type	For $R_{50} > 3 \text{ g/cm}^2$, plane parallel or cylindrical For $R_{50} \leq 3 \text{ g/cm}^2$, <u>plane parallel</u>
Reference point of chamber	For plane parallel chambers, on the inner surface of the window at its centre ^a For cylindrical chambers, on the central axis at the centre of the cavity volume
Position of reference point of chamber	For plane parallel chambers, at the point of interest ^b For cylindrical chambers, $0.5r_{\text{cyl}}$ deeper than the point of interest ^c
Source-surface distance	100 cm
Field size at phantom surface	<u>At least $10 \text{ cm} \times 10 \text{ cm}$</u>

“The same applicator can be used for all beam energies up to 22 MeV for the measurement of the beam quality; there is no requirement to use a larger field size for higher energies.”

D_w

MV electrons - D_w

Revision 1

Original

TABLE 7.II. REFERENCE CONDITIONS FOR THE DETERMINATION OF ABSORBED DOSE IN ELECTRON BEAMS

Influence quantity	Reference value or reference characteristic
Phantom material	for $R_{50} \geq 4 \text{ g cm}^{-2}$, water. For $R_{50} < 4 \text{ g cm}^{-2}$, <u>water or plastic</u>
Chamber type	for $R_{50} \geq 4 \text{ g cm}^{-2}$, plane-parallel or cylindrical. For $R_{50} < 4 \text{ g cm}^{-2}$, <u>plane parallel</u>
Measurement depth z_{ref}	$0.6 R_{50} - 0.1 \text{ g cm}^{-2}$
Reference point of chamber	for plane-parallel chambers, on the inner surface of the window at its centre. For cylindrical chambers, on the central axis at the centre of the cavity volume
Position of reference point of chamber	for plane-parallel chambers, at z_{ref} . For cylindrical chambers, $0.5 r_{cyl}$ deeper than z_{ref}
SSD	100 cm
Field size at phantom surface	<u>10 cm x 10 cm</u> or that used for normalization of output factors, whichever is larger

TABLE 19. REFERENCE CONDITIONS FOR THE DETERMINATION OF ABSORBED DOSE IN ELECTRON BEAMS

Influence quantity	Reference value or reference characteristic
Phantom material	<u>Water</u>
Chamber type	For $R_{50} \geq 3 \text{ g/cm}^2$, plane parallel or cylindrical ^a For $R_{50} < 3 \text{ g/cm}^2$, <u>plane parallel</u>
Measurement depth, z_{ref}	$0.6R_{50} - 0.1 \text{ g/cm}^2$
Reference point of chamber	For plane parallel chambers, on the inner surface of the window at its centre ^b For cylindrical chambers, on the central axis at the centre of the cavity volume
Position of reference point of chamber	For plane parallel chambers, at z_{ref} For cylindrical chambers, $0.5r_{cyl}$ deeper than z_{ref} ^c
Source-surface distance	100 cm
Field size at phantom surface	<u>10 cm × 10 cm</u>

In the text it says larger is allowed p108

MV electrons - uncertainties

Revision 1

Original

TABLE 7.VII. ESTIMATED RELATIVE STANDARD UNCERTAINTY ^a OF $D_{w,Q}$ AT THE REFERENCE DEPTH IN WATER AND FOR AN ELECTRON BEAM, BASED ON A CHAMBER CALIBRATION IN ⁶⁰Co GAMMA RADIATION

Physical quantity or procedure	Relative standard uncertainty (%)	
	User chamber type: cylindrical Beam quality range: $R_{50} \geq 4 \text{ g cm}^{-2}$	plane-parallel $R_{50} \geq 1 \text{ g cm}^{-2}$
Combined standard uncertainty of $D_{w,Q}$ (Steps 1+2)	1.6	2.1

TABLE 7.VIII. ESTIMATED RELATIVE STANDARD UNCERTAINTY ^a OF $D_{w,Q}$ AT THE REFERENCE DEPTH IN WATER AND FOR AN ELECTRON BEAM, BASED ON A CHAMBER CALIBRATION IN A HIGH-ENERGY ELECTRON BEAM

Physical quantity or procedure	Relative standard uncertainty (%)	
	User chamber type: cylindrical Beam quality range: $R_{50} \geq 4 \text{ g cm}^{-2}$	plane-parallel $R_{50} \geq 1 \text{ g cm}^{-2}$
Combined standard uncertainty of $D_{w,Q}$ (Steps 1+2)	1.4	1.4

TABLE 24. ESTIMATED RELATIVE STANDARD UNCERTAINTY^a OF $D_{w,Q}$ AT THE REFERENCE DEPTH IN WATER AND FOR AN ELECTRON BEAM, BASED ON A CHAMBER CALIBRATION IN ⁶⁰Co GAMMA RADIATION (cont.)

Physical quantity or procedure	Relative standard uncertainty (%)	
	Cylindrical $R_{50} \geq 3 \text{ g/cm}^2$	Plane parallel $R_{50} \geq 2 \text{ g/cm}^2$
Combined uncertainty of step 2	0.9	1.0
Combined standard uncertainty of $D_{w,Q}$ (steps 1 and 2)	1.1	1.2

TABLE 25. ESTIMATED RELATIVE STANDARD UNCERTAINTY^a OF $D_{w,Q}$ AT THE REFERENCE DEPTH IN WATER FOR AN ELECTRON BEAM, BASED ON A CHAMBER CALIBRATION IN A HIGH ENERGY ELECTRON BEAM

Physical quantity or procedure	Relative standard uncertainty (%)	
	Cylindrical $R_{50} \geq 3 \text{ g/cm}^2$	Plane parallel $R_{50} \geq 2 \text{ g/cm}^2$
Combined uncertainty of step 2	0.6	0.7
Combined standard uncertainty of $D_{w,Q}$ (steps 1 and 2)	0.8	0.9

MV electrons

Original

Recommended **not** using a plane-parallel chamber with a ^{60}Co calibration for MeV electrons

Revision 1

Recommendation remains but is weaker. Only the text at the start of the chapter suggests this path *not* be used:

“Ideally, the chamber should be calibrated in an electron beam, either directly at a standards laboratory or by cross-calibration in a clinical electron beam.”

Low- and medium-energy X-rays

- Revision 1 allows N_K as well as $N_{D,w}$ pathways

N_K pathway - chamber is calibrated for air kerma

$N_{D,w}$ pathway - chamber is calibrated for absorbed dose to water

- Emphasis on beam quality as both kV and HVL
- Updated backscatter factors and μ_{en}/ρ ratios
- Dosimetry data available from a **web database**

<http://52.233.195.208/About>

IAEA TRS-398 kV x-rays data

A web app for back scatter factors and water/air ratios of mass energy-absorption coefficients

About

BmuenAl

muen2Cu

BmuenCu

kgBwAl

kgmuen2Cu

DATA FOR THE DOSIMETRY OF LOW- AND MEDIUM-ENERGY KV X RAYS USING IAEA TRS-398

This web site provides graphical user interfaces (GUIs) for the calculation of dosimetric quantities for the dosimetry of low- and medium-energy kV x rays, as a function of the beam quality Q specified by the kilovoltage and half-value layer in mm of Al or mm of Cu, $Q(\text{kV}, \text{HVL})$. The calculated quantities correspond to the two routes described in the Code of Practice:

1. Measurements with ionization chambers calibrated in terms of air kerma free-in-air (FIA)

- For **low-energy kV x rays**, the GUI [BmuenAl](#) calculates backscatter factors in water, $B_w(Q, f, \text{SSD})$, and water/air ratios of mass energy-absorption coefficients free-in-air, $[\mu_{\text{en}}(Q)/\rho]_{\text{w,air}}^{\text{FIA}}$, for the determination of the absorbed dose to water at the surface of a water phantom based on in-air measurements with a field diameter f and a source-to-surface distance SSD. The ranges included are 10-150 kV, HVL between 0.01 and 10 mm Al, f between 1 cm and 30 cm, and SSD between 10 cm and 100 cm.

Low energy kV x-rays

Original

8.4.1. Reference conditions

The reference conditions for the determination of absorbed dose to water are given in Table 8.II.

TABLE 8.II. REFERENCE CONDITIONS FOR THE DETERMINATION OF ABSORBED DOSE IN LOW-ENERGY X-RAY BEAMS

Influence quantity	Reference value or reference characteristics
Phantom material	water-equivalent plastic or PMMA
Chamber type	plane-parallel for low-energy x-rays
Measurement depth z_{ref}	phantom surface
Reference point of the chamber	at the centre of outside surface of chamber window or additional build-up foil if used ^a
SSD	usual treatment distance as determined by the reference applicator ^b
Field size	3 cm x 3 cm, or 3 cm diameter, or as determined by the reference applicator ^b

^a The reference point of the chamber is the outside surface because the calibration factor $N_{D,w,Q}$ is given in terms of the absorbed dose to the surface of water.

^b An applicator with a field size equal to (or otherwise minimally larger than) the reference field size should be chosen as the reference applicator.

In-phantom method

Revision 1

TABLE 27. REFERENCE CONDITIONS FOR THE DETERMINATION OF ABSORBED DOSE IN LOW ENERGY X RAY BEAMS USING THE IN-PHANTOM METHOD

Influence quantity	Reference value or reference characteristic
Phantom material	Water equivalent plastic or PMMA
Chamber type	Plane parallel for low energy X rays (up to 100 kV)
Measurement depth	Phantom surface
Reference point of the chamber	At the centre of the outside surface of the chamber window (or foil, if used)
Source–surface distance	Defined by the end of the reference applicator
Field size	Same field size as that used for the calibration at the standards laboratory

In-phantom method

(in-air method allowed – see next slide)

Low energy kV x-rays

Revision 1

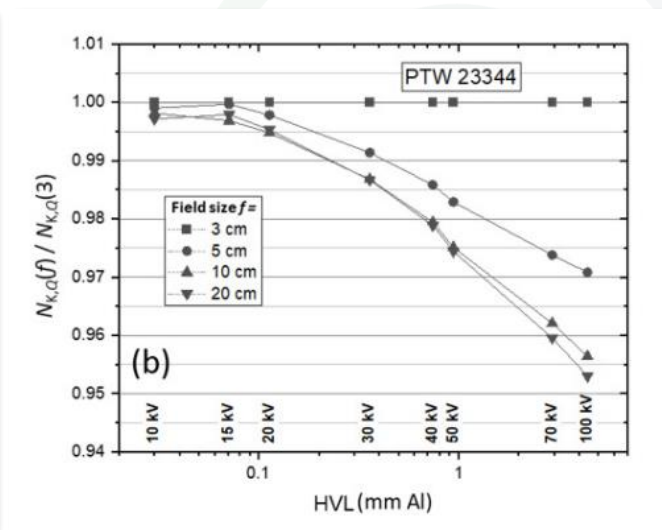
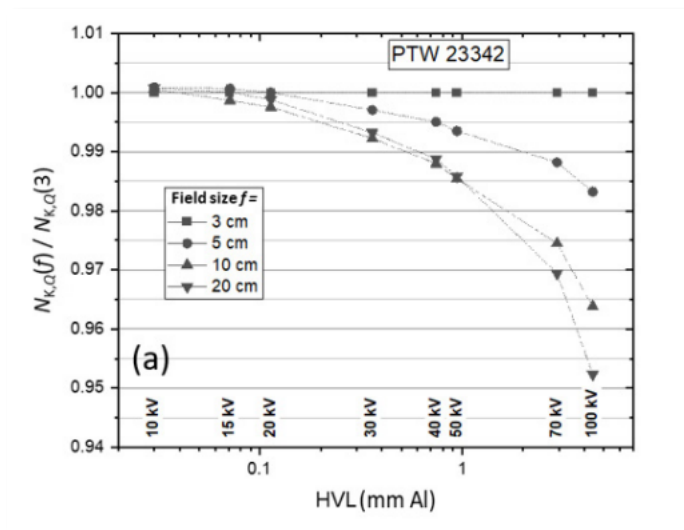
TABLE 26. REFERENCE CONDITIONS FOR THE DETERMINATION OF ABSORBED DOSE IN LOW ENERGY X RAY BEAMS USING THE IN-AIR METHOD

Influence quantity	Reference value or reference characteristic
Chamber type	Plane parallel for low energy X rays (up to 100 kV) Cylindrical chamber for X ray energies above 70 kV
Measurement point	Free in air at the end of the applicator
Reference point of the chamber	Plane parallel chamber: at the centre of the outside surface of the chamber window (or foil, if used) Cylindrical chamber: the reference point of the cylindrical chamber is taken to be on the chamber axis at the centre of the cavity volume
Source–surface distance	Defined by the end of the reference applicator
Field size, f	Parallel plate chamber: 10 cm diameter (or 10 cm × 10 cm) ^a Cylindrical chamber: 5 cm diameter (or 5 cm × 5 cm)

^a If this field size is not available in the clinical beam, the air kerma calibration coefficients can be corrected for other field sizes using the data shown in Fig. 11.

In-air method

Low-energy kV: now includes field-size corrections

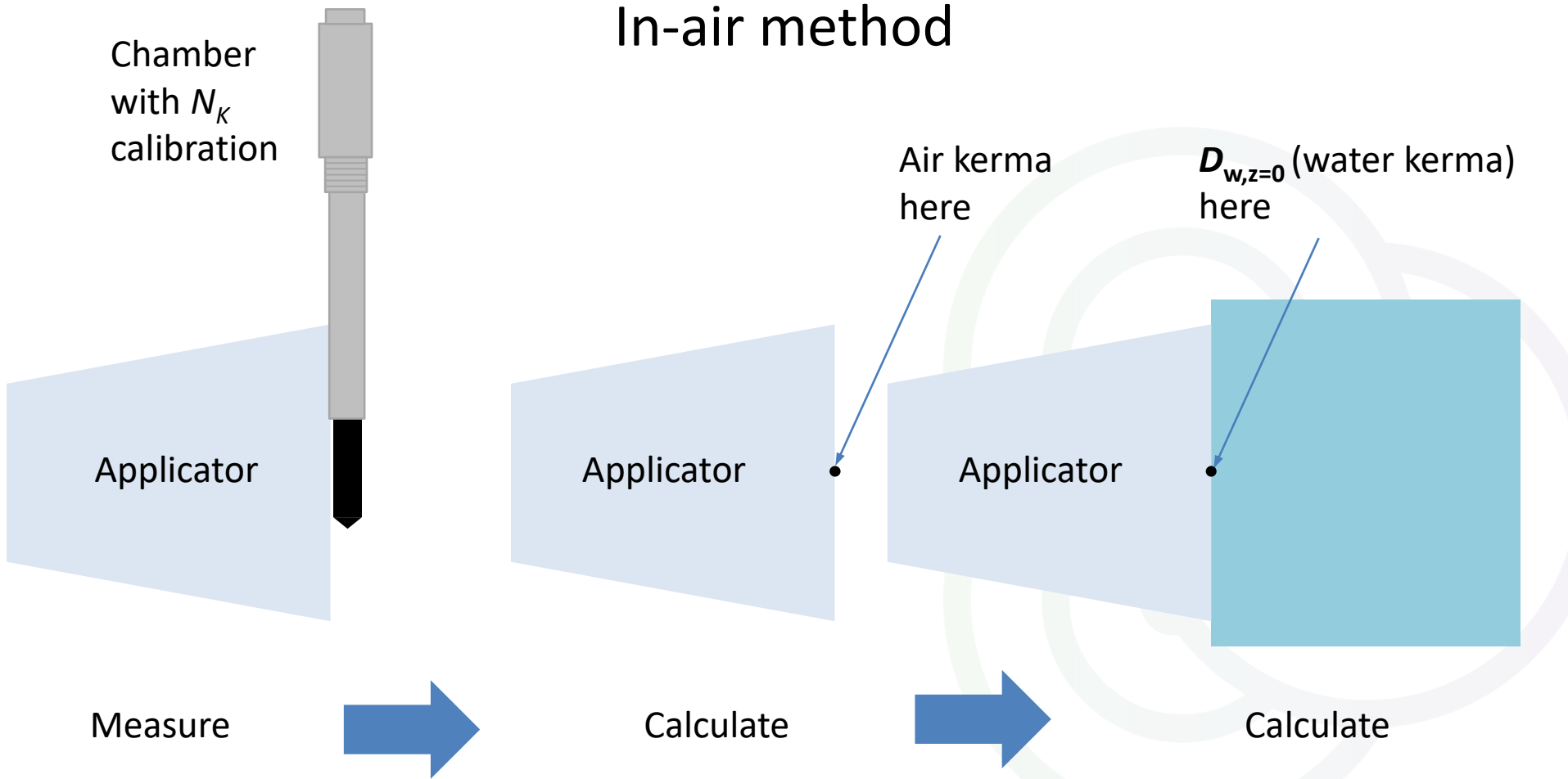


- Measured by PTB, Germany, at 30 cm

Medium-energy kV photons: In-water measurement

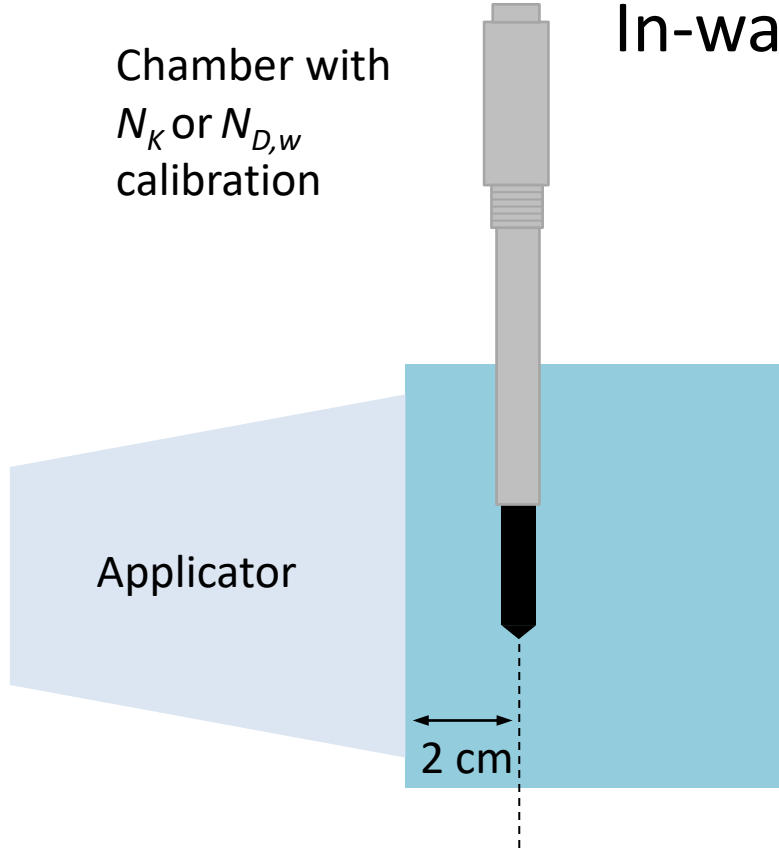
- Like previous version only allows in-water method, not in-air
 - Thimble chamber placed in water at 2 cm depth
 - In-air measurement not allowed
- AAPM TG-61 (and IPEMB) allows in-air method
- In Australia/NZ nearly all dosimetry is performed in air
- Adopting TRS-398 would involve significant effort

In-air method

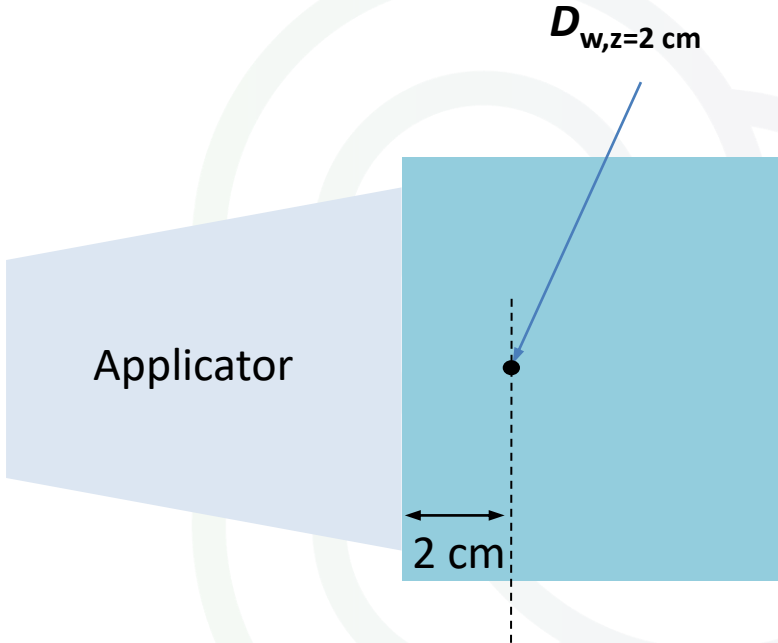
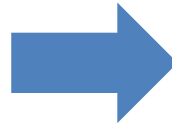


In-water method

Chamber with
 N_K or $N_{D,w}$
calibration

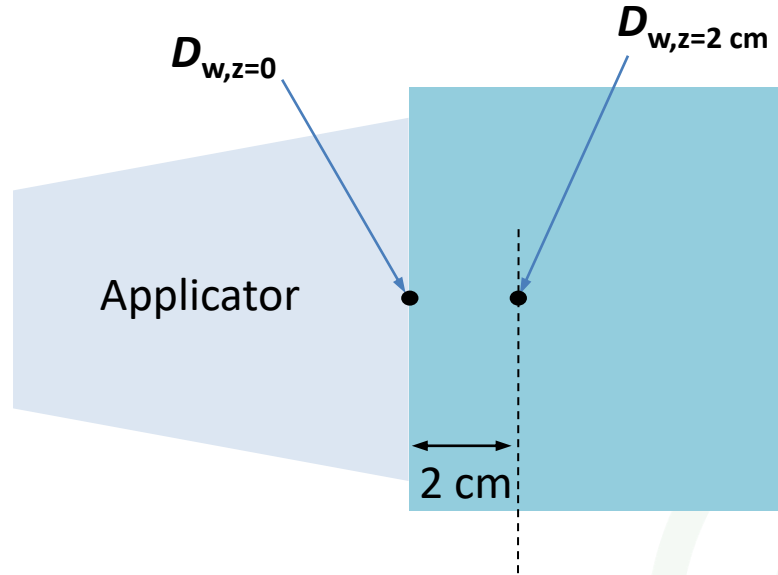


Measure



Calculate

In-air method v in-water method



To change to in-water method, need accurate measurement of $D_{w,z=0} / D_{w,z=2\text{ cm}}$

- to compare with previous
- to calculate prescribed doses if prescribed at $z=0$

Not so easy to measure at surface “ $z=0$ ”

Adopting TRS-398 Revision 1 for kV not recommended at this stage

- No kV D_w standards in Australian/NZ,
- 2 cm not usually closer to target depth

Advantages minimal

Lots of effort

Still need in-air method below 100 kV

Interpolation to clinic Q ?

“The air kerma calibration coefficients $N_{K,air,Q}$ of the user chamber for clinical qualities are obtained (usually by interpolation) from those provided by the calibration laboratory for a set of standard $(Q, f, SSD)_{lab}$ conditions; as the in-air calibration coefficients have a negligible dependence on f and SSD ⁶⁴ for the limited range of values used at the calibration laboratory, only the beam quality needs to be considered for their derivation”

MV protons

- More emphasis on pencil beam scanning (PBS) delivery
- Re-calculated k_Q values, ICRU-90 based, but still analytical (and within 2% of 1st edition)
- Changes to reference depths in plateau region
- Addresses issues with recombination and polarity
- New supplement on calibration of monitor chambers to be published separately

Protons - beam quality

$$R_{\text{res}} = R_p - z$$

Original

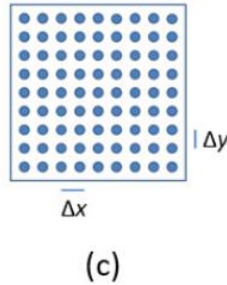
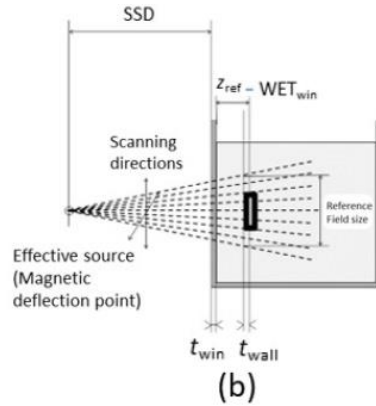
Influence quantity	Reference value or reference characteristics
Phantom material	water
Chamber type	<u>cylindrical and plane-parallel</u>
Reference point of chamber	for plane-parallel chambers, on the inner surface of the window at its centre. For cylindrical chambers, on the central axis at the centre of the cavity volume
Position of reference point of chamber	for plane-parallel and cylindrical chambers, at the point of interest
SSD	clinical treatment distance
Field size at the phantom surface	10 cm x 10 cm For small field applications (i.e. eye treatments), 10 cm x 10 cm or the largest field clinically available

Revision 1

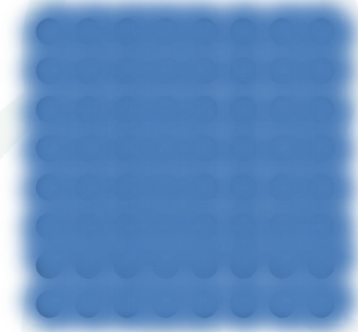
Influence quantity	Reference value or reference characteristic
Phantom material	Water
Chamber type	<u>Plane parallel</u>
Reference point of the chamber	On the inner surface of the window at its centre
Position of the reference point of the chamber	At the point of interest
Source-surface distance	Clinical treatment distance
Field size at the phantom surface	For broad beams, 10 cm × 10 cm For small field applications (i.e. eye treatments), 10 cm × 10 cm or the largest field clinically available <u>For scanned beams, the spot size of a single energy static pencil beam</u>

Protons - dosimetry

- Absorbed dose under reference conditions



Same MU (or NP) per spot



Symmetry of <1% and flatness of <2% required

$$D_{w,Q}(z_{\text{ref}}) = M_Q N_{D,w,Q_0} k_{Q,Q_0}$$

Original version of TRS-398: PBS is only a footnote

TABLE 10.II. REFERENCE CONDITIONS FOR THE DETERMINATION OF ABSORBED DOSE IN PROTON BEAMS

Influence quantity	Reference value or reference characteristics
Phantom material	water
Chamber type	for $R_{res} \geq 0.5 \text{ g cm}^{-2}$, cylindrical and plane-parallel. for $R_{res} < 0.5 \text{ g cm}^{-2}$, plane-parallel.
Measurement depth z_{ref}	middle of the SOBP ^a
Reference point of chamber	for plane-parallel chambers, on the inner surface of the window at its centre. For cylindrical chambers, on the central axis at the centre of the cavity volume
Position of reference point of chamber	for plane-parallel and cylindrical chambers, at the measurement depth z_{ref} .
SSD	clinical treatment distance
Field size at the phantom surface	10 cm x 10 cm, or that used for normalization of the output factors whichever is larger. For small field applications (i.e. eye treatments), 10 cm x 10 cm or the largest field clinically available

^a The reference depth can be chosen in the "plateau region", at a depth of 3 g cm^{-2} , for clinical applications with a mono-energetic proton beam (e.g. for plateau irradiations).

Broad beams

Revision 1

Pencil Beam Scanning

TABLE 35. REFERENCE CONDITIONS FOR THE DETERMINATION OF ABSORBED DOSE TO WATER IN BROAD PROTON BEAMS CALIBRATED IN A SPREAD-OUT BRAGG PEAK

Influence quantity	Reference value or reference characteristic
Phantom material	Water
Chamber type	For $R_{\text{res}} > 0.5 \text{ g/cm}^2$, cylindrical and plane parallel For $R_{\text{res}} < 0.5 \text{ g/cm}^2$, plane parallel
Measurement depth, z_{ref}	Middle of the spread out Bragg peak
Reference point of the chamber	For plane parallel chambers, on the inner surface of the window, at its centre For cylindrical chambers, on the central axis, at the centre of the cavity volume
Position of the reference point of the chamber	For plane parallel and cylindrical chambers, at the measurement depth z_{ref}
Source–surface distance	Clinical treatment distance
Field size at the phantom surface	10 cm $\times$ 10 cm, or the size used for the normalization of the field output factors, whichever is larger For small field applications (i.e. eye treatments), 10 cm $\times$ 10 cm or the largest field clinically available

TABLE 36. REFERENCE CONDITIONS FOR THE DETERMINATION OF ABSORBED DOSE TO WATER IN SCANNED PROTON BEAMS CALIBRATED IN A SINGLE ENERGY PENCIL BEAM USING A SINGLE ENERGY LAYER SCANNED FIELD

Influence quantity	Reference value or reference characteristic
Phantom material	Water
Chamber type	For $R_{\text{res}} \geq 15 \text{ g/cm}^2$, cylindrical and plane parallel For $R_{\text{res}} < 15 \text{ g/cm}^2$, plane parallel
Measurement depth, z_{ref}	The plateau region, at a depth of 2 g/cm ² , for beams with $R_p \geq 5.0 \text{ g/cm}^2$ The plateau region, at a depth of 1 g/cm ² , for beams with $R_p > 5.0 \text{ g/cm}^2$
Reference point of the chamber	For plane parallel chambers, on the inner surface of the window at its centre For cylindrical chambers, on the central axis at the centre of the cavity volume
Position of the reference point of the chamber	For cylindrical and plane parallel chambers, at the measurement depth z_{ref}
Source–surface distance	Clinical treatment distance
Reference field size at the phantom surface	Uniform scanned field, large enough to achieve at least 99.5% of lateral charged particle equilibrium (i.e. the field output factor changes by <0.5% for fields larger than the reference field)

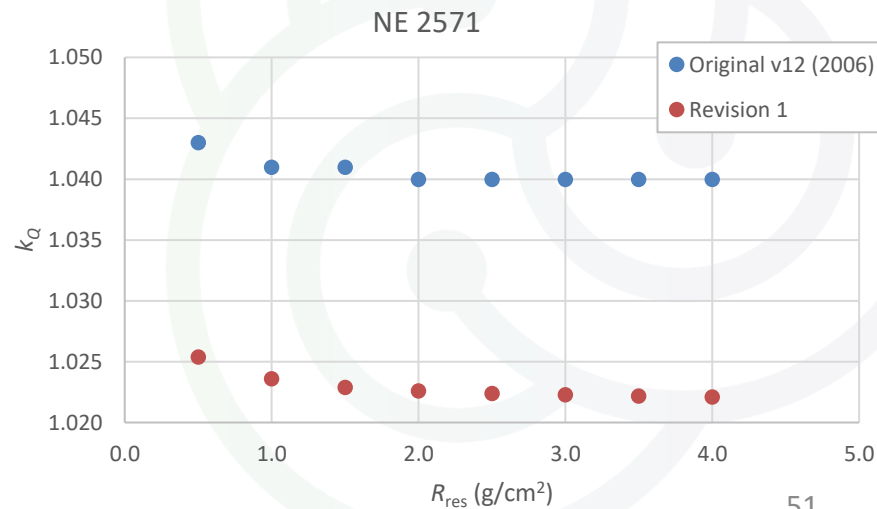
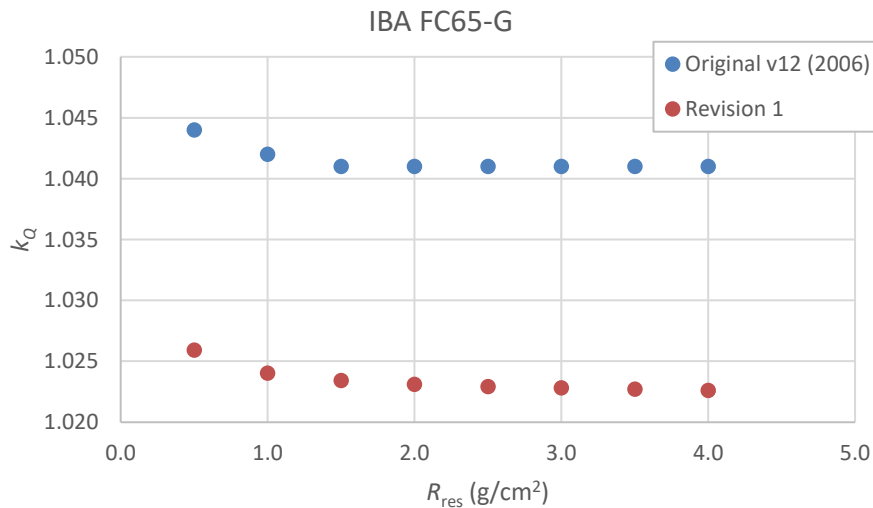
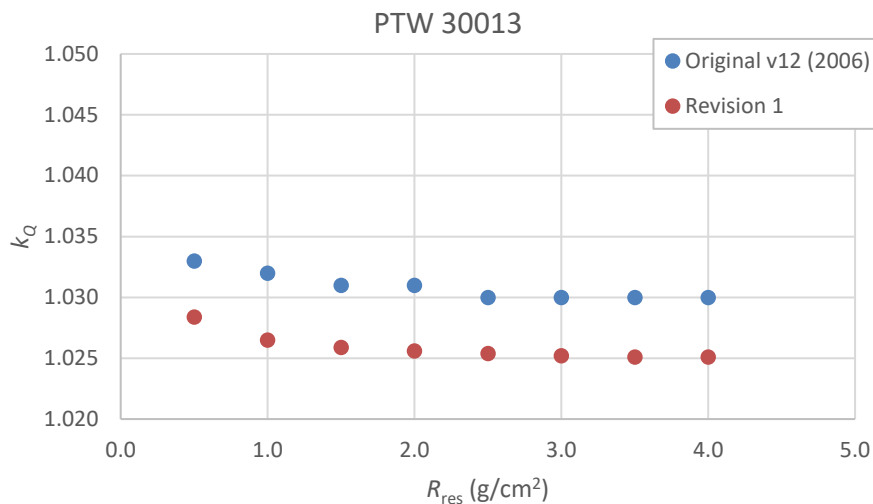
MV proton k_Q factors

- Updated values published in:

Palmans H, Lourenço A, Medin J, Vatnitsky S, Andreo P. *Current best estimates of beam quality correction factors for reference dosimetry of clinical proton beams*. Phys Med Biol. 2022 Sep 29;**67**(19)

- Plane-parallel k_Q factors changed by 0.2% - 0.5%
(NACP02, Markus, Roos)
- Thimble k_Q factors up to 1.7% change

MV protons: thimble k_Q



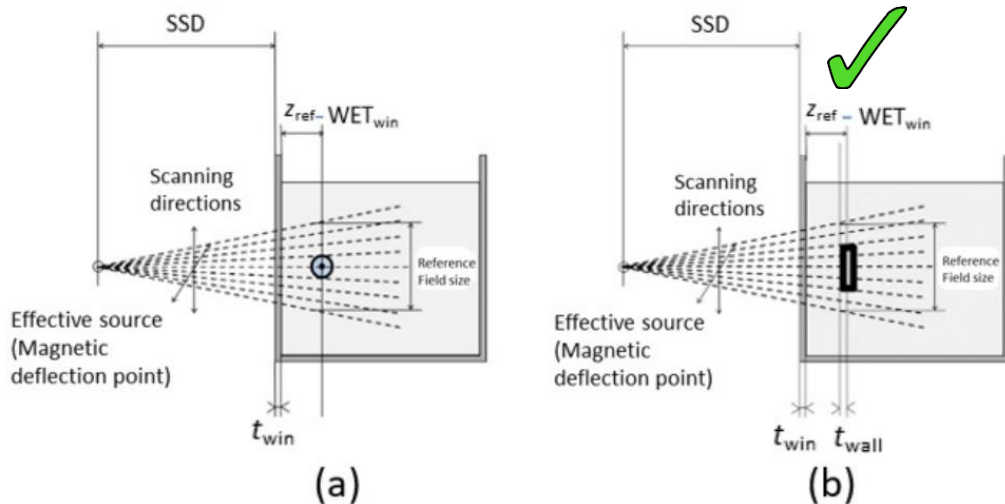
Potential for ambiguity in reference point

Reference point
of the chamber

For plane parallel chambers, on the inner surface of the
window, at its centre



For cylindrical chambers, on the central axis, at the centre of
the cavity volume



4.2.5.2 “...On the other hand, in charged particle beams, the energy loss due to the chamber wall can be significantly different from that caused by the same thickness of phantom material, and **the water equivalent thickness of the chamber wall has to be taken into account** when calculating where to position the chamber”

Appendix II

DETERMINATION OF k_{Q,Q_0} AND ITS UNCERTAINTY

- Details!
- Goes through all the derivations
- Lots of data
- Some k_Q factors still based on minimal published data

Recommendations

- Joint ROSIG/ARPANSA statement?

Recommendations regarding the adoption of the IAEA TRS-398 Code of Practice Revision 1

Authors? All members of that meeting?

Jeffrey Barber, Rhonda Brown, Duncan Butler, Brendan Healy, Robin Hill, Joerg Lehmann, Chris Oliver, Madelaine Tyler, Stewart Midgley, Allan Stewart, Brindha [Subramanian](#),...Scott Penfolds

Can we call ourselves an ad hoc working party :)? Or make this a joint statement?

1. Introduction

The IAEA Technical Report Series 398 *Code of Practice for the determination of absorbed dose to water in external beam radiotherapy*¹ has been widely adopted in Australia and New Zealand since its introduction in 2000. In March 2024, the IAEA released a new version of TRS-398: Revision 1². Here we provide recommendations regarding the adoption of TRS 398 Revision 1 and discuss some of the changes that may require consideration.

We note that the original TRS-398 underwent minor changes until version 12, and our comments refer to this 2006 version as the “previous TRS-398”. TRS-398 Revision 1 is the first official update from the IAEA. Despite being very similar to the previous versions it nevertheless may result in small changes to dosimetry results, documented below.

Proposal

2. Recommendation

We recommend radiotherapy clinics adopt TRS-398 Revision 1 for megavoltage photons, electrons, and protons, and continue to use AAPM TG-61³ for kilovoltage photons⁴.

3. Timeline

We recommend that TRS-398 Revision 1² be implemented by 1 July 2025.

- ARPANSA will change to TRS-398 Revision 1 on 1 July 2024, affecting the calibration service for plane-parallel chambers calibrated in a high-energy electron beam. The change will be described in the calibration certificates.
- The ACDS will audit against TRS-398 Revision 1 from 1 July 2024. Explanatory notes will accompany audit findings that relate to differences in the protocol used at the clinic.

Summary

- Main difference for clinics probably MV electrons (up to 1.4%)
- Can re-calculate without re-measuring
- Be careful! (wrong way and ~3% error)
- ARPANSA electron cross-calibrations can be changed via:

Reference chamber make and model	TRS-398 v12 (2006) k_Q		TRS-398 Revision 1 k_Q		Correction factor for k_Q and $N_{D,w}$	
	15E $R_{50} = 5.89$ cm	18E $R_{50} = 7.13$ cm	15E $R_{50} = 5.89$ cm	18E $R_{50} = 7.13$ cm	15E $R_{50} = 5.89$ cm	18E $R_{50} = 7.13$ cm
PTW 30013	0.9043	0.9006	0.9118	0.9083	1.0083	1.0086
IBA FC65-G	0.9131	0.9096	0.9148	0.9111	1.0019	1.0016
NE 2571	0.9112	0.9087	0.9122	0.9089	1.0010	1.0002



Australian Government

**Australian Radiation Protection
and Nuclear Safety Agency**



THANK YOU

CONTACT ARPANSA

Email:

psdl@arpansa.gov.au

Website:

www.arpansa.gov.au

Telephone:

+61 3 9433 2211

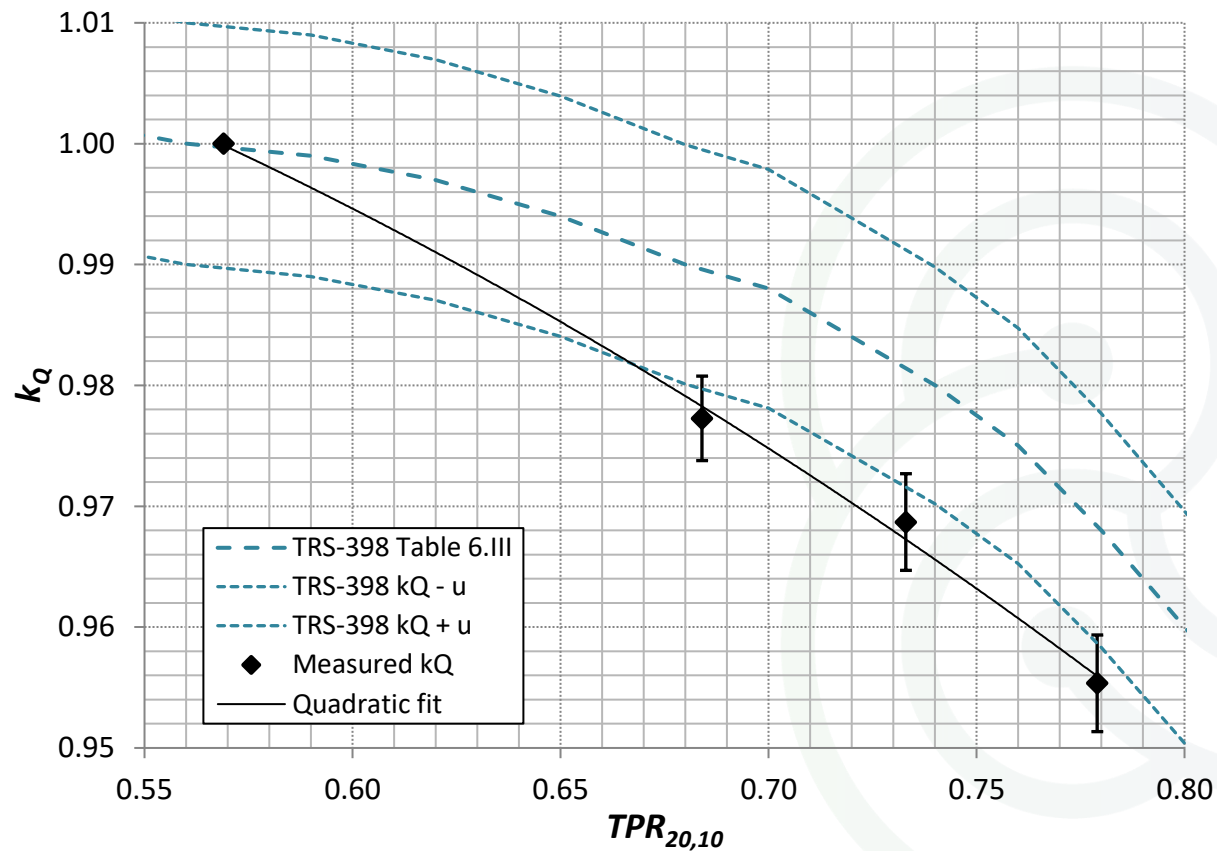
Freecall 1800 022 333

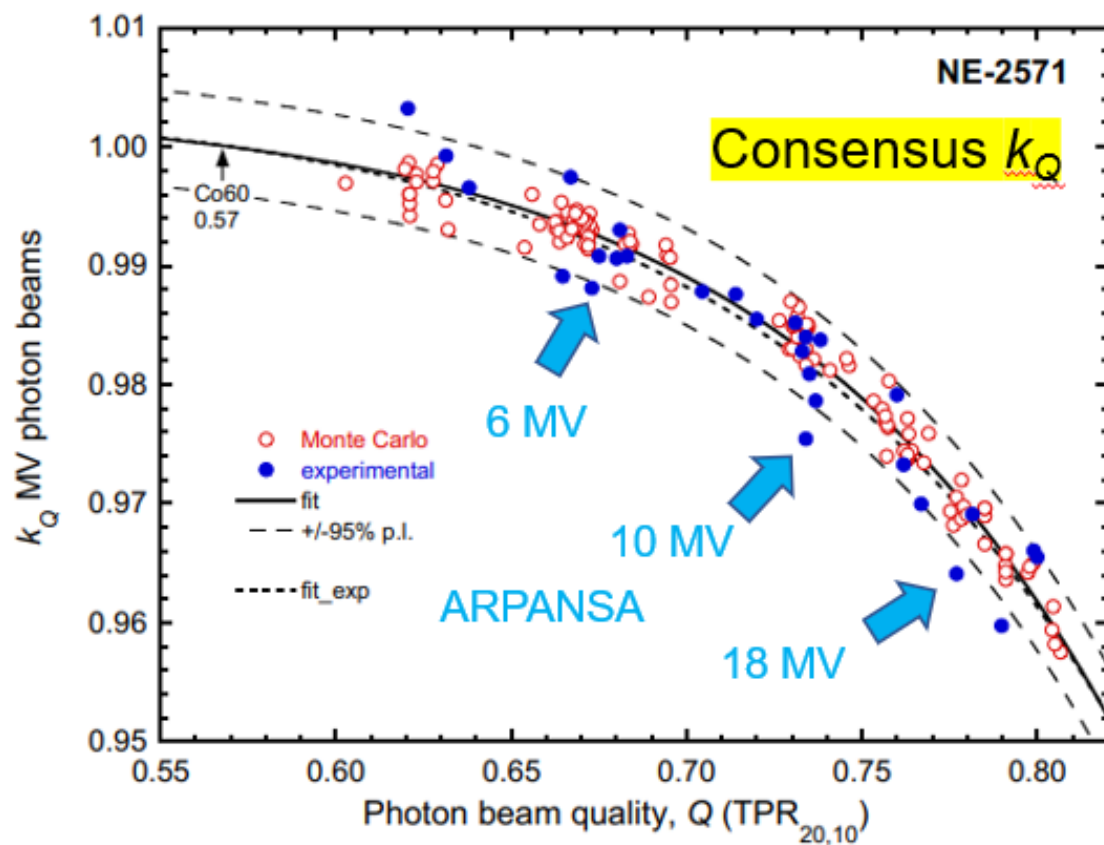
General Fax:

+61 3 9432 1835



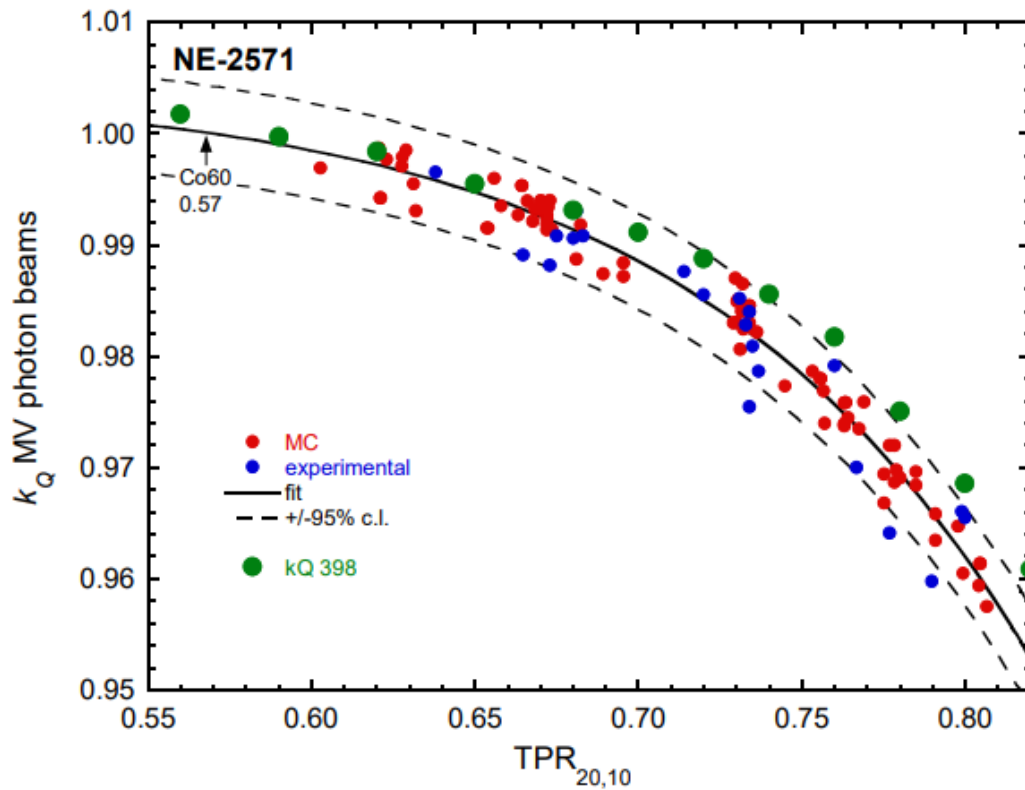
On an ARPANSA calibration report...





Compare with NE-2571 previous data

Photon k_Q from MC calcs by different groups (red) and measured at PSDLs (blue) for a NE-2571 chamber yield mean values



From Pedro Andreo's powerpoint