ERRATA LIST AND UPDATES TO IAEA TRS-398 (2000) [1]

1. page 034 Table 3 (cont)
Chambers SNC 100730 and 100740 are replaced, respectively, by model numbers SNC 100700-0 and 100700-1. Their radii are changed to 3.05 mm (instead of 3.5 mm).
Chambers PTW 31006 and 31014, both Pin Point type, have been added.
All chamber specifications from Scanditronix-Wellhöfer have been modified according to new information provided by the manufacturer.

FOR ALL THE CHAMBERS ADDED OR MODIFIED,
NEW k_Q VALUES HAVE BEEN COMPUTED

2. page 052

$$k_{pol} = \frac{k_{pol}}{[k_{pol}]_{Q_o}}$$ is replaced by: $$k'_{pol} = \frac{[k_{pol}]_Q}{[k_{pol}]_{Q_o}}$$

3. page 52 line 15

k_{pol} is replaced by $[k_{pol}]_Q$

4. page 52, last sentence in subsection (b)

A notation of modified polarity correction k'_{pol} is inserted

5. page 058 line 7
t_{win} (ρ_{pl} is replaced by t_{win} ρ_{pl}

6. page 064

nC/dg replaced with nC/rdg

[1] These are included in the latest electronic version of the Code of Practice, V12 of 2006 (marked in red)

7. page 065 line 5

   $M = M_1/k_{TP}\ k_{elec}\ k_{pol}\ k_s$ is replaced by $M = M_1\ k_{TP}\ k_{elec}\ k_{pol}\ k_s$

8. page 073

   Identification and values for the SNC chambers have been modified.

   Chambers PTW 31006 and 31014, Pin Point have been added.

9. page 074

   Values for the Scdx-Wellhöfer chambers have been modified

10. page 091 table 18:

    new data for Roos and NE-2581 chambers **(already included as erratum in printed copies)**

11. page 092 table 18

    Chambers PTW 30006/30013, and Pin Point 31006 and 31014, have been added

    Scdx-Wellhöfer chambers have been added.

12. page 095 second parr, second line should read

    readings $M^{ref}_{Q_{cross}}$ and $M^{x}_{Q_{cross}}$ should be the averages $\overline{M^{ref}_{Q_{cross}} / M^{em}_{Q_{cross}}}$ and $\overline{M^{x}_{Q_{cross}} / M^{em}_{Q_{cross}}}$

13. page 097 table 19

    Chambers PTW 30006/30013, and Pin Point 31006 and 31014, have been added

    Scdx-Wellhöfer chambers have been added.

14. page 098 line 1 should read

    The values for $k^{x}_{Q,Q_{cross}}$ are derived using the procedure of Section 3.2.1;

15. page 098 line 3 should read

    where $k^{x}_{Q,Q_{\mathrm{int}}}$ and …

16. page 107

    Rating setting replaced with Range setting

17. page 111 Table 24.

    The three columns with a “mm” label (3, 5 and 7) should be labelled with “µm”.

Footnote a should refer to Ref [64]

18. page 113, Figure 10:

    units for $N_{k,Q}$ - ordinate label - should be Gy/nC

19. page 122 third paragraph, fourth line, should read
    accepted Codes of Practice (see Appendix I).

20. page 124, Figure 12

    units for $N_{D,w,Q}$ - ordinate label - should be Gy/nC

21. page 141 Last three lines of Section 10.4.2 should read
    dosimeter at the reference quality Q_o and k_{Q,Q_o} is a chamber-specific factor which corrects for differences between the reference beam quality Q_o and the actual quality being used Q

22. page 143 table 31
    Chambers PTW 31006 and 31014, both Pin Point type, have been added
    Identification and values for the SNC chambers have been modified.

23. page 144 table 31
    Identification and values for the Scdx-Wellhöfer chambers have been modified.

24. page 160 table 34
    Chambers PTW 31006 and 31014, both Pin Point type, have been added
    Identification and values for the SNC chambers have been modified.
    Identification and values for the Scdx-Wellhöfer chambers have been modified.

25. page 161 table 35

Combined uncertainty in step 2 for plane parallel chamber should be 3.4

26. page 177

text regarding the source of p_{wall} for Roos chamber being based on Palm et al (2000) added at the end of Sect II.2.3.3.

27. page 180 table 37

Chambers PTW 31006 and 31014, both Pin Point type, have been added

Identification and values for the SNC chambers have been modified.

Identification and values for the Scdx-Wellhöfer chambers have been modified.

28. page 183, table 39

The uncertainty for W_{air} / e relative to ^{60}Co (third row) should be 0.5

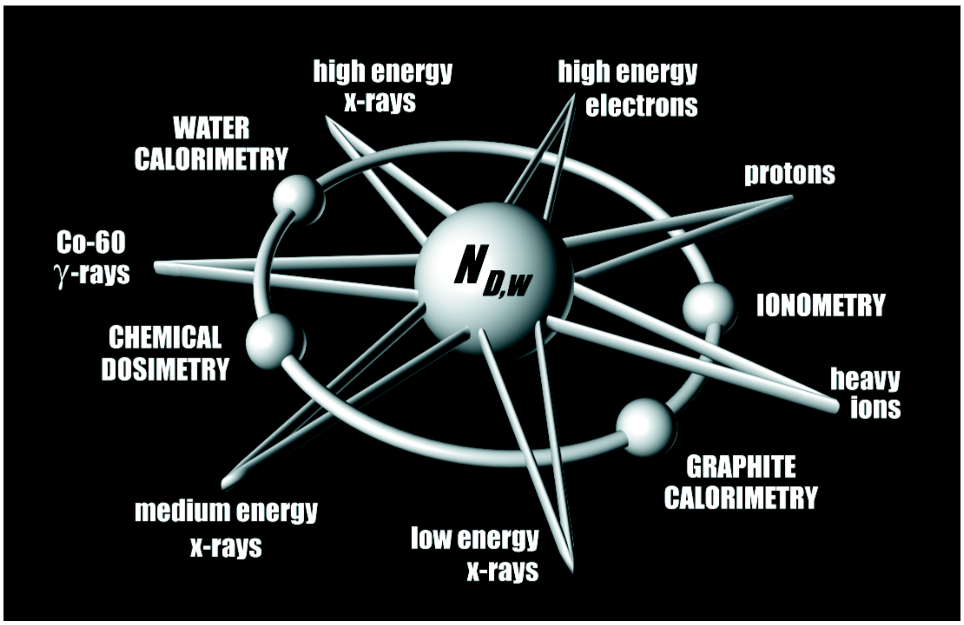
29. page 225

Reference Palm et al (2000) added.

Note that ref Andreo and Brahme [148] in the draft, was suppressed in the printed version due to "technical reasons" and the printed list has one ref less than the draft. The ref is still maintained in the draft also due to "technical reasons".

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 Measures (BIPM)
Klaus Hohlfeld, Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany
M Saiful Huq, Thomas Jefferson University, Philadelphia, USA
Tatsuaki Kanai, National Institute of Radiological Sciences (NIRS), Chiba, Japan
Fedele Laitano, 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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TABLE 4.I. CHARACTERISTICS OF CYLINDRICAL IONIZATION CHAMBER TYPES (*as stated by manufacturers*).

Ionization chamber type [a]	Cavity volume (cm^3)	Cavity length (mm)	Cavity radius (mm)	Wall material	Wall thickness ($g\ cm^{-2}$)	Build-up cap material [b,c]	Build-up cap thickness [b,c] ($g\ cm^{-2}$)	Central electrode material [c]	Waterproof
Capintec PR-05P mini	0.07	5.5	2.0	C-552	0.220	polystyrene	0.568	C-552	N
Capintec PR-05 mini	0.14	11.5	2.0	C-552	0.220	polystyrene	0.568	C-552	N
Capintec PR-06C/G Farmer	0.65	22.0	3.2	C-552	0.050	C-552	0.924	C-552	N
Capintec PR-06C/G Farmer	0.65	22.0	3.2	C-552	0.050	polystyrene	0.537	C-552	N
Capintec PR-06C/G Farmer	0.65	22.0	3.2	C-552	0.050	PMMA [d]	0.547	C-552	N
Exradin A2 Spokas (2 mm cap)	0.53	11.4	4.8	C-552	0.176	C-552	0.352	C-552	Y
Exradin T2 Spokas (4 mm cap)	0.53	11.4	4.8	A-150	0.113	A-150	0.451	A-150	Y
Exradin A1 mini Shonka (2 mm cap)	0.05	5.7	2.0	C-552	0.176	C-552	0.352	C-552	Y
Exradin T1 mini Shonka (4 mm cap)	0.05	5.7	2.0	A-150	0.113	A-150	0.451	A-150	Y
Exradin A12 Farmer	0.65	24.2	3.1	C-552	0.088	C-552	0.493	C-552	Y
Far West Tech IC-18	0.1	9.5	2.3	A-150	0.183	A-150	0.386	A-150	N
FZH TK 01	0.4	12.0	3.5	Delrin	0.071	Delrin	0.430		Y
Nuclear Assoc 30-750	0.03	3.6	2.0	C-552	0.068			C-552	Y
Nuclear Assoc 30-749	0.08	4.0	3.0	C-552	0.068			C-552	Y
Nuclear Assoc 30-744	0.13	5.8	3.0	C-552	0.068			C-552	Y
Nuclear Assoc 30-716	0.25	10.0	3.0	C-552	0.068			C-552	Y
Nuclear Assoc 30-753 Farmer shortened	0.25	9.0	3.1	C-552	0.068	Delrin	0.560	C-552	Y
Nuclear Assoc 30-751 Farmer	0.69	23.0	3.1	Delrin	0.056	Delrin	0.560	aluminium	Y
Nuclear Assoc 30-752 Farmer	0.69	23.0	3.1	graphite	0.072	Delrin	0.560	aluminium	Y
NE 2515	0.2	7.0	3.0	Tufnol	0.074	PMMA	0.543	aluminium	N
NE 2515/3	0.2	7.0	3.2	graphite	0.066	PMMA	0.543	aluminium	N
NE 2577	0.2	8.3	3.2	graphite	0.066	Delrin	0.552	aluminium	N
NE 2505 Farmer	0.6	24.0	3.0	Tufnol	0.075	PMMA	0.545	aluminium	N
NE 2505/A Farmer	0.6	24.0	3.0	nylon 66	0.063	PMMA	0.545	aluminium	N
NE 2505/3, 3A Farmer	0.6	24.0	3.2	graphite	0.065	PMMA	0.551	aluminium	N
NE 2505/3, 3B Farmer	0.6	24.0	3.2	nylon 66	0.041	PMMA	0.551	aluminium	N
NE 2571 Farmer	0.6	24.0	3.2	graphite	0.065	Delrin	0.551	aluminium	N
NE 2581 Farmer (PMMA cap)	0.6	24.0	3.2	A-150	0.041	PMMA	0.584	A-150	N
NE 2581 Farmer (polystyrene cap)	0.6	24.0	3.2	A-150	0.041	polystyrene	0.584	A-150	N
NE 2561/ 2611 Sec Std	0.33	9.2	3.7	graphite	0.090	Delrin	0.600	aluminium (hollow)	N
PTW 23323 micro	0.1	12.0	1.6	PMMA [e]	0.197	PMMA	0.357	aluminium	Y
PTW 23331 rigid	1.0	22.0	4.0	PMMA [e]	0.060	PMMA	0.345	aluminium	N
PTW 23332 rigid	0.3	18.0	2.5	PMMA [e]	0.054	PMMA	0.357	aluminium	N

Ionization chamber type [a]	Cavity volume (cm^3)	Cavity length (mm)	Cavity radius (mm)	Wall material	Wall thickness (g cm^{-2})	Build-up cap material [b,c]	Build-up cap thickness [b,c] (g cm^{-2})	Central electrode material [c]	Waterproof
PTW 23333 (3 mm cap)	0.6	21.9	3.1	PMMA [e]	0.059	PMMA	0.356	aluminium	N
PTW 23333 (4.6 mm cap)	0.6	21.9	3.1	PMMA [e]	0.053	PMMA	0.551	aluminium	N
PTW 30001 Farmer	0.6	23.0	3.1	PMMA [e]	0.045	PMMA	0.541	aluminium	N
PTW 30010 Farmer	0.6	23.0	3.1	PMMA [e]	0.057	PMMA	0.541	aluminium	N
PTW 30002/30011 Farmer	0.6	23.0	3.1	graphite	0.079	PMMA	0.541	graphite	N
PTW 30004/30012 Farmer	0.6	23.0	3.1	graphite	0.079	PMMA	0.541	aluminium	N
PTW 30006/30013 Farmer	0.6	23.0	3.1	PMMA [e]	0.057	PMMA	0.541	aluminium	Y
PTW 31002 flexible	0.13	6.5	2.8	PMMA [e]	0.078	PMMA	0.357	aluminium	Y
PTW 31003 flexible	0.3	16.3	2.8	PMMA [e]	0.078	PMMA	0.357	aluminium	Y
PTW 31006 PinPoint	0.015	5.0	1.0	PMMA [e]	0.078			steel	Y
PTW 31014 PinPoint	0.015	5.0	1.0	graphite	0.086			aluminium	Y
SNC 100700-0 Farmer	0.6	24.4	3.1	PMMA	0.060	PMMA	0.536	aluminium	N
SNC 100700-1 Farmer	0.6	24.4	3.1	graphite	0.085	PMMA	0.536	aluminium	N
Victoreen Radocon III 550	0.3	4.3	2.5	Delrin	0.529		0.536		N
Victoreen Radocon II 555	0.1	23.0	2.4	polystyrene	0.117	PMMA	0.481		N
Victoreen 30-348	0.3	18.0	2.5	PMMA	0.060	PMMA	0.360		N
Victoreen 30-351	0.6	23.0	3.1	PMMA	0.060	PMMA	0.360		N
Victoreen 30-349	1.0	22.0	4.0	PMMA	0.060	PMMA	0.360		N
Victoreen 30-361	0.4	22.3	2.4	PMMA	0.144	PMMA	0.360		N
Scdx-Wellhöfer CC01	0.01	3.6	1.0	C-552	0.088			steel	Y
Scdx-Wellhöfer CC04/IC04	0.04	3.6	2.0	C-552	0.070			C-552	Y
Scdx-Wellhöfer CC08/IC05/IC06	0.08	4.0	3.0	C-552	0.070			C-552	Y
~~Scdx-Wellhöfer IC06~~	~~0.08~~	~~4.0~~	~~3.0~~	~~C-552~~	~~0.068~~			~~C-552~~	~~Y~~
~~Scdx-Wellhöfer IC10~~	~~0.14~~	~~6.3~~	~~3.0~~	~~C-552~~	~~0.068~~			~~C-552~~	~~Y~~
Scdx-Wellhöfer CC13/IC10/IC15	0.13	5.8	3.0	C-552	0.070			C-552	Y
Scdx-Wellhöfer CC25/IC25	0.25	10.0	3.0	C-552	0.070			C-552	Y
Scdx-Wellhöfer FC23-C/IC28 Farmer shortened	0.23	8.8	3.1	C-552	0.070	POM [f]	0.560	C-552	Y
Scdx-Wellhöfer FC65-P/IC 69 Farmer	0.65	23.1	3.1	POM [f]	0.057	POM [f]	0.560	aluminium	Y
Scdx-Wellhöfer FC65-G/IC 70 Farmer	0.65	23.1	3.1	graphite	0.073	POM [f]	0.560	aluminium	Y

[a] Some of the chambers listed in this Table fail to meet the minimum requirements described in Section 4.2.1. However, they have been included because of their current clinical use.

[b] For dose determinations based on standards of absorbed dose to water, the information related to the build-up cap of an ionization chamber is not relevant. It is given here to enable comparisons with previous formalisms based on standards of air kerma.

[c] Blanks correspond to no information available.

[d] Polymethyl Methacrylate ($C_5H_8O_2$), also known as acrylic. Trade names are *Lucite*, *Plexiglas* or *Perspex*.

[e] Like most chamber types with non-conductive plastic walls, the chamber wall has an inner conductive layer made of graphite. For this chamber type, the thickness and density of the graphite layer is supplied in the chamber specifications.

[f] Poly Oxy Methylene (CH_2O). A trade name is *Delrin*.

where M_+ and M_- are the electrometer readings obtained at positive and negative polarity, respectively, and M is the electrometer reading obtained with the polarity used routinely (positive or negative). The readings M_+ and M_- should be made with care, ensuring that the chamber reading is stable following any change in polarity (some chambers can take up to 20 minutes to stabilize). To minimize the influence of fluctuations in the output of radiation generators (clinical accelerators, x-ray therapy units, etc), it is preferable that all the readings be normalized to that of an external monitor. Ideally, the external monitor should be positioned approximately at the depth of measurement but at a distance of 3 to 4 cm from the chamber centre along the major axis in the transverse plane of the beam.

When the chamber is sent for calibration, a decision is normally made, either by the user or by the calibration laboratory, on the polarizing potential and polarity to be adopted for the routine use of the chamber. The calibration should be carried out at this polarizing potential (and polarity, if only one polarity is used for the calibration), or if not, clearly stated. The calibration laboratory may or may not correct for the polarity effect at the calibration quality Q_0. This should be stated in the calibration certificate.

When the calibration laboratory has already corrected for the polarity effect, then the user must apply the correction factor k_{pol} derived using Eq. (4.4) to all measurements made using the routine polarity. When the calibration laboratory has *not* corrected for the polarity effect, the subsequent treatment of the polarity effect depends on the facilities available to the user, and on what beam qualities must be measured:

(a) If the user beam quality is the same as the calibration quality and the chamber is used at the *same polarizing potential and polarity*, then k_{pol} will be the same in both cases and the user must *not* apply a polarity correction for that particular beam (or equivalently k_{pol} is set equal to 1 in the worksheet). If it is not possible to use the same polarizing potential then the polarity effect will not be exactly the same in both cases. The difference should be small and should be estimated and included as an uncertainty.

(b) If the user beam quality is *not* the same as the calibration quality, but it is possible to reproduce the calibration quality, then the polarity correction $[k_{pol}]_{Q_0}$ that was not applied at the time of calibration must be estimated using Eq. (4.4) and using the *same polarizing potential and polarity* as was used at the calibration laboratory. The polarity effect at the user beam quality, $[k_{pol}]_Q$,must also be determined from Eq. (4.4.) using the polarizing potential and polarity adopted for routine use. A modified polarity correction k_{pol}' is then evaluated as follows:

$$k_{pol}' = \frac{[k_{pol}]_Q}{[k_{pol}]_{Q_o}} \qquad (4.5)$$

This is then used to correct the dosimeter readings for polarity for each beam quality Q.

Note that if the user beam quality is not the same as the calibration quality and it is *not* possible to reproduce the calibration quality to estimate the correction $[k_{pol}]_{Q_0}$, then this must be estimated from a knowledge of the chamber response to different beam qualities and polarities. If this can not be done with a relative standard uncertainty (see Appendix D.3) of less than 0.5% then either the chamber should not be used, or it should be sent to a calibration laboratory that can perform the required polarity correction.

TABLE 6.III. CALCULATED VALUES OF k_Q FOR HIGH-ENERGY PHOTON BEAMS, FOR VARIOUS CYLINDRICAL IONIZATION CHAMBERS AS A FUNCTION OF BEAM QUALITY $TPR_{20,10}$
(Adapted from Andreo [20]*)*

	Beam quality $TPR_{20,10}$														
Ionization chamber type [a]	0.50	0.53	0.56	0.59	0.62	0.65	0.68	0.70	0.72	0.74	0.76	0.78	0.80	0.82	0.84
Capintec PR-05P mini	1.004	1.003	1.002	1.001	1.000	0.998	0.996	0.994	0.991	0.987	0.983	0.975	0.968	0.960	0.949
Capintec PR-05 mini	1.004	1.003	1.002	1.001	1.000	0.998	0.996	0.994	0.991	0.987	0.983	0.975	0.968	0.960	0.949
Capintec PR-06C/G Farmer	1.001	1.001	1.000	0.998	0.998	0.995	0.992	0.990	0.988	0.984	0.980	0.972	0.965	0.956	0.944
Exradin A2 Spokas	1.001	1.001	1.001	1.000	0.999	0.997	0.996	0.994	0.992	0.989	0.986	0.979	0.971	0.962	0.949
Exradin T2 Spokas	1.002	1.001	0.999	0.996	0.993	0.988	0.984	0.980	0.977	0.973	0.969	0.962	0.954	0.946	0.934
Exradin A1 mini Shonka	1.002	1.002	1.001	1.000	1.000	0.998	0.996	0.994	0.991	0.986	0.982	0.974	0.966	0.957	0.945
Exradin T1 mini Shonka	1.003	1.001	0.999	0.996	0.993	0.988	0.984	0.980	0.975	0.970	0.965	0.957	0.949	0.942	0.930
Exradin A12 Farmer	1.001	1.001	1.000	1.000	0.999	0.997	0.994	0.992	0.990	0.986	0.981	0.974	0.966	0.957	0.944
Far West Tech IC-18	1.005	1.003	1.000	0.997	0.993	0.988	0.983	0.979	0.976	0.971	0.966	0.959	0.953	0.945	0.934
FZH TK 01	1.002	1.001	1.000	0.998	0.996	0.993	0.990	0.987	0.984	0.980	0.975	0.968	0.960	0.952	0.939
Nuclear Assoc 30-750	1.001	1.001	1.000	0.999	0.998	0.996	0.994	0.991	0.988	0.984	0.979	0.971	0.963	0.954	0.941
Nuclear Assoc 30-749	1.001	1.000	1.000	0.999	0.998	0.996	0.994	0.992	0.989	0.984	0.980	0.972	0.964	0.956	0.942
Nuclear Assoc 30-744	1.001	1.000	1.000	0.999	0.998	0.996	0.994	0.992	0.989	0.984	0.980	0.972	0.964	0.956	0.942
Nuclear Assoc 30-716	1.001	1.000	1.000	0.999	0.998	0.996	0.994	0.992	0.989	0.984	0.980	0.972	0.964	0.956	0.942
Nuclear Assoc 30-753 Farmer shortened	1.001	1.000	1.000	0.999	0.998	0.996	0.994	0.992	0.989	0.985	0.980	0.973	0.965	0.956	0.943
Nuclear Assoc 30-751 Farmer	1.002	1.002	1.000	0.999	0.997	0.994	0.991	0.989	0.985	0.981	0.977	0.969	0.961	0.953	0.940
Nuclear Assoc 30-752 Farmer	1.004	1.003	1.001	1.000	0.998	0.996	0.993	0.991	0.989	0.985	0.981	0.974	0.967	0.959	0.947
NE 2515	1.001	1.001	1.000	0.999	0.997	0.994	0.991	0.988	0.984	0.980	0.975	0.967	0.959	0.950	0.937
NE 2515/3	1.005	1.004	1.002	1.000	0.998	0.995	0.993	0.991	0.989	0.986	0.982	0.975	0.969	0.961	0.949
NE 2577	1.005	1.004	1.002	1.000	0.998	0.995	0.993	0.991	0.989	0.986	0.982	0.975	0.969	0.961	0.949
NE 2505 Farmer	1.001	1.001	1.000	0.999	0.997	0.994	0.991	0.988	0.984	0.980	0.975	0.967	0.959	0.950	0.937
NE 2505/A Farmer	1.005	1.003	1.001	0.997	0.995	0.990	0.985	0.982	0.978	0.974	0.969	0.962	0.955	0.947	0.936
NE 2505/3, 3A Farmer	1.005	1.004	1.002	1.000	0.998	0.995	0.993	0.991	0.989	0.986	0.982	0.975	0.969	0.961	0.949
NE 2505/3, 3B Farmer	1.006	1.004	1.001	0.999	0.996	0.991	0.987	0.984	0.980	0.976	0.971	0.964	0.957	0.950	0.938
NE 2571 Farmer	1.005	1.004	1.002	1.000	0.998	0.995	0.993	0.991	0.989	0.986	0.982	0.975	0.969	0.961	0.949
NE 2581 Farmer	1.005	1.003	1.001	0.998	0.995	0.991	0.986	0.983	0.980	0.975	0.970	0.963	0.956	0.949	0.937
NE 2561 / 2611 Sec Std	1.006	1.004	1.001	0.999	0.998	0.994	0.992	0.990	0.988	0.985	0.982	0.975	0.969	0.961	0.949

Ionization chamber type [a]	Beam quality $TPR_{20,10}$ 0.50	0.53	0.56	0.59	0.62	0.65	0.68	0.70	0.72	0.74	0.76	0.78	0.80	0.82	0.84
PTW 23323 micro	1.003	1.003	1.000	0.999	0.997	0.993	0.990	0.987	0.984	0.980	0.975	0.967	0.960	0.953	0.941
PTW 23331 rigid	1.004	1.003	1.000	0.999	0.997	0.993	0.990	0.988	0.985	0.982	0.978	0.971	0.964	0.956	0.945
PTW 23332 rigid	1.004	1.003	1.001	0.999	0.997	0.994	0.990	0.988	0.984	0.980	0.976	0.968	0.961	0.954	0.943
PTW 23333	1.004	1.003	1.001	0.999	0.997	0.994	0.990	0.988	0.985	0.981	0.976	0.969	0.963	0.955	0.943
PTW 30001/30010 Farmer	1.004	1.003	1.001	0.999	0.997	0.994	0.990	0.988	0.985	0.981	0.976	0.969	0.962	0.955	0.943
PTW 30002/30011 Farmer	1.006	1.004	1.001	0.999	0.997	0.994	0.992	0.990	0.987	0.984	0.980	0.973	0.967	0.959	0.948
PTW 30004/30012 Farmer	1.006	1.005	1.002	1.000	0.999	0.996	0.994	0.992	0.989	0.986	0.982	0.976	0.969	0.962	0.950
PTW 30006/30013 Farmer	1.002	1.002	1.000	0.999	0.997	0.994	0.990	0.988	0.984	0.980	0.975	0.968	0.960	0.952	0.940
PTW 31002 flexible	1.003	1.002	1.000	0.999	0.997	0.994	0.990	0.988	0.984	0.980	0.975	0.968	0.960	0.952	0.940
PTW 31003 flexible	1.003	1.002	1.000	0.999	0.997	0.994	0.990	0.988	0.984	0.980	0.975	0.968	0.960	0.952	0.940
PTW 31006 PinPoint	1.004	1.003	1.001	0.999	0.998	0.995	0.992	0.989	0.985	0.980	0.974	0.966	0.959	0.951	0.940
PTW 31014 PinPoint	1.004	1.003	1.001	0.999	0.998	0.995	0.992	0.989	0.985	0.980	0.975	0.967	0.959	0.952	0.941
SNC 100700-0 Farmer	1.005	1.004	1.001	0.999	0.998	0.995	0.992	0.989	0.986	0.981	0.976	0.969	0.962	0.954	0.943
SNC 100700-1 Farmer	1.007	1.006	1.003	1.001	0.999	0.997	0.995	0.993	0.990	0.986	0.983	0.976	0.969	0.961	0.951
Victoreen Radocon III 550	1.005	1.004	1.001	0.998	0.996	0.993	0.989	0.986	0.983	0.979	0.975	0.968	0.961	0.954	0.943
Victoreen Radocon II 555	1.005	1.003	1.000	0.997	0.995	0.990	0.986	0.983	0.979	0.975	0.970	0.963	0.956	0.949	0.938
Victoreen 30-348	1.004	1.003	1.000	0.998	0.996	0.992	0.989	0.986	0.982	0.978	0.973	0.966	0.959	0.951	0.940
Victoreen 30-351	1.004	1.002	1.000	0.998	0.996	0.992	0.989	0.986	0.983	0.979	0.974	0.967	0.960	0.952	0.941
Victoreen 30-349	1.003	1.002	1.000	0.998	0.996	0.992	0.989	0.986	0.983	0.980	0.976	0.969	0.962	0.954	0.942
Victoreen 30-361	1.004	1.003	1.000	0.998	0.996	0.992	0.989	0.986	0.983	0.979	0.974	0.967	0.960	0.953	0.942
Scdx-Wellhöfer CC01	1.002	1.002	1.002	1.001	1.000	0.999	0.996	0.994	0.991	0.986	0.981	0.972	0.964	0.956	0.944
Scdx-Wellhöfer CC04/IC04	1.001	1.001	1.001	1.000	0.999	0.997	0.995	0.992	0.989	0.984	0.979	0.970	0.962	0.953	0.941
Scdx-Wellhöfer CC08/IC05/IC06	1.001	1.001	1.001	1.000	0.999	0.997	0.995	0.993	0.989	0.985	0.980	0.972	0.964	0.955	0.943
Scdx-Wellhöfer CC13/IC10/IC15	1.001	1.001	1.001	1.000	0.999	0.997	0.995	0.993	0.989	0.985	0.980	0.972	0.964	0.955	0.943
Scdx-Wellhöfer CC25/IC25	1.001	1.001	1.001	1.000	0.999	0.997	0.995	0.993	0.989	0.985	0.980	0.972	0.964	0.955	0.943
Scdx-Wellhöfer FC23-C/IC28 Farmer shortened	1.001	1.001	1.001	1.000	0.999	0.997	0.995	0.993	0.990	0.985	0.980	0.972	0.964	0.955	0.943
Scdx-Wellhöfer FC65-P/IC69 Farmer	1.003	1.002	1.001	0.999	0.998	0.995	0.993	0.990	0.986	0.981	0.976	0.968	0.960	0.952	0.940
Scdx-Wellhöfer FC65-G/IC70 Farmer	1.005	1.004	1.002	1.000	0.998	0.997	0.995	0.992	0.989	0.985	0.981	0.973	0.966	0.958	0.947

[a] Some of the chambers listed in this table fail to meet some of the minimum requirements described in Section 4.2.1. However, they have been included in this table because of their current clinical use.

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
Plane-parallel chambers																	
Attix RMI 449	0.953	0.943	0.932	0.925	0.919	0.913	0.908	0.904	0.900	0.896	0.893	0.886	0.881	0.871	0.859	0.849	0.837
Capintec PS-033	-	-	0.921	0.920	0.919	0.918	0.917	0.916	0.915	0.913	0.912	0.908	0.905	0.898	0.887	0.877	0.866
Exradin P11	0.958	0.948	0.937	0.930	0.923	0.918	0.913	0.908	0.904	0.901	0.897	0.891	0.885	0.875	0.863	0.853	0.841
Holt (Memorial)	0.971	0.961	0.950	0.942	0.936	0.931	0.926	0.921	0.917	0.913	0.910	0.903	0.897	0.887	0.875	0.865	0.853
NACP / Calcam	0.952	0.942	0.931	0.924	0.918	0.912	0.908	0.903	0.899	0.895	0.892	0.886	0.880	0.870	0.858	0.848	0.836
Markus	-	-	0.925	0.920	0.916	0.913	0.910	0.907	0.904	0.901	0.899	0.894	0.889	0.881	0.870	0.860	0.849
Roos	0.965	0.955	0.944	0.937	0.931	0.925	0.920	0.916	0.912	0.908	0.904	0.898	0.892	0.882	0.870	0.860	0.848
Cylindrical chambers																	
Capintec PR06C (Farmer)	-	-	-	-	-	-	0.916	0.914	0.912	0.911	0.909	0.906	0.904	0.899	0.891	0.884	0.874
Exradin A2 (Spokas)	-	-	-	-	-	-	0.914	0.913	0.913	0.913	0.912	0.911	0.910	0.908	0.903	0.897	0.888
Exradin T2 (Spokas)	-	-	-	-	-	-	0.882	0.881	0.881	0.881	0.880	0.879	0.878	0.876	0.871	0.865	0.857
Exradin A12 (Farmer)	-	-	-	-	-	-	0.921	0.919	0.918	0.916	0.914	0.911	0.909	0.903	0.896	0.888	0.878
NE 2571 (Guarded Farmer)	-	-	-	-	-	-	0.918	0.916	0.915	0.913	0.911	0.909	0.906	0.901	0.893	0.886	0.876
NE 2581 (Robust Farmer)	-	-	-	-	-	-	0.899	0.898	0.896	0.894	0.893	0.890	0.888	0.882	0.875	0.868	0.859
PTW 30001/30010 (Farmer)	-	-	-	-	-	-	0.911	0.909	0.907	0.905	0.904	0.901	0.898	0.893	0.885	0.877	0.868
PTW 30002/30011 (Farmer)	-	-	-	-	-	-	0.916	0.914	0.912	0.910	0.909	0.906	0.903	0.897	0.890	0.882	0.873
PTW 30004/30012 (Farmer)	-	-	-	-	-	-	0.920	0.918	0.916	0.915	0.913	0.910	0.907	0.902	0.894	0.887	0.877
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
PTW 31002/31003 (flexible)							0.912	0.910	0.908	0.906	0.905	0.901	0.898	0.893	0.885	0.877	0.867
PTW 31006 PinPoint	-	-	-	-	-	-	0.928	0.924	0.921	0.918	0.915	0.910	0.905	0.896	0.885	0.876	0.865
PTW 31014 PinPoint	-	-	-	-	-	-	0.929	0.925	0.922	0.919	0.916	0.910	0.905	0.897	0.886	0.876	0.865
Scdx-Wellhöfer CC01	-	-	-	-	-	-	0.942	0.938	0.935	0.932	0.929	0.923	0.918	0.909	0.898	0.889	0.878
Scdx-Wellhöfer CC04/IC04	-	-	-	-	-	-	0.928	0.925	0.922	0.920	0.918	0.913	0.910	0.902	0.893	0.884	0.874
Scdx-Wellhöfer CC08/IC05/IC06	-	-	-	-	-	-	0.920	0.918	0.917	0.915	0.913	0.910	0.907	0.902	0.894	0.886	0.877
Scdx-Wellhöfer CC13/IC10/IC15	-	-	-	-	-	-	0.920	0.918	0.917	0.915	0.913	0.910	0.907	0.902	0.894	0.886	0.877
Scdx-Wellhöfer CC25/IC25	-	-	-	-	-	-	0.920	0.918	0.917	0.915	0.913	0.910	0.907	0.902	0.894	0.886	0.877
Scdx-Wellhöfer FC23-C/IC28 Farmer shortened	-	-	-	-	-	-	0.920	0.918	0.916	0.914	0.913	0.910	0.907	0.902	0.894	0.886	0.877
Scdx-Wellhöfer FC65-P/IC69 Farmer	-	-	-	-	-	-	0.914	0.912	0.911	0.909	0.907	0.904	0.902	0.896	0.889	0.881	0.872
Scdx-Wellhöfer FC65-G/IC70 Farmer	-	-	-	-	-	-	0.920	0.918	0.916	0.914	0.913	0.910	0.907	0.902	0.894	0.887	0.877
Victoreen 30-348	-	-	-	-	-	-	0.910	0.908	0.906	0.903	0.902	0.898	0.895	0.888	0.880	0.872	0.862
Victoreen 30-351	-	-	-	-	-	-	0.906	0.904	0.902	0.901	0.899	0.896	0.893	0.888	0.880	0.873	0.864
Victoreen 30-349	-	-	-	-	-	-	0.899	0.898	0.897	0.896	0.895	0.893	0.891	0.888	0.881	0.875	0.866

[a] Some of the chambers listed in this table fail to meet all of the minimum requirements described in Section 4.2.1. However, they have been included in this table because of their current clinical use.

TABLE 7.IV. CALCULATED VALUES FOR $k_{Q,Q_{int}}$ FOR VARIOUS CHAMBER TYPES CALIBRATED IN ELECTRON BEAMS, 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 and taking the value Q_{int} = 7.5 g cm^{-2}.)

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
Plane-parallel chambers																	
Attix RMI 449	1.078	1.068	1.055	1.047	1.040	1.034	1.028	1.023	1.019	1.014	1.010	1.003	0.997	0.986	0.972	0.961	0.948
Capintec PS-033	-	-	1.016	1.015	1.014	1.013	1.012	1.010	1.009	1.007	1.006	1.002	0.998	0.990	0.978	0.968	0.955
Exradin P11	1.078	1.068	1.055	1.047	1.040	1.034	1.028	1.023	1.019	1.014	1.010	1.003	0.997	0.986	0.972	0.961	0.948
Holt (Memorial)	1.078	1.068	1.055	1.047	1.040	1.034	1.028	1.023	1.019	1.014	1.010	1.003	0.997	0.986	0.972	0.961	0.948
NACP / Calcam	1.078	1.068	1.055	1.047	1.040	1.034	1.028	1.023	1.019	1.014	1.010	1.003	0.997	0.986	0.972	0.961	0.948
Markus	-	-	1.038	1.032	1.028	1.024	1.020	1.017	1.014	1.011	1.008	1.003	0.997	0.988	0.976	0.965	0.952
Roos	1.078	1.068	1.055	1.047	1.040	1.034	1.028	1.023	1.019	1.014	1.010	1.003	0.997	0.986	0.972	0.961	0.948
Cylindrical chambers																	
Capintec PR06C (Farmer)	-	-	-	-	-	-	1.012	1.010	1.008	1.006	1.005	1.001	0.999	0.993	0.984	0.976	0.966
Exradin A2 (Spokas)	-	-	-	-	-	-	1.003	1.003	1.002	1.002	1.002	1.001	0.999	0.996	0.991	0.984	0.975
Exradin T2 (Spokas)	-	-	-	-	-	-	1.003	1.003	1.002	1.002	1.002	1.001	0.999	0.996	0.991	0.984	0.975
Exradin A12 (Farmer)	-	-	-	-	-	-	1.012	1.010	1.008	1.006	1.005	1.002	0.998	0.993	0.984	0.976	0.965
NE 2571 (Guarded Farmer)	-	-	-	-	-	-	1.012	1.010	1.008	1.006	1.005	1.001	0.999	0.993	0.984	0.976	0.966
NE 2581 (Robust Farmer)	-	-	-	-	-	-	1.012	1.010	1.008	1.006	1.005	1.001	0.999	0.993	0.984	0.976	0.966
PTW 30001/30010 (Farmer)	-	-	-	-	-	-	1.013	1.010	1.008	1.007	1.005	1.002	0.998	0.992	0.984	0.976	0.965
PTW 30002/30011 (Farmer)	-	-	-	-	-	-	1.013	1.010	1.008	1.007	1.005	1.002	0.998	0.992	0.984	0.976	0.965
PTW 30004/30012 (Farmer)	-	-	-	-	-	-	1.013	1.010	1.008	1.007	1.005	1.002	0.998	0.992	0.984	0.976	0.965
PTW 30006/30013 Farmer	-	-	-	-	-	-	1.013	1.010	1.008	1.007	1.005	1.002	0.998	0.992	0.984	0.976	0.965
PTW 31002/31003 (flexible)	-	-	-	-	-	-	1.014	1.011	1.009	1.007	1.005	1.002	0.998	0.992	0.983	0.974	0.964
PTW 31006 PinPoint	-	-	-	-	-	-	1.023	1.019	1.015	1.012	1.009	1.003	0.997	0.988	0.976	0.965	0.953
PTW 31014 PinPoint	-	-	-	-	-	-	1.023	1.019	1.015	1.012	1.009	1.003	0.997	0.988	0.976	0.965	0.953
Scdx-Wellhöfer CC01	-	-	-	-	-	-	1.023	1.019	1.015	1.012	1.009	1.003	0.997	0.988	0.976	0.965	0.953
Scdx-Wellhöfer CC04/IC04	-	-	-	-	-	-	1.018	1.015	1.012	1.009	1.007	1.002	0.998	0.990	0.980	0.970	0.959
Scdx-Wellhöfer CC08/IC05/IC06	-	-	-	-	-	-	1.013	1.011	1.009	1.007	1.005	1.002	0.998	0.992	0.984	0.975	0.965
Scdx-Wellhöfer CC13/IC10/IC15	-	-	-	-	-	-	1.013	1.011	1.009	1.007	1.005	1.002	0.998	0.992	0.984	0.975	0.965
Scdx-Wellhöfer CC25/IC25	-	-	-	-	-	-	1.013	1.011	1.009	1.007	1.005	1.002	0.998	0.992	0.984	0.975	0.965
Scdx-Wellhöfer FC23-C/IC28 Farmer shortened	-	-	-	-	-	-	1.012	1.010	1.008	1.006	1.005	1.002	0.998	0.993	0.984	0.976	0.965
Scdx-Wellhöfer FC65-P/IC69 Farmer	-	-	-	-	-	-	1.012	1.010	1.008	1.006	1.005	1.002	0.998	0.993	0.984	0.976	0.965
Scdx-Wellhöfer FC65-G/IC70 Farmer	-	-	-	-	-	-	1.012	1.010	1.008	1.006	1.005	1.002	0.998	0.993	0.984	0.976	0.965
Victoreen 30-348	-	-	-	-	-	-	1.015	1.013	1.010	1.008	1.006	1.002	0.998	0.991	0.982	0.973	0.962
Victoreen 30-351	-	-	-	-	-	-	1.013	1.010	1.008	1.007	1.005	1.002	0.998	0.992	0.984	0.976	0.965
Victoreen 30-349	-	-	-	-	-	-	1.008	1.006	1.005	1.004	1.003	1.001	0.999	0.995	0.988	0.980	0.971

[a] Some of the chambers listed in this table fail to meet all of the minimum requirements described in Section 4.2.1. However, they have been included in this table because of their current clinical use.

TABLE 10.III. CALCULATED VALUES OF k_Q FOR PROTON BEAMS, FOR VARIOUS CYLINDRICAL AND PLANE-PARALLEL IONIZATION CHAMBERS AS A FUNCTION OF BEAM QUALITY R_{res}

Ionization chamber type [a]	Beam quality R_{res} (g cm^{-2})															
	0.25	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	7.5	10	15	20	30
Cylindrical chambers																
Capintec PR-05P mini	-	1.046	1.045	1.044	1.044	1.044	1.043	1.043	1.043	1.043	1.043	1.043	1.043	1.043	1.042	1.042
Capintec PR-05 mini	-	1.046	1.045	1.044	1.044	1.044	1.043	1.043	1.043	1.043	1.043	1.043	1.043	1.043	1.042	1.042
Capintec PR-06C/G Farmer	-	1.038	1.037	1.036	1.036	1.036	1.036	1.035	1.035	1.035	1.035	1.035	1.035	1.035	1.034	1.034
Exradin A2 Spokas	-	1.057	1.055	1.054	1.054	1.054	1.054	1.054	1.054	1.054	1.054	1.053	1.053	1.053	1.053	1.052
Exradin T2 Spokas	-	1.020	1.018	1.018	1.018	1.017	1.017	1.017	1.017	1.017	1.017	1.017	1.017	1.016	1.016	1.016
Exradin A1 mini Shonka	-	1.045	1.043	1.043	1.042	1.042	1.042	1.042	1.042	1.042	1.042	1.042	1.042	1.041	1.041	1.041
Exradin T1 mini Shonka	-	1.009	1.007	1.007	1.006	1.006	1.006	1.006	1.006	1.006	1.006	1.005	1.005	1.005	1.005	1.004
Exradin A12 Farmer	-	1.043	1.042	1.041	1.041	1.041	1.041	1.040	1.040	1.040	1.040	1.040	1.040	1.040	1.039	1.039
Far West Tech IC-18	-	1.007	1.006	1.005	1.005	1.005	1.004	1.004	1.004	1.004	1.004	1.004	1.004	1.003	1.003	1.003
FZH TK 01	-	1.032	1.031	1.030	1.030	1.030	1.030	1.029	1.029	1.029	1.029	1.029	1.029	1.029	1.028	1.028
Nuclear Assoc 30-750	-	1.037	1.035	1.034	1.034	1.034	1.034	1.034	1.034	1.033	1.033	1.033	1.033	1.033	1.033	1.032
Nuclear Assoc 30-749	-	1.041	1.039	1.039	1.038	1.038	1.038	1.038	1.038	1.038	1.038	1.037	1.037	1.037	1.037	1.036
Nuclear Assoc 30-744	-	1.041	1.039	1.039	1.038	1.038	1.038	1.038	1.038	1.038	1.038	1.037	1.037	1.037	1.037	1.036
Nuclear Assoc 30-716	-	1.041	1.039	1.039	1.038	1.038	1.038	1.038	1.038	1.038	1.038	1.037	1.037	1.037	1.037	1.036
Nuclear Assoc 30-753 Farmer shortened	-	1.041	1.040	1.039	1.039	1.038	1.038	1.038	1.038	1.038	1.038	1.038	1.038	1.037	1.037	1.037
Nuclear Assoc 30-751 Farmer	-	1.037	1.036	1.035	1.035	1.035	1.035	1.034	1.034	1.034	1.034	1.034	1.034	1.034	1.033	1.033
Nuclear Assoc 30-752 Farmer	-	1.044	1.042	1.041	1.041	1.041	1.041	1.041	1.041	1.040	1.040	1.040	1.040	1.040	1.040	1.039
NE 2515	-	1.033	1.032	1.031	1.031	1.031	1.031	1.030	1.030	1.030	1.030	1.030	1.030	1.030	1.029	1.029
NE 2515/3	-	1.043	1.041	1.041	1.040	1.040	1.040	1.040	1.040	1.040	1.040	1.039	1.039	1.039	1.039	1.038
NE 2577	-	1.043	1.041	1.041	1.040	1.040	1.040	1.040	1.040	1.040	1.040	1.039	1.039	1.039	1.039	1.038
NE 2505 Farmer	-	1.033	1.032	1.031	1.031	1.031	1.031	1.030	1.030	1.030	1.030	1.030	1.030	1.030	1.029	1.029
NE 2505/A Farmer	-	1.021	1.019	1.019	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.017	1.017	1.017	1.016
NE 2505/3, 3A Farmer	-	1.043	1.041	1.041	1.040	1.040	1.040	1.040	1.040	1.040	1.040	1.039	1.039	1.039	1.039	1.038
NE 2505/3, 3B Farmer	-	1.025	1.023	1.023	1.022	1.022	1.022	1.022	1.022	1.022	1.022	1.021	1.021	1.021	1.021	1.020
NE 2571 Farmer	-	1.043	1.041	1.041	1.040	1.040	1.040	1.040	1.040	1.040	1.040	1.039	1.039	1.039	1.039	1.038
NE 2581 Farmer	-	1.020	1.018	1.017	1.017	1.017	1.017	1.017	1.017	1.016	1.016	1.016	1.016	1.016	1.016	1.015
NE 2561 / 2611 Sec Std	-	1.040	1.038	1.038	1.037	1.037	1.037	1.037	1.037	1.037	1.037	1.037	1.036	1.036	1.036	1.036
PTW 23323 micro	-	1.027	1.025	1.025	1.025	1.024	1.024	1.024	1.024	1.024	1.024	1.024	1.024	1.023	1.023	1.023
PTW 23331 rigid	-	1.037	1.035	1.034	1.034	1.034	1.034	1.034	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.032
PTW 23332 rigid	-	1.031	1.029	1.028	1.028	1.028	1.028	1.028	1.027	1.027	1.027	1.027	1.027	1.027	1.027	1.026
PTW 23333	-	1.033	1.031	1.031	1.030	1.030	1.030	1.030	1.030	1.030	1.030	1.029	1.029	1.029	1.029	1.028
PTW 30001/30010 Farmer	-	1.033	1.031	1.031	1.030	1.030	1.030	1.030	1.030	1.030	1.030	1.029	1.029	1.029	1.029	1.028

Ionization chamber type [a]	Beam quality R_{res} (g cm^{-2})															
	0.25	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	7.5	10	15	20	30
PTW 30002/30011 Farmer	-	1.036	1.035	1.034	1.034	1.034	1.034	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.032	1.032
PTW 30004/30012 Farmer	-	1.044	1.042	1.041	1.041	1.041	1.041	1.041	1.041	1.041	1.040	1.040	1.040	1.040	1.040	1.039
PTW 30006/30013 Farmer	-	1.033	1.032	1.031	1.031	1.031	1.030	1.030	1.030	1.030	1.030	1.030	1.030	1.029	1.029	1.029
PTW 31002 flexible	-	1.032	1.030	1.029	1.029	1.029	1.029	1.029	1.029	1.029	1.029	1.028	1.028	1.028	1.028	1.027
PTW 31003 flexible	-	1.032	1.030	1.029	1.029	1.029	1.029	1.029	1.029	1.029	1.029	1.028	1.028	1.028	1.028	1.027
PTW 31006 PinPoint	-	1.027	1.025	1.025	1.024	1.024	1.024	1.024	1.024	1.024	1.024	1.024	1.023	1.023	1.023	1.022
PTW 31014 PinPoint	-	1.028	1.026	1.025	1.025	1.025	1.025	1.025	1.025	1.025	1.024	1.024	1.024	1.024	1.024	1.023
SNC 100700-0 Farmer	-	1.033	1.031	1.030	1.030	1.030	1.030	1.030	1.030	1.030	1.030	1.029	1.029	1.029	1.029	1.028
SNC 100700-1 Farmer	-	1.044	1.042	1.042	1.042	1.041	1.041	1.041	1.041	1.041	1.041	1.041	1.041	1.040	1.040	1.040
Victoreen Radocon III 550	-	1.031	1.030	1.029	1.029	1.028	1.028	1.028	1.028	1.028	1.028	1.028	1.028	1.027	1.027	1.027
Victoreen Radocon II 555	-	1.014	1.012	1.012	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.010	1.010	1.010	1.010
Victoreen 30-348	-	1.023	1.022	1.021	1.021	1.021	1.020	1.020	1.020	1.020	1.020	1.020	1.020	1.020	1.019	1.019
Victoreen 30-351	-	1.026	1.024	1.023	1.023	1.023	1.023	1.023	1.023	1.022	1.022	1.022	1.022	1.022	1.022	1.021
Victoreen 30-349	-	1.030	1.028	1.027	1.027	1.027	1.027	1.027	1.027	1.026	1.026	1.026	1.026	1.026	1.026	1.025
Victoreen 30-361	-	1.023	1.021	1.020	1.020	1.020	1.020	1.020	1.020	1.020	1.020	1.019	1.019	1.019	1.019	1.018
Scdx-Wellhöfer CC01		1.042	1.040	1.040	1.040	1.039	1.039	1.039	1.039	1.039	1.039	1.039	1.039	1.038	1.038	1.038
Scdx-Wellhöfer CC04/IC04		1.037	1.035	1.035	1.034	1.034	1.034	1.034	1.034	1.034	1.034	1.034	1.033	1.033	1.033	1.032
Scdx-Wellhöfer CC08/IC05/IC06	-	1.041	1.039	1.039	1.039	1.038	1.038	1.038	1.038	1.038	1.038	1.038	1.038	1.037	1.037	1.037
Scdx-Wellhöfer CC13/IC10/IC15	-	1.041	1.039	1.039	1.039	1.038	1.038	1.038	1.038	1.038	1.038	1.038	1.038	1.037	1.037	1.037
Scdx-Wellhöfer CC25/IC25	-	1.041	1.039	1.039	1.039	1.038	1.038	1.038	1.038	1.038	1.038	1.038	1.038	1.037	1.037	1.037
Scdx-Wellhöfer FC23-C/IC28 Farmer shortened	-	1.042	1.040	1.039	1.039	1.039	1.039	1.039	1.038	1.038	1.038	1.038	1.038	1.038	1.038	1.037
Scdx-Wellhöfer FC65-P/IC69 Farmer	-	1.037	1.036	1.035	1.035	1.035	1.035	1.034	1.034	1.034	1.034	1.034	1.034	1.034	1.033	1.033
Scdx-Wellhöfer FC65-G/IC70 Farmer	-	1.044	1.042	1.041	1.041	1.041	1.041	1.041	1.041	1.041	1.040	1.040	1.040	1.040	1.040	1.039
Plane-parallel chambers																
Attix RMI 449	0.995	0.992	0.990	0.989	0.989	0.989	0.989	0.989	0.989	0.989	0.989	0.988	0.988	0.988	0.988	0.987
Capintec PS-033	1.029	1.026	1.024	1.024	1.023	1.023	1.023	1.023	1.023	1.023	1.023	1.022	1.022	1.022	1.022	1.021
Exradin P11	1.000	0.997	0.995	0.994	0.994	0.994	0.994	0.994	0.994	0.994	0.993	0.993	0.993	0.993	0.993	0.992
Holt (Memorial)	1.014	1.010	1.009	1.008	1.008	1.008	1.008	1.008	1.007	1.007	1.007	1.007	1.007	1.007	1.007	1.006
NACP / Calcam	0.994	0.991	0.989	0.989	0.988	0.988	0.988	0.988	0.988	0.988	0.988	0.987	0.987	0.987	0.987	0.986
Markus	1.009	1.005	1.004	1.003	1.003	1.003	1.003	1.003	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.001
Roos	1.008	1.004	1.003	1.002	1.002	1.002	1.002	1.002	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.000

[a] Some of the chambers listed in this table fail to meet some of the minimum requirements described in Section 4.2.1. However, they have been included in this table because of their current clinical use

TABLE 11.II. CALCULATED VALUES OF k_Q FOR HEAVY-ION BEAMS, FOR VARIOUS CYLINDRICAL AND PLANE-PARALLEL IONIZATION CHAMBERS

Ionization chamber type [a]	k_Q
Cylindrical chambers	
Capintec PR-05P mini	1.045
Capintec PR-05 mini	1.045
Capintec PR-06C/G Farmer	1.037
Exradin A2 Spokas	1.055
Exradin T2 Spokas	1.018
Exradin A1 mini Shonka	1.043
Exradin T1 mini Shonka	1.007
Exradin A12 Farmer	1.042
Far West Tech IC-18	1.006
FZH TK 01	1.031
Nuclear Assoc 30-750	1.035
Nuclear Assoc 30-749	1.039
Nuclear Assoc 30-744	1.039
Nuclear Assoc 30-716	1.039
Nuclear Assoc 30-753 Farmer shortened	1.040
Nuclear Assoc 30-751 Farmer	1.036
Nuclear Assoc 30-752 Farmer	1.042
NE 2515	1.032
NE 2515/3	1.041
NE 2577	1.041
NE 2505 Farmer	1.032
NE 2505/A Farmer	1.019
NE 2505/3, 3A Farmer	1.041
NE 2505/3, 3B Farmer	1.023
NE 2571 Farmer	1.041
NE 2581 Farmer	1.018
NE 2561 / 2611 Sec Std	1.038
PTW 23323 micro	1.026
PTW 23331 rigid	1.035
PTW 23332 rigid	1.029
PTW 23333	1.031
PTW 30001/30010 Farmer	1.031
PTW 30002/30011 Farmer	1.035
PTW 30004/30012 Farmer	1.042
PTW 30006/30013 Farmer	1.032
PTW 31002 flexible	1.030
PTW 31003 flexible	1.030
PTW 31006 PinPoint	1.025
PTW 31014 PinPoint	1.026
SNC 100700-0 Farmer	1.031
SNC 100700-1 Farmer	1.042
Victoreen Radocon III 550	1.030
Victoreen Radocon II 555	1.012
Victoreen 30-348	1.022
Victoreen 30-351	1.024
Victoreen 30-349	1.028
Victoreen 30-361	1.021

Ionization chamber type [a]	k_Q
Scdx-Wellhöfer CC01	1.041
Scdx-Wellhöfer CC04/IC04	1.035
Scdx-Wellhöfer CC08/IC05/IC06	1.040
Scdx-Wellhöfer CC13/IC10/IC15	1.040
Scdx-Wellhöfer CC25/IC25	1.040
Scdx-Wellhöfer FC23-C/IC28 Farmer shortened	1.040
Scdx-Wellhöfer FC65-P/IC69 Farmer	1.036
Scdx-Wellhöfer FC65-G/IC70 Farmer	1.042
Plane-parallel chambers	
Attix RMI 449	0.990
Capintec PS-033	1.024
Exradin P11	0.995
Holt (Memorial)	1.009
NACP / Calcam	0.989
Markus	1.004
Roos	1.003

[a] Some of the chambers listed in this table fail to meet some of the minimum requirements described in Section 4.2.1. However, they have been included in this table because of their current clinical use.

11.7. Estimated uncertainty in the determination of absorbed dose to water under reference conditions

At present, uncertainties in the dosimetry of heavy ions are rather large compared with the dosimetry of other radiotherapy beams. For the calculated k_Q factors given in this Code of Practice, the uncertainties are dominated by those of the stopping-power ratio and W-value. Detailed comparisons between ionization chamber dosimetry and water calorimetry are still necessary for further developments in the field. Also a more comprehensive investigation on projectile and target fragmentation is necessary to improve the dosimetry of heavy ions. The estimated uncertainties given in Table 11.III should therefore be regarded as preliminary.

TABLE 11.III. ESTIMATED RELATIVE STANDARD UNCERTAINTY [a] OF $D_{w,Q}$ AT THE REFERENCE DEPTH IN WATER AND FOR A CLINICAL HEAVY-ION BEAM, BASED ON A CHAMBER CALIBRATION IN ^{60}Co GAMMA RADIATION

Physical quantity or procedure	Relative standard uncertainty (%)	
User chamber type:	cylindrical	plane-parallel
Step 1: Standards Laboratory	*SSDL* [b]	*SSDL* [b]
$N_{D,w}$ calibration of secondary standard at PSDL	0.5	0.5
Long term stability of secondary standard	0.1	0.1
$N_{D,w}$ calibration of the user dosimeter at the standard laboratory	0.4	0.4
Combined uncertainty in Step 1	*0.6*	*0.6*
Step 2: User heavy-ion beam		
Long-term stability of user dosimeter	0.3	0.4
Establishment of reference conditions	0.4	0.6
Dosimeter reading M_Q relative to beam monitor	0.6	0.6
Correction for influence quantities k_i	0.4	0.5
Beam quality correction, k_Q	2.8	3.2
Combined uncertainty in Step 2	*2.9*	*3.4*
Combined standard uncertainty in $D_{w,Q}$ (Steps 1 + 2)	**3.0**	**3.4**

[a] See ISO Guide to the expression of uncertainty [32] or Appendix D. The estimates given in the table should be considered typical values; these may vary depending on the uncertainty quoted by standards laboratories for calibration factors and on the experimental uncertainty at the user's institution.

[b] If the calibration of the user dosimeter is performed at a PSDL then the combined standard uncertainty in Step 1 is lower. The combined standard uncertainty in D_w should be adjusted accordingly.

$$\tau(t_s) = e^{-11.88 t_w}(1 - e^{-11.88 t_s}) \quad \text{(B.4b)}$$

where t_w and t_s are, respectively, the thickness of the wall and the sleeve (in g cm^{-2}). These are based on the experimental data of Lempert *et al* [136] for which no uncertainty estimates were given. Andreo *et al* [80] compared the calculated ratios of p_{wall} for some materials with the experimental data of Johansson *et al* [132] and found agreement within 0.4%. Based on this, a combined standard uncertainty of 0.5% is estimated for p_{wall}.

This estimate applies also to plastic-walled chambers having a thin conductive layer or coating of graphite ("dag"). The effect of this coating on p_{wall} is difficult to estimate and both Monte Carlo calculations and experiments have so far failed to provide a satisfactory explanation of the underlying phenomena (see Ref. [137]). In addition, manufacturers do not generally provide information on the exact thickness of the coating, an exception being PTW (see footnote in Table 4.I). An alternative calculation of p_{wall} for the PTW-30001 chamber type has been made using Eq. (B.4), taking the 0.15 mm graphite coating (of density ρ = 0.82 g cm^{-3}) to be the chamber wall and including the PMMA section of the wall as part of the waterproof sleeve. This results in a value for p_{wall} which is approximately 0.3% lower for ^{60}Co gamma-rays. However, approximately the same decrease is obtained for p_{wall} for high-energy photons, so that the effect of the graphite coating largely cancels in the ratio of p_{wall} values entering into the calculation of k_Q. These agree within 0.1% with the k_Q values obtained for this type of chamber under the assumption that the entire wall is made of PMMA (it is these latter values which are adopted for high-energy photons in the present Code of Practice). The contribution to the uncertainty of p_{wall} arising from this effect is considered to be negligible (<0.1%).

For plane-parallel chamber types, p_{wall} is problematic and variations of up to 3% between chambers of the same type have been reported [138]. It is for this reason that the cross-calibration method is included in Section 7. Nevertheless, values have been derived by a combination of measurement and calculation. Those given in TRS-381 [21] for a number of chamber types have been used. In addition, values for the Attix, Exradin and Holt chamber types have been taken from the calculations of Rogers [139], and for the Roos chamber from Palm et al [182]. By assuming that the 3% variations represent the 67% (k=1) confidence interval of a normal distribution, the standard uncertainty is estimated to be 1.5%.

B.2.3.4. Values for p_{cel} in ^{60}Co

For cylindrical chamber types, p_{cel} corrects for the lack of air equivalence of the central electrode. The correction for this effect is negligible for plastic and graphite central electrodes, as shown by the Monte Carlo calculations of Ma and Nahum [140] and the experimental determinations of Palm and Mattsson [141]. Both groups also showed that an aluminium central electrode of diameter 1 mm, as used in many Farmer-type chambers, increases the chamber response by around 0.7% at the reference depth in ^{60}Co. These findings were in good agreement with the increased response previously measured by Mattsson [142]. Thus a value for p_{cel} of 0.993 has been used here for chambers with an aluminium central electrode of 1 mm diameter. The uncertainty of the most recent measurements is 0.2% [141]. It is important to note that this value agrees with that used in TRS-277 [17], in which a value for $p_{cel\text{-}gbl}$ of unity was assumed for all cylindrical chamber types having a 1 mm diameter aluminium electrode as a result of the cancellation between the effect in air and in water measurements (see Appendix A).

B.2.4. Summary of values and uncertainties in ^{60}Co

Table B.I lists the values used for the factors p_{dis}, p_{wall} and p_{cel} and for the product $s_{w,air}\, p_Q$, for the cylindrical chamber types listed in Table 4.I. The uncertainty estimates as discussed above are summarized in Table B.II.

TABLE B.I. VALUES FOR THE FACTORS p_{dis}, p_{wall} AND p_{cel} AND FOR THE PRODUCT $s_{w,air}\, p_Q$ IN ^{60}Co GAMMA RADIATION, FOR VARIOUS CYLINDRICAL AND PLANE-PARALLEL IONIZATION CHAMBERS

(The value $s_{w,air}$ = 1.133 is assumed, as noted in the text. For non waterproof cylindrical chambers the calculation of p_{wall} includes a 0.5 mm thick PMMA sleeve.)

Ionization chamber type [a]	p_{dis}	p_{wall}	p_{cel}	$s_{w,air}\, p_Q$
Cylindrical chambers				
Capintec PR-05P mini	0.992	0.977	1.000	1.098
Capintec PR-05 mini	0.992	0.977	1.000	1.098
Capintec PR-06C / G Farmer	0.987	0.989	1.000	1.107
Exradin A2 Spokas	0.981	0.978	1.000	1.088
Exradin T2 Spokas	0.981	1.013	1.000	1.127
Exradin A1 mini Shonka	0.992	0.978	1.000	1.100
Exradin T1 mini Shonka	0.992	1.013	1.000	1.139
Exradin A12 Farmer	0.988	0.984	1.000	1.101
Far West Tech IC-18	0.991	1.016	1.000	1.141
FZH TK 01	0.986	0.996	1.000	1.113
Nuclear Assoc 30-750	0.992	0.986	1.000	1.109
Nuclear Assoc 30-749	0.988	0.986	1.000	1.104
Nuclear Assoc 30-744	0.988	0.986	1.000	1.104
Nuclear Assoc 30-716	0.988	0.986	1.000	1.104
Nuclear Assoc 30-753 Farmer shortened	0.988	0.986	1.000	1.104
Nuclear Assoc 30-751 Farmer	0.988	0.997	0.993	1.108
Nuclear Assoc 30-752 Farmer	0.988	0.991	0.993	1.101
NE 2515	0.988	1.000	0.993	1.112
NE 2515/3	0.987	0.992	0.993	1.102
NE 2577	0.987	0.992	0.993	1.102
NE 2505 Farmer	0.988	1.000	0.993	1.112
NE 2505/A Farmer	0.988	1.012	0.993	1.126
NE 2505/3, 3A Farmer	0.987	0.992	0.993	1.102
NE 2505/3, 3B Farmer	0.987	1.009	0.993	1.122
NE 2571 Farmer	0.987	0.992	0.993	1.102
NE 2581 Farmer	0.987	1.007	1.000	1.127
NE 2561 / 2611 Sec Std	0.985	0.990	1.000	1.105
PTW 23323 micro	0.993	1.001	0.993	1.119
PTW 23331 rigid	0.984	1.001	0.993	1.109
PTW 23332 rigid	0.990	1.001	0.993	1.115
PTW 23333	0.988	1.001	0.993	1.113
PTW 30001/30010 Farmer	0.988	1.001	0.993	1.113
PTW 30002/30011 Farmer	0.988	0.991	1.000	1.109
PTW 30004/30012 Farmer	0.988	0.991	0.993	1.101
PTW 30006/30013 Farmer	0.988	1.001	0.993	1.112
PTW 31002 flexible	0.989	1.001	0.993	1.114
PTW 31003 flexible	0.989	1.001	0.993	1.114
PTW 31006 Pin Point	0.996	0.999	0.993	1.119
PTW 31014 Pin Point	0.996	0.998	0.993	1.118
SNC 100700-0 Farmer	0.988	1.001	0.993	1.113
SNC 100700-1 Farmer	0.988	0.990	0.993	1.101
Victoreen Radocon III 550	0.990	0.993	1.000	1.115
Victoreen Radocon II 555	0.990	1.010	1.000	1.134
Victoreen 30-348	0.990	1.001	1.000	1.123
Victoreen 30-351	0.988	1.001	1.000	1.121
Victoreen 30-349	0.984	1.001	1.000	1.116

Ionization chamber type [a]	p_{dis}	p_{wall}	p_{cel}	$s_{w,air}\, p_Q$
Victoreen 30-361	0.990	1.001	1.000	1.124
Scdx-Wellhöfer CC01	0.996	0.984	0.993	1.103
Scdx-Wellhöfer CC04/IC04	0.992	0.986	1.000	1.108
Scdx-Wellhöfer CC08/IC05/IC06	0.988	0.986	1.000	1.104
Scdx-Wellhöfer CC13/IC10/IC15	0.988	0.986	1.000	1.104
Scdx-Wellhöfer CC25/IC25	0.988	0.986	1.000	1.104
Scdx-Wellhöfer FC23-C/IC28 Farmer shortened	0.988	0.986	1.000	1.104
Scdx-Wellhöfer FC65-P/IC69 Farmer	0.988	0.997	0.993	1.108
Scdx-Wellhöfer FC65-G/IC70 Farmer	0.988	0.991	0.993	1.101
Plane-parallel chambers				
Attix RMI 449		1.023		1.159
Capintec PS-033		0.989		1.121
Exradin P11		1.018		1.154
Holt (Memorial)		1.004		1.138
NACP / Calcam		1.024		1.161
Markus		1.009		1.144
Roos		1.010		1.145

[a] Some of the chambers listed in this table fail to meet some of the minimum requirements described in Section 4.2.1. However, they have been included in this table because of their current clinical use

TABLE B.II. ESTIMATED RELATIVE STANDARD UNCERTAINTIES OF THE PARAMETERS ENTERING INTO THE DENOMINATOR OF Eq. (B.1) AT THE ^{60}Co BEAM QUALITY

Component	Chamber type:	cylindrical u_c (%)	plane-parallel u_c (%)
$s_{w,air}$		0.5	0.5
Assignment of $s_{w,air}$ to beam quality		0.1	0.1
W_{air} / e		0.2	0.2
p_{cav}		<0.1	<0.1
p_{dis}		0.3	0.2
p_{wall}		0.5	1.5
p_{cel}		0.2	-
Combined standard uncertainty		0.8	1.6

B.3. High-energy photon beams

The individual parameters entering in the numerator of Eq. (B.1) for high-energy photon beams are discussed below. In estimating the uncertainties, correlations between the values for these parameters in ^{60}Co and in the high-energy photon beams are taken into account, since it is only ratios which enter into the k_Q factor.

B.3.1. Values for $s_{w,air}$ in high-energy photon beams

The Spencer-Attix stopping-power ratios $s_{w,air}$, are taken from the calculations of Andreo [143, 144]. These calculations were performed by using the electron stopping-power data tabulated in the ICRU Report 37 [66]. In estimating the uncertainty of $s_{w,air}$ relative to the ^{60}Co value, correlations are not large because the main effects are those arising from the uncertainty of the *I*-value for water, which is important for ^{60}Co but not for high energies, and the density effect model used for water, which is important only at higher energies. A value of 0.5% has been estimated. The uncertainty in assigning stopping-power ratios to a particular user beam quality is estimated to be 0.2%.

B.3.2. Value for W_{air} in high-energy photon beams

The value for W_{air} normally used for high-energy photon beams is the same as that used for ^{60}Co, and this practice is followed in the present Code of Practice. However, there is growing evidence [55] that this assumption could be in error by up to 1%. To account for this, an uncertainty component of 0.5% is assumed for the W_{air} ratio entering in Eq. (B.1).

B.3.3. Values for p_Q in high-energy photon beams

The components of the perturbation correction as given by Eq. (B.2) are discussed separately. Only cylindrical chamber types are considered, since plane-parallel chambers should not be used for reference dosimetry in high-energy photon beams.

B.3.3.1. Values for p_{cav} in high-energy photon beams

As in ^{60}Co, transient equilibrium is assumed to exist at the reference depth and the value for p_{cav} is taken to be unity with a negligible uncertainty (< 0.1%).

B.3.3.2. Values for p_{dis} in high-energy photon beams

In high-energy photon beams the displacement effect is one of the major contributions to the final uncertainty in k_Q. The only set of experimental data available is due to Johansson *et al* [132], with an estimated uncertainty of 0.3%. However, these values were determined mainly using accelerators of old design and at a time when beam qualities were specified in terms of 'MV'. The values for this correction factor given by AAPM TG-21 [9] differ from the Johansson values by up to 0.6% for a Farmer type chamber, and even more for chambers of larger diameter, but these differences can be assumed to be consistent with the uncertainty estimate given above [45]. The values for ^{60}Co and for high-energy photons must be correlated, but the extent of this correlation is difficult to estimate. An estimate of the uncertainty of the p_{dis} ratio entering into the k_Q value is 0.5%.

B.3.3.3. Values for p_{wall} in high-energy photon beams

As for ^{60}Co, Eq. (B.4) is used for the calculation of p_{wall}, assuming a PMMA sleeve of thickness 0.5 mm. The use of this expression instead of the more common expression developed by Almond and Svensson [133] yields a maximum increase in p_{wall} of 0.2% for certain chamber types and beam qualities. The values for $s_{med,air}$ were evaluated by Andreo [143, 144] using the electron stopping-power data of ICRU Report 37 [66]. Values for the ratios of photon mass energy-absorption coefficients are taken from

[45] According to ISO [32] when there is no specific knowledge about the possible values of a variable X_i within an interval, one can only assume that the variable X_i lies within a uniform rectangular distribution with an expected value x_i in the midpoint of the interval and an associated variance $u^2(x_i)=a^2/3$, where a is the half-width of the interval.

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