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Dosimetry of photon beams

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Physics versus simplicity

ion chamber

- Physics – Raport 277
- Simplicity – Raport 398

calibration factor

$$D_{water} = M \cdot N_{cal,\,fact} \cdot F_{cor}$$

what we measure (charge)

factor which corrects for
changes of energy and/or
for perturbation of the radiation
field caused by the presence of
detector

Physics Raport 277

$$D_{water} = M_{cor} \cdot N_{D,Air} \cdot \left(\frac{S_{col}}{\rho}\right)_{water} \Big/ \left(\frac{S_{col}}{\rho}\right)_{air} \cdot p_u$$

$N_{D,Air}$	callibration factor in terms of dose to Air; <u>independent on energy</u>
$\left(\frac{S_{col}}{\rho}\right)_{water} \Big/ \left(\frac{S_{col}}{\rho}\right)_{air}$	ratio of dose to water and dose to air of mass stopping powers
$p_u = p_{wall} \cdot p_{dis} \cdot p_{cav} \cdot p_{cel}$	perturbation correction factor; ratio for Energy Q
M_{cor}	signal we measure; corrected for the actual conditions (temperature and preassure)

$$D_{water} = M_{cor} \cdot N_{D,Air} \cdot \left(\frac{L_{\Delta}}{\rho}\right)_{water} \Big/ \left(\frac{L_{\Delta}}{\rho}\right)_{air} \cdot p_u$$

$$\left(\frac{L_{\Delta}}{\rho}\right)_{water} \Big/ \left(\frac{L_{\Delta}}{\rho}\right)_{air}$$

restricted mass stopping collision power

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Simplicity: dosimetry-cook-book

Raport 398

$$D_{water} = M_{cor} \cdot N_{D,water} \cdot k_{Q,Q_0}$$

$N_{D,water}$ = callibration factor in terms of dose to water; <u>dependent on energy</u>

k_{Q,Q_0} = factor which converts calibration factor from reference energy to user energy

M_{cor} = signal we measure; corrected for the actual conditions (temperature and preassure)

Raport 398

$N_{D,water}$ for the chamber and for the energy (type of radiation and spectrum)

We receive this factor from primary or secondary standard laboratory
FOR ONE ENERGY!

Most often calibration factor is established in Co60 beam, and

if in Co60 then following notation is used $k_{Q,Q0} = k_Q$

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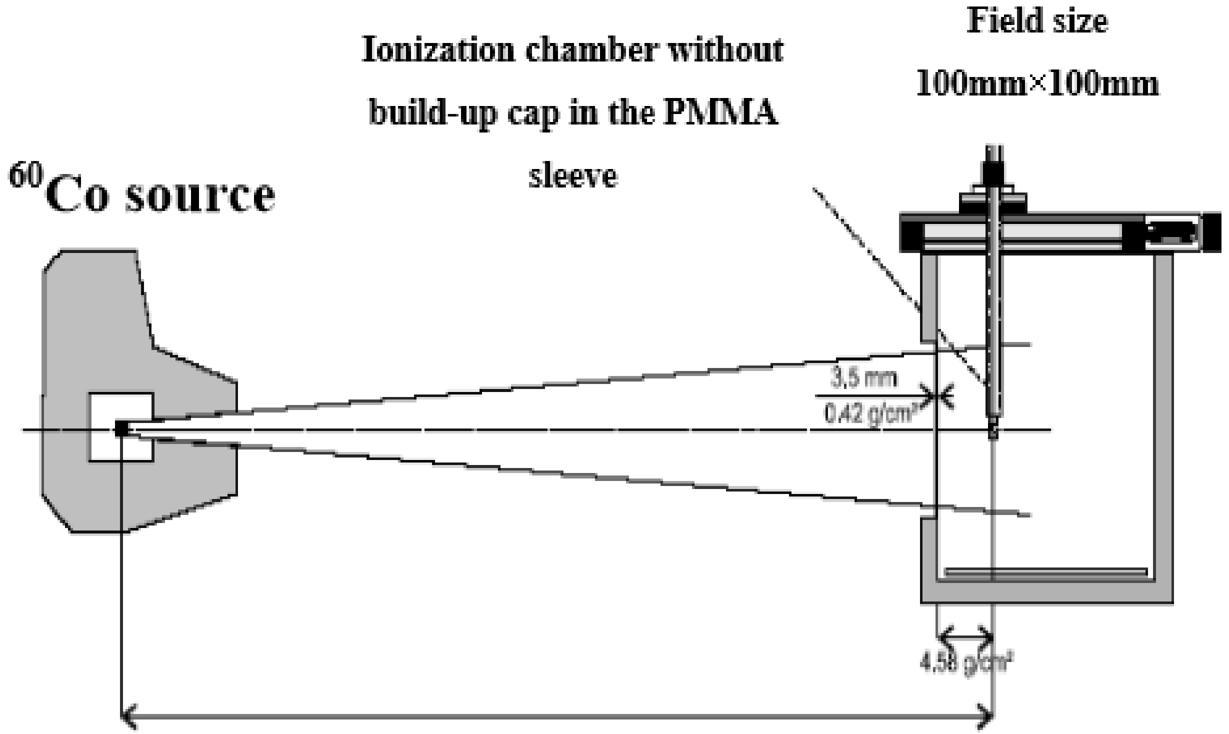
$k_{Q,Q0}$ from Raport 398

$$k_{Q,Q_0} = \frac{\left(\frac{S_{col}}{\rho}\right)^{w}_{air,Q} \cdot p_{u,Q}}{\left(\frac{S_{col}}{\rho}\right)^{w}_{air,Q_0} \cdot p_{u,Q_0}}$$

$$p_u = p_{wall} \cdot p_{dis} \cdot p_{cav} \cdot p_{cel}$$

$$\left(N_{D,water}\right)_Q = \left(N_{D,water}\right)_{Q_0} \cdot k_{Q,Q_0}$$

Calibration procedure



Signal is measured with reference chamber and a chamber for which calibration factor is to be measured.
For Reference Chamber $N_{D,w}$ calibration factor should be known.

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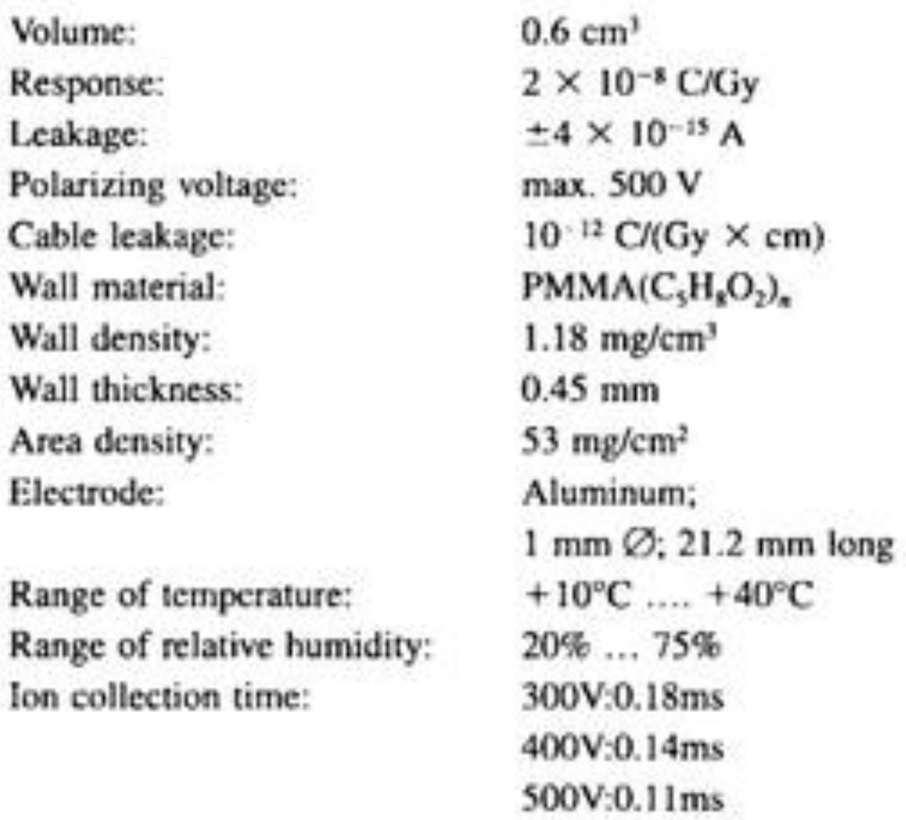
Introduction

Characteristics of the studied cylindrical ionization chambers, based on the data provided by the manufacturers:

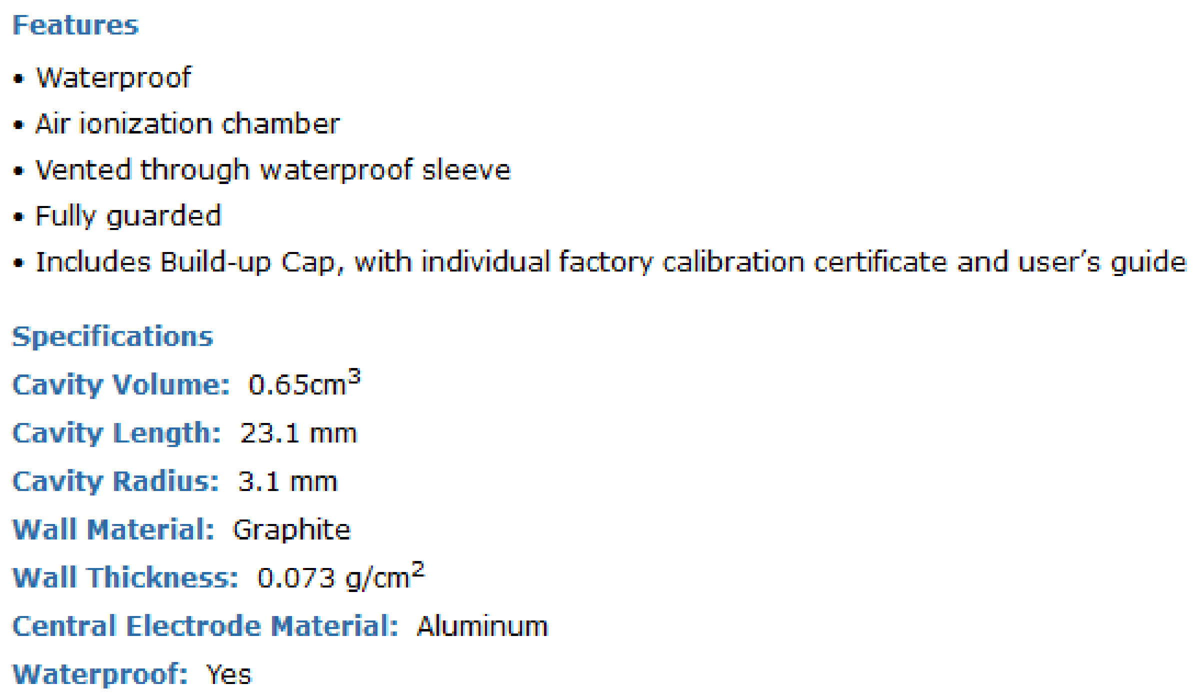
PTW 30001



Volume:	0.6 cm^3
Response:	2 × 10^{-8} C/Gy
Leakage:	±4 × 10^{-15} A
Polarizing voltage:	max. 500 V
Cable leakage:	10^{-12} C/(Gy × cm)
Wall material:	PMMA$(C_5H_8O_2)_n$
Wall density:	1.18 mg/cm^3
Wall thickness:	0.45 mm
Area density:	53 mg/cm^2
Electrode:	Aluminum; 1 mm ∅; 21.2 mm long
Range of temperature:	+10°C .... +40°C
Range of relative humidity:	20% ... 75%
Ion collection time:	300V:0.18ms 400V:0.14ms 500V:0.11ms

Similar 30013

FC65-G



Features

- Waterproof
- Air ionization chamber
- Vented through waterproof sleeve
- Fully guarded
- Includes Build-up Cap, with individual factory calibration certificate and user's guide

Specifications

Cavity Volume: 0.65cm^3
Cavity Length: 23.1 mm
Cavity Radius: 3.1 mm
Wall Material: Graphite
Wall Thickness: 0.073 g/cm^2
Central Electrode Material: Aluminum
Waterproof: Yes

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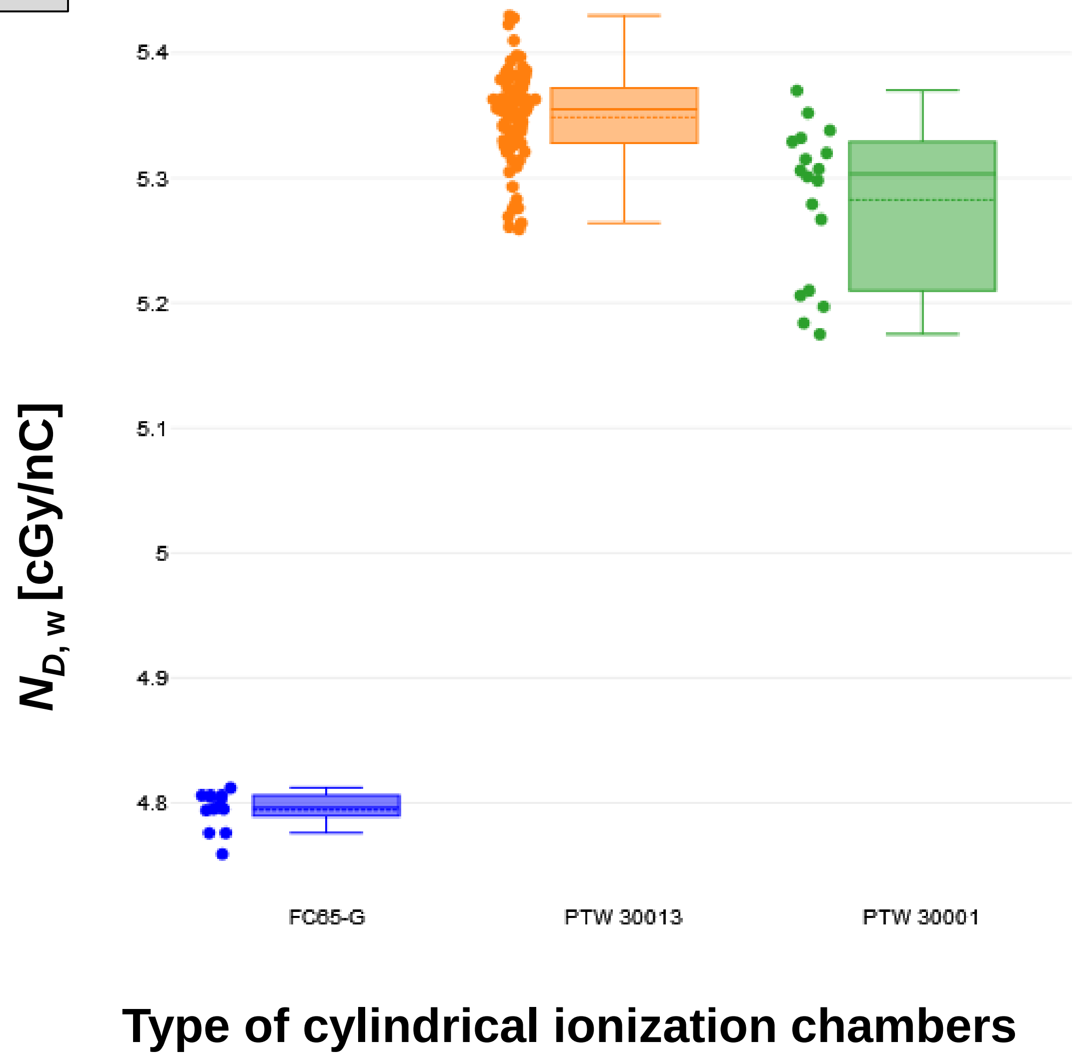
Iwona Grabska, Paweł Kukołowicz

Results

Calibration coefficients for cylindrical ionization chambers

Box plot



Descriptive statistics

Type of chambers	FC65-G	PTW 30013	PTW 30001
Sample size: n	13	82	18
Arithmetic mean value of $N_{D,w}$ [cGy/nC]	4.795	5.348	5.283
Median value of $N_{D,w}$ [cGy/nC]	4.796	5.355	5.303
Standard deviation value of $N_{D,w}$ [cGy/nC]	0.015	0.037	0.062
Standard deviation value of $N_{D,w}$ expressed as a percentage of the arithmetic mean value of $N_{D,w}$ [%]	0.32	0.70	1,16
Q_1 [cGy/nC]	4.759	5.328	5.210
Q_3 [cGy/nC]	4.806	5.372	5.329
$N_{D,w\ max}$ [cGy/nC]	4.812	5.430	5.370
$N_{D,w\ min}$ [cGy/nC]	4.759	5.259	5.175
$N_{D,w\ max} / N_{D,w\ min}$	1.01	1.03	1.04
Outliers	4.759	5.259, 5.261	none

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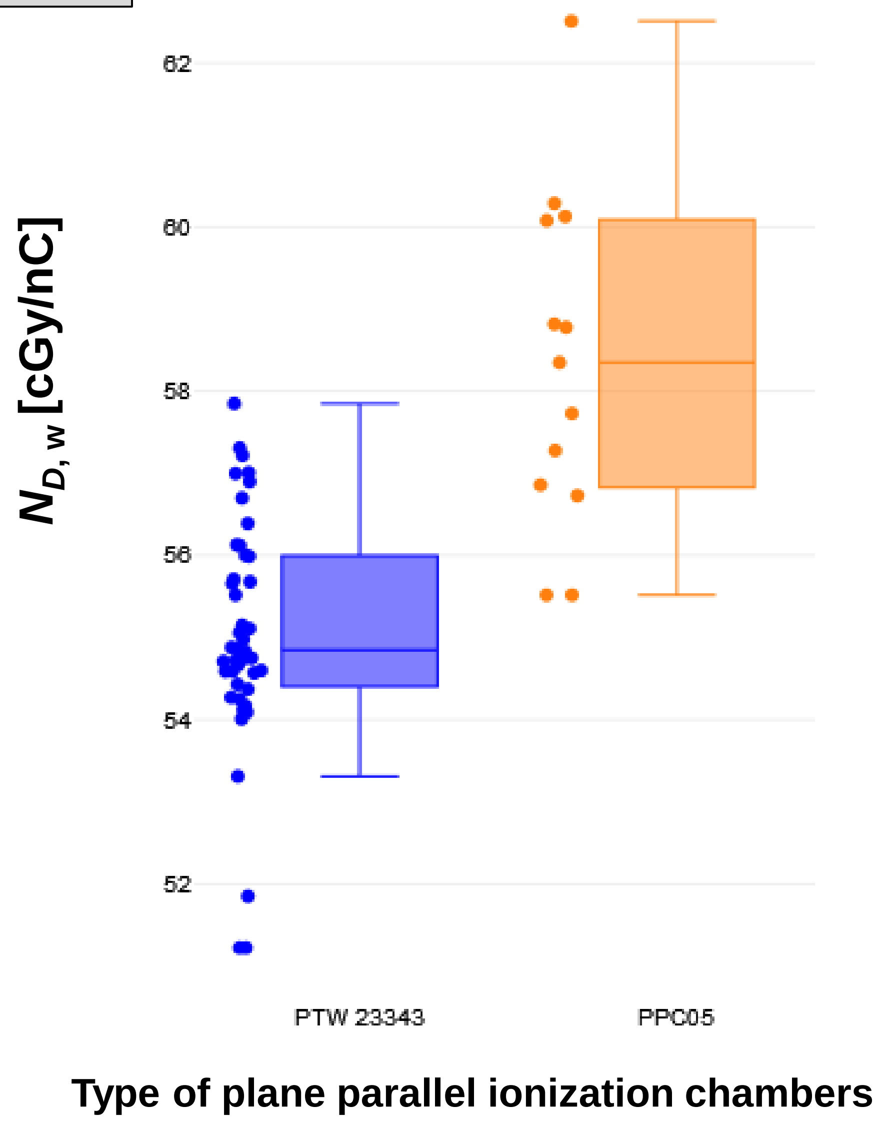
Results

Calibration coefficients for PTW 23343 and PPC05 ionization chambers

Box plot



Descriptive statistics

Type of chambers	PTW 23343	PPC05
Sample size: n	44	13
Arithmetic mean value of $N_{D,w}$ [cGy/nC]	55.03	58.35
Median value of $N_{D,w}$ [cGy/nC]	54.85	58.35
Standard deviation value of $N_{D,w}$ [cGy/nC]	1.44	2.04
Standard deviation value of $N_{D,w}$ expressed as a percentage of the arithmetic mean value of $N_{D,w}$ [%]	2.61	3.50
Q_1 [cGy/nC]	54.40	56.86
Q_3 [cGy/nC]	55.99	60.08
$N_{D,w\ max}$ [cGy/nC]	57.85	62.51
$N_{D,w\ min}$ [cGy/nC]	51.22	55.52
$N_{D,w\ max}$ / $N_{D,w\ min}$	1.13	1.13
Outliers	51.22, 51.85, 51.22	none

Calibration coefficients for PTW 23343 and PPC05 ionization chambers Plane pallaler chamber

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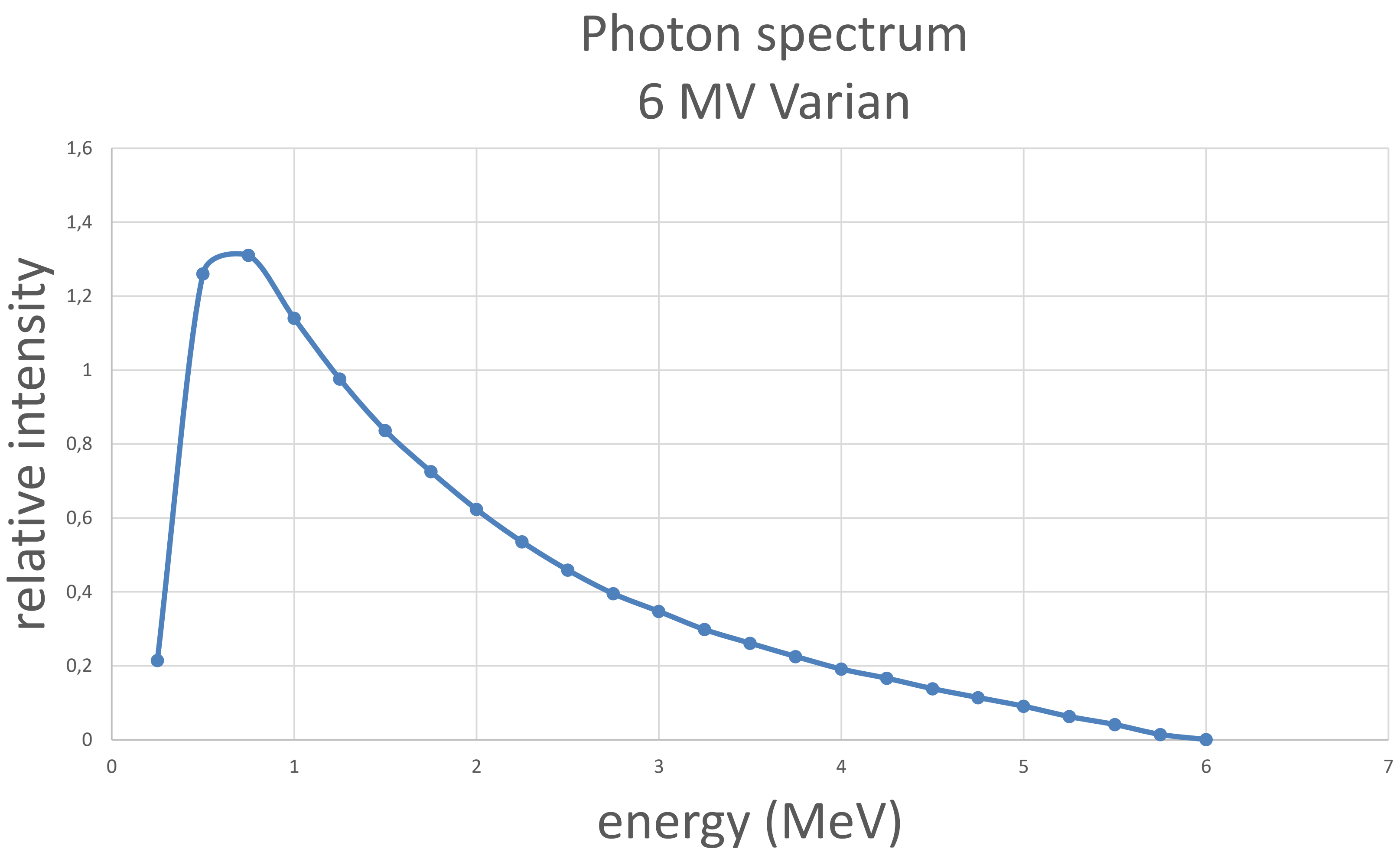
Outliers	51.22, 51.85, 51.22	none

Spectrum of photon beam Energy
6 MV Varian



$$\left(N_{D,water}\right)_Q$$

$$k_{Q,Q_0} = \frac{\left(\dfrac{S_{col}}{\rho}\right)^{w}_{air,Q} \cdot p_{u,Q}}{\left(\dfrac{S_{col}}{\rho}\right)^{w}_{air,Q_0} \cdot p_{u,Q_0}}$$

Monte Carlo calculation of nine megavoltage photon beam spectra using the BEAM code

Daryoush Sheikh-Bagheri[a] and D. W. O. Rogers[b]

$$k_{Q,Q_0} \cong \frac{\left(\dfrac{S_{col}}{\rho}\right)^{w}_{air,Q}}{\left(\dfrac{S_{col}}{\rho}\right)^{w}_{air,Q_0}}$$

6MV/15 MV 1,02

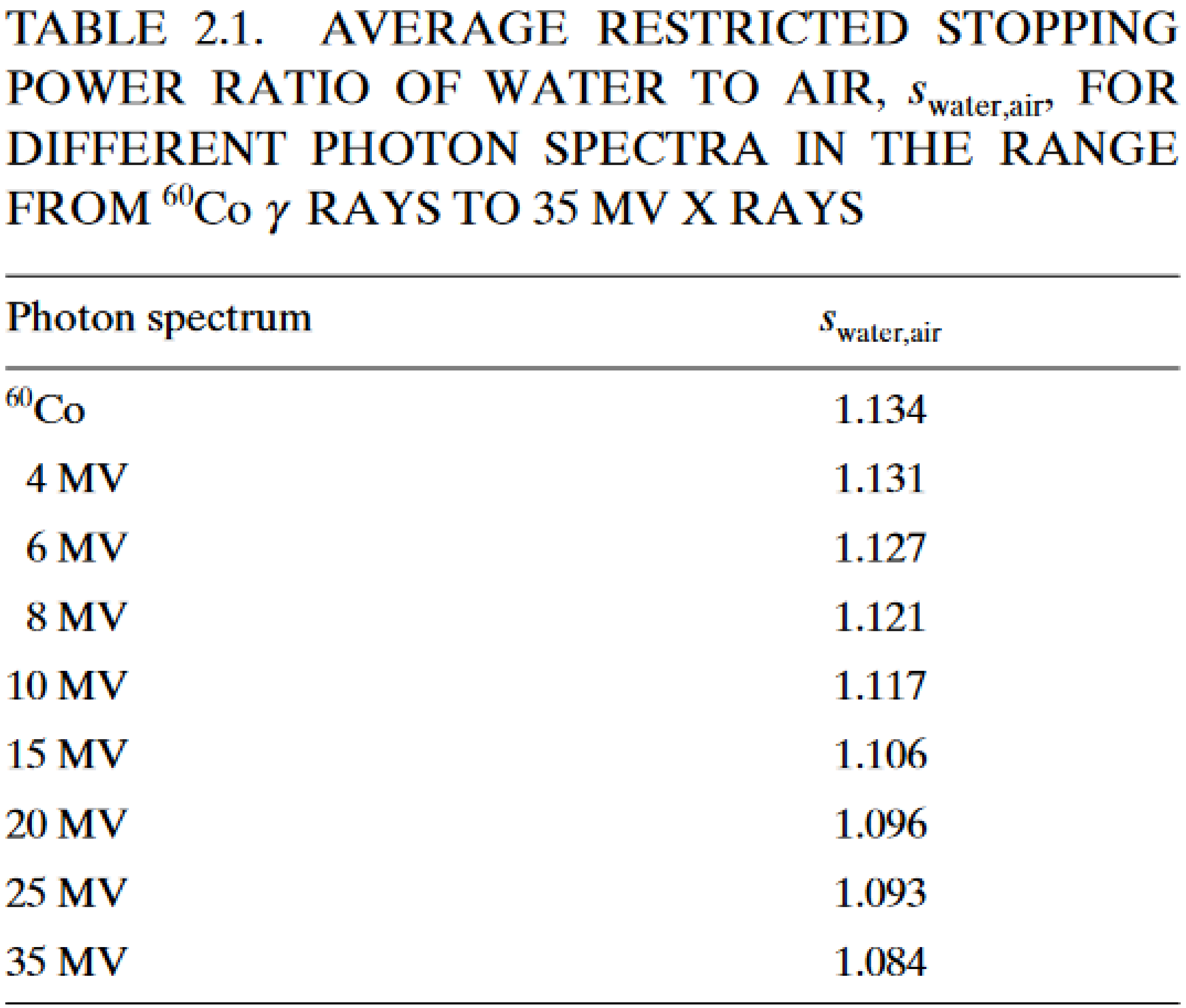


TABLE 2.1. AVERAGE RESTRICTED STOPPING POWER RATIO OF WATER TO AIR, $s_{\text{water,air}}$, FOR DIFFERENT PHOTON SPECTRA IN THE RANGE FROM ^{60}Co γ RAYS TO 35 MV X RAYS

Photon spectrum	$s_{\text{water,air}}$
^{60}Co	1.134
4 MV	1.131
6 MV	1.127
8 MV	1.121
10 MV	1.117
15 MV	1.106
20 MV	1.096
25 MV	1.093
35 MV	1.084

Dependence of spectrum on depth and position in beam

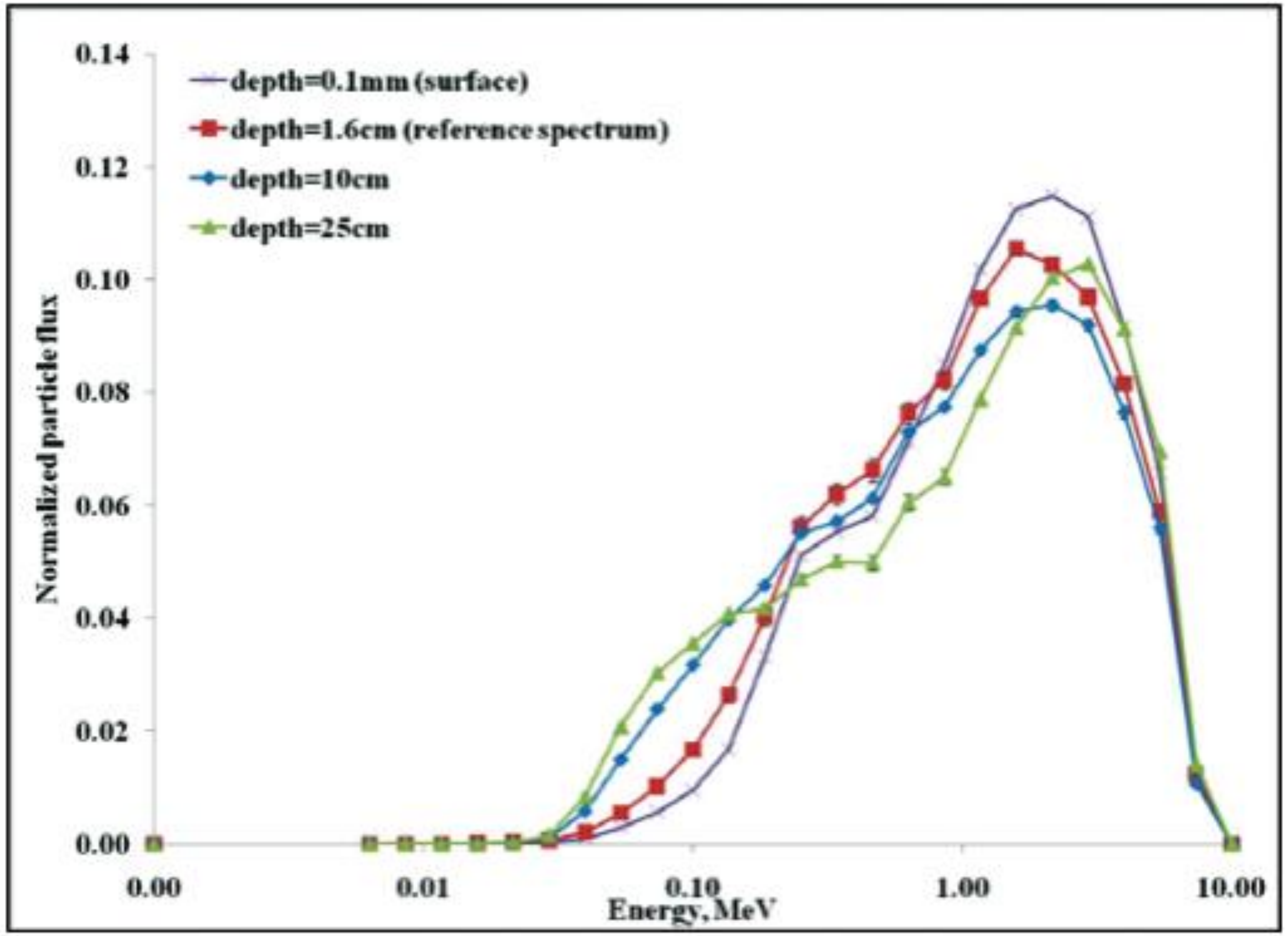


FIG. 2. Variations in photon energy spectra as a function of depth along central axis for a 6 MV 10 cm × 10 cm field.

Variations in photon energy spectra of a 6 MV beam and their impact on TLD response

Sarah B. Scarboro, David S. Followill, Rebecca M. Howell, and Stephen F. Kry[a]

Dependence of spectrum on depth and position in beam

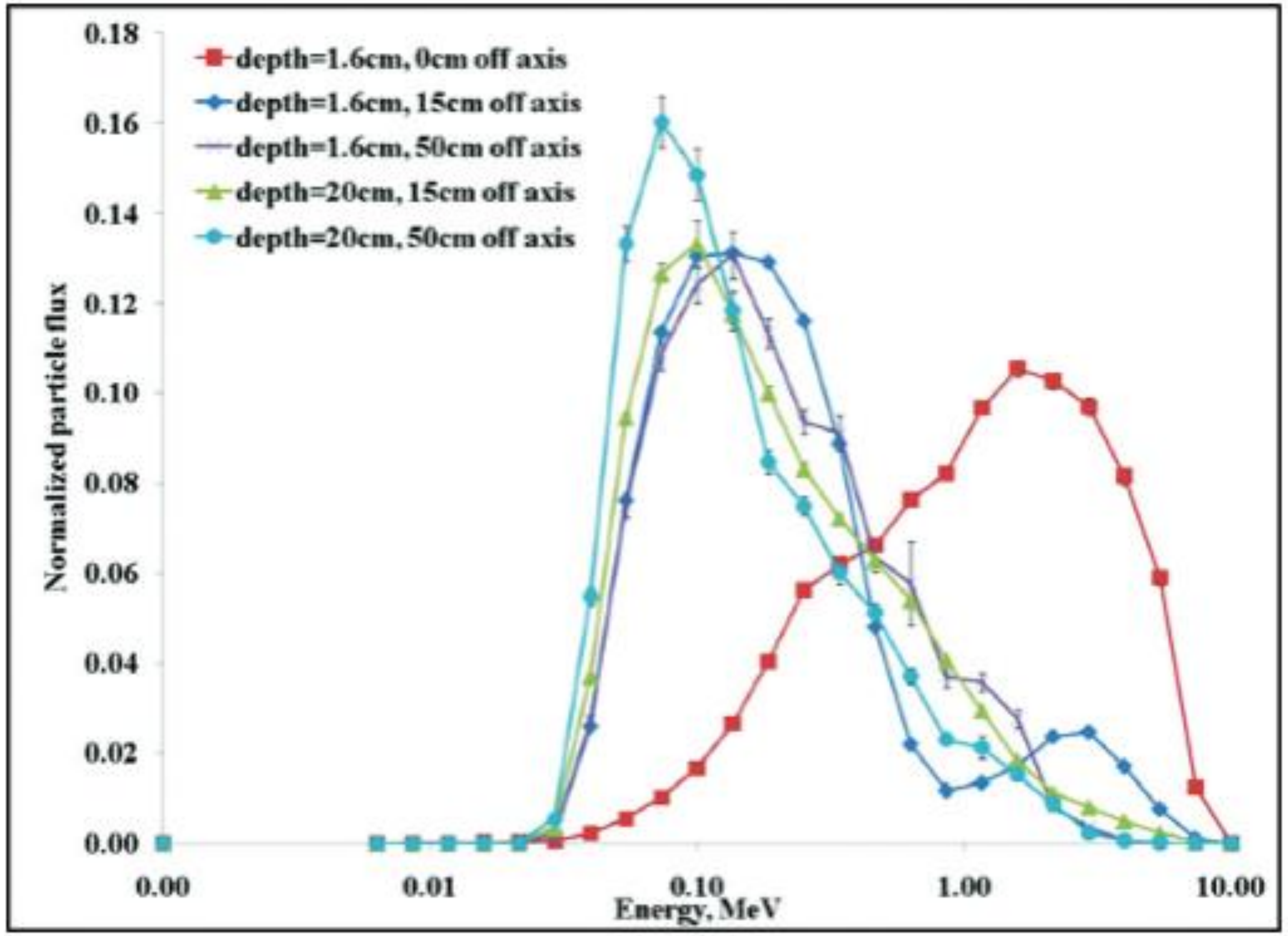


FIG. 4. Variations in out-of-field photon energy spectra as a function of distance from the central axis for 10 cm × 10 cm field.

Variations in photon energy spectra of a 6 MV beam and their impact on TLD response

Sarah B. Scarboro, David S. Followill, Rebecca M. Howell, and Stephen F. Kry[a]

A synthetic spectrum parameter

- easily measured
- with small uncertainty

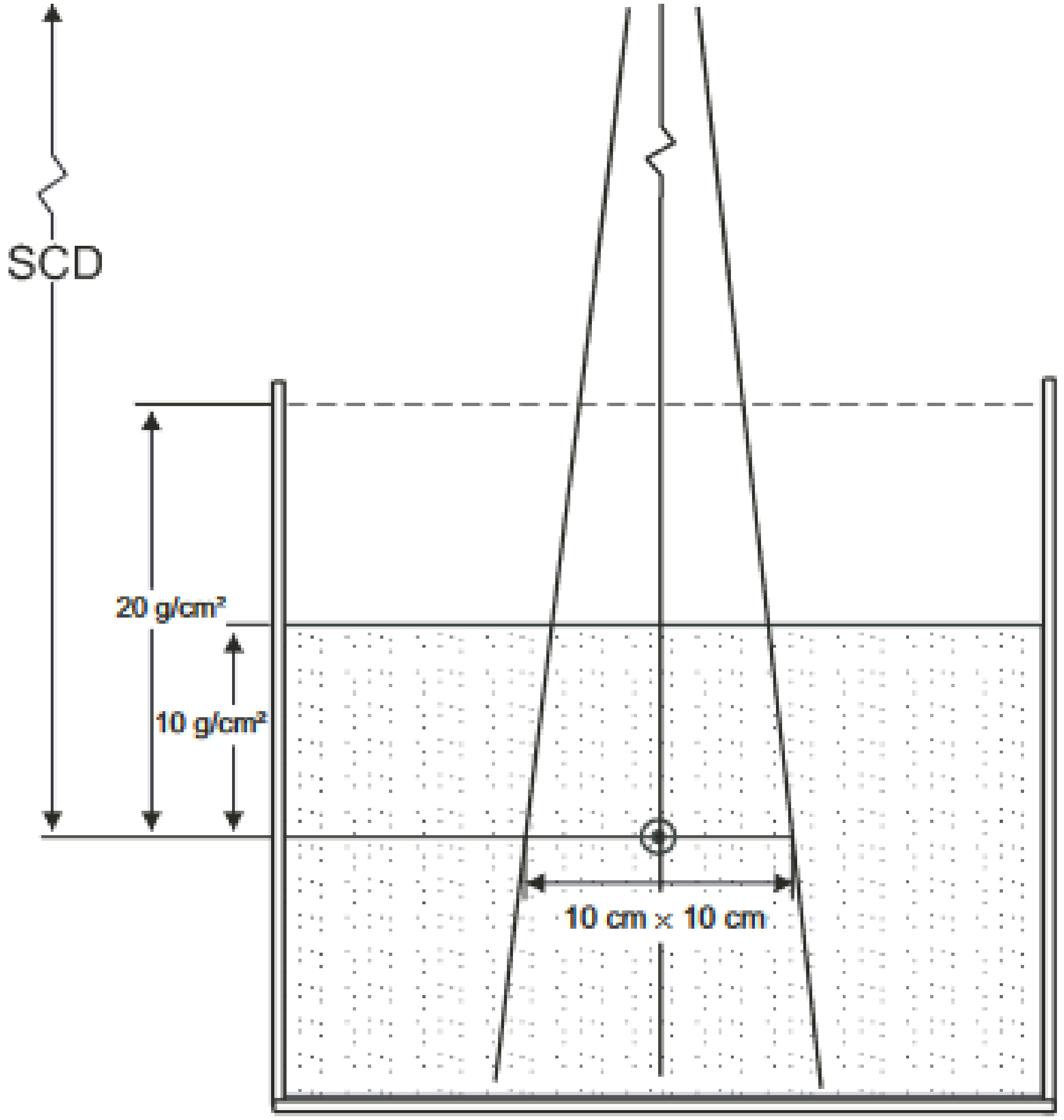
and

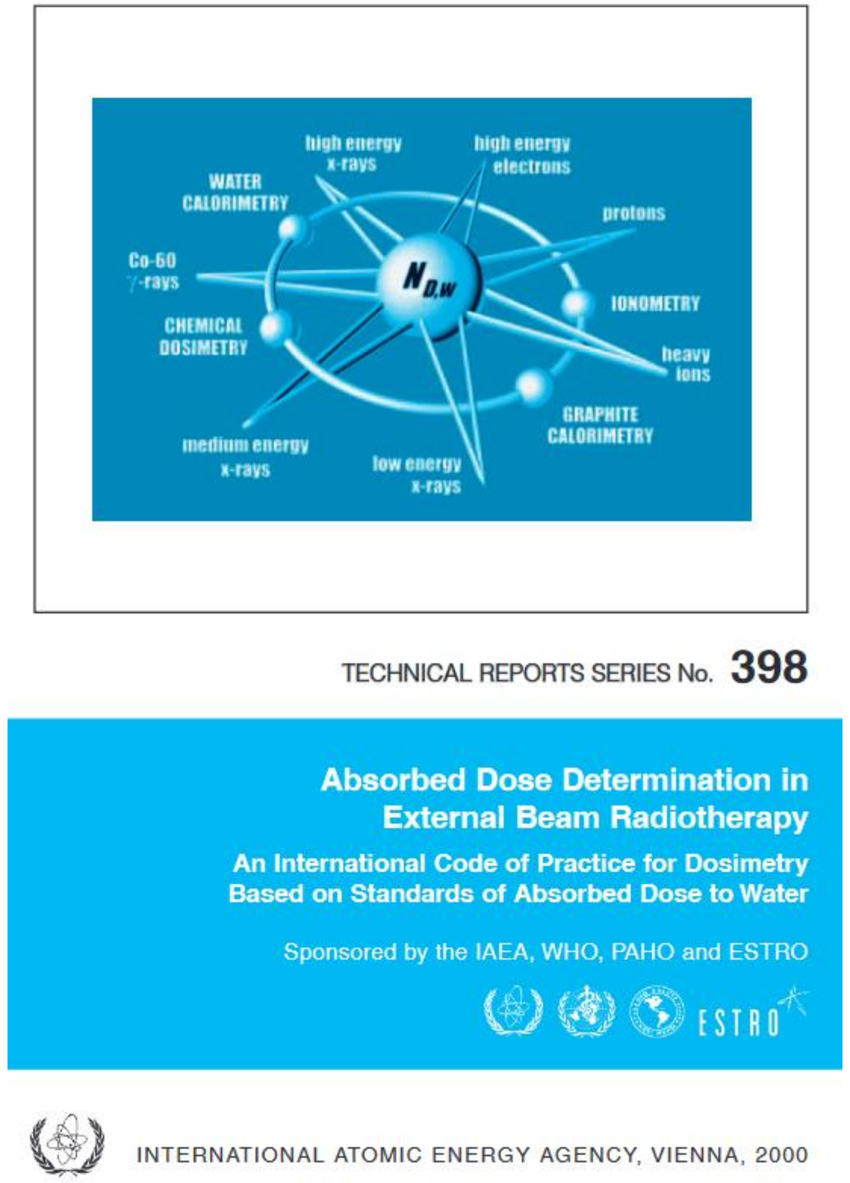
the dependence between the ratio of (restricted) mass stopping powers for water and air can be defined

$$k_{Q,Q_0} = \frac{\left(\frac{S_{col}}{\rho}\right)^{w}_{air,Q} \cdot p_{u,Q}}{\left(\frac{S_{col}}{\rho}\right)^{w}_{air,Q_0} \cdot p_{u,Q_0}}$$

Report 398 – beam qulity index

$TPR_{20,10}$





TECHNICAL REPORTS SERIES No. 398

Absorbed Dose Determination in External Beam Radiotherapy

An International Code of Practice for Dosimetry Based on Standards of Absorbed Dose to Water

Sponsored by the IAEA, WHO, PAHO and ESTRO

INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 2000

$$TPR_{20,10} = \frac{M_{water}(20, SCD = 100cm)}{M_{water}(10, SCD = 100cm)}$$

Report 398 – beam qulity index

TPR20/10

TPR20,10 can also be obtained from PDD (percent depth dose)

$$TPR_{20,10} = 1.2661 \cdot PDD_{20,10} - 0.0595$$

$$PDD_{20,10} = \frac{PDD(10{,}10{,}20, SSD = 100cm)}{PDD(10{,}10{,}10, SSD = 100cm)}$$

TPR20/10

TPR20,10 can also be obtained from PDD

$$TPR_{20,10} = -0.7898 + 0.0329 \cdot PDD(10{,}10{,}10, SSD = 100cm) - 0.000166 \cdot \left(PDD(10{,}10{,}10, SSD = 100cm)\right)^2$$

Corrections for influence quantities

$$D_{water} = \boxed{M_{cor}} \cdot N_{D,water} \cdot k_{Q,Q_0}$$

for preassure and temperature

$$k_{T,P} = \frac{(273.2+T)}{(273.2+T_0)} \cdot \frac{P_0}{P}$$

T_0, P_0 are the temperature and preassure used for callibration

for humidity
no corrections for humidity are needed if the calibration factor was reffered to a relative humidity of 50% and is used in a relative humidity between 20 and 80%

Corrections for influence quantities

$$D_{water} = \boxed{M_{cor}} \cdot N_{D,water} \cdot k_{Q,Q_0}$$

Polarity effect

The influence of polarization on the chamber reading should be accounted for.

Correction factor

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

M+, M- are reading obtained for positive and negative polarity
M reading for polarity used routinely

Polarity effect

The signal measured with the chamber changes the value, when the polarity is reversed.

Why?

For pallarel chamber (easiest to understand) – in the measuring electrode

more electrons are removed from the measurement area than are retained

a small positive charge is produced

when the polarity is changed, this charge is added to the measured signal

Corrections for influence quantities

$$D_{water} = \boxed{M_{cor}} \cdot N_{D,water} \cdot k_{Q,Q_0}$$

Polarity effect

User should inform teh callibration laboratory on the polarization potential and polarity used in daily measurements.

After changing polarity one should wait some time to obtain
a stable reading of the chamber. For some chambers it may be even 20 min.

Corrections for influence quantities

$$D_{water} = \boxed{M_{cor}} \cdot N_{D,water} \cdot k_{Q,Q_0}$$

Ion recombination correction factor k_s

The two voltage method is used.

Reading is measured for two voltages V1 and V2. V1/V2 ≥ 3

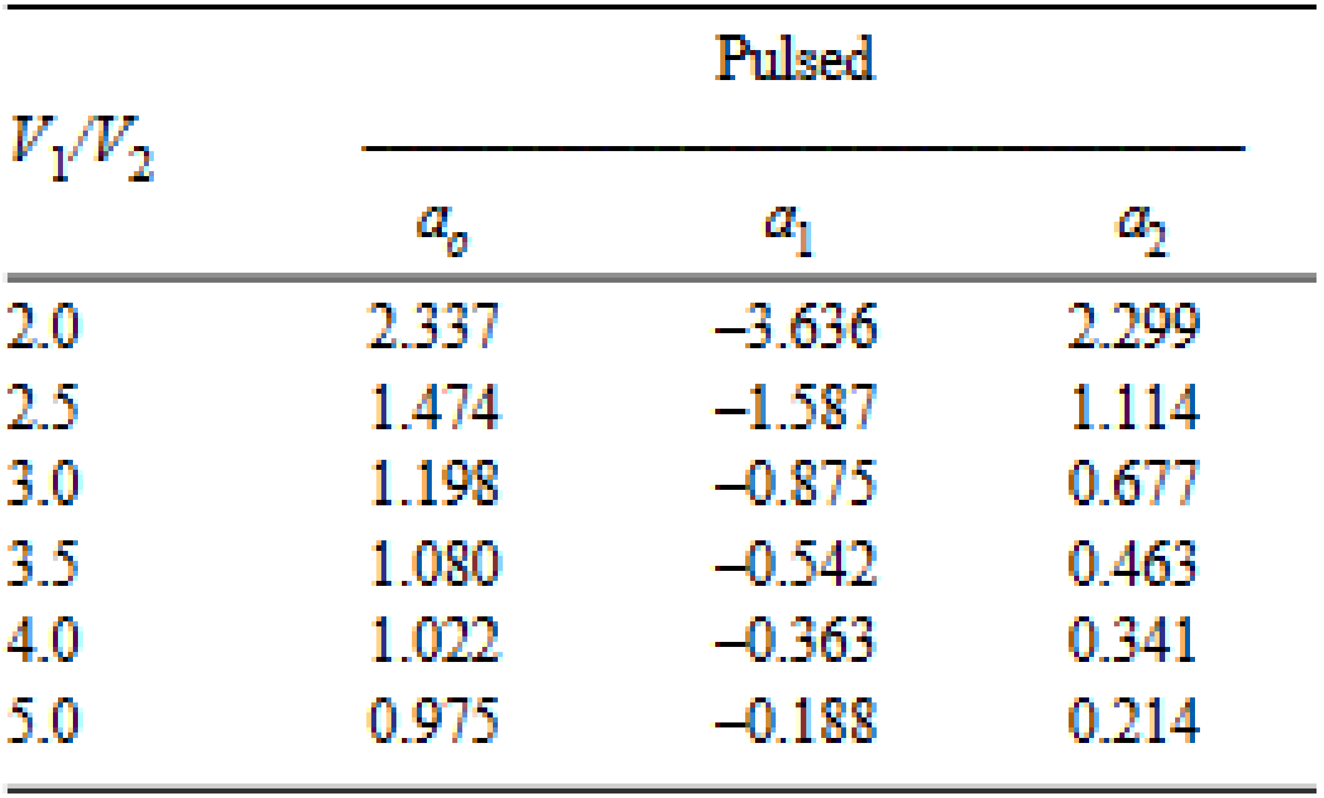
Correction factor

$$k_s = a_0 + a_1 \cdot \left(\frac{M1}{M2}\right) + a_2 \cdot \left(\frac{M1}{M2}\right)^2$$

Corrections for influence quantities

$$D_{water} = \boxed{M_{cor}} \cdot N_{D,water} \cdot k_{Q,Q_0}$$

$$k_s = a_0 + a_1 \cdot \left(\frac{M1}{M2}\right) + a_2 \cdot \left(\frac{M1}{M2}\right)^2$$



V_1/V_2	Pulsed		
	a_0	a_1	a_2
2.0	2.337	–3.636	2.299
2.5	1.474	–1.587	1.114
3.0	1.198	–0.875	0.677
3.5	1.080	–0.542	0.463
4.0	1.022	–0.363	0.341
5.0	0.975	–0.188	0.214

Coefficients from Table 9
Report 398
Two sets of data for pulsed
and pulsed-scanned dose.
Almost all beams are pulsed.

Ion recombination correction factor

Not all ions produced in the chamber reach the collection electrode

Some of them recombine

Factor little > 1 should be used

Flash (ultra high dose rate) ≈ 1.02

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$k_{Q,Q0}$ (in fact k_Q)

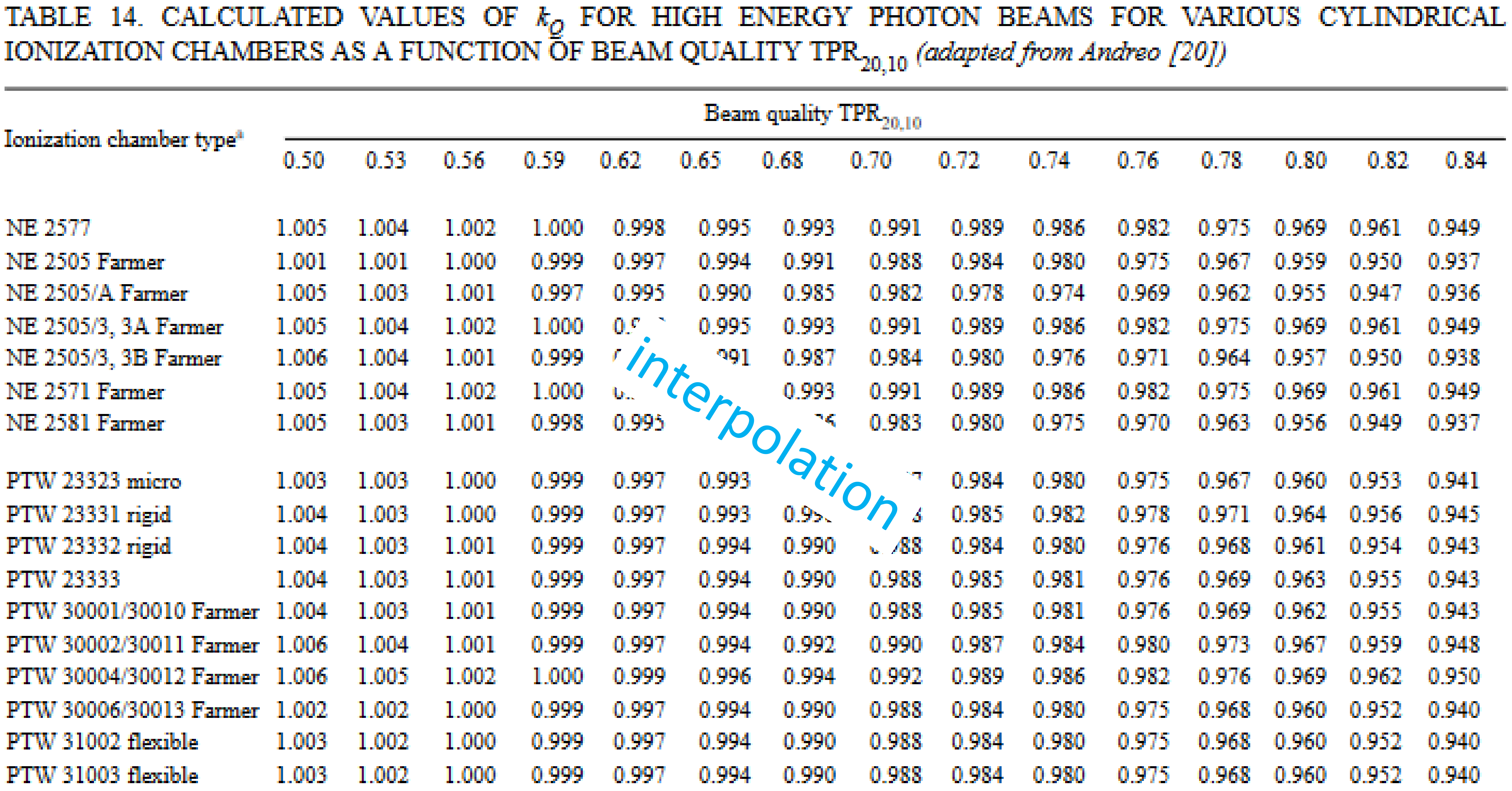

TABLE 14. CALCULATED VALUES OF k_Q FOR HIGH ENERGY PHOTON BEAMS FOR VARIOUS CYLINDRICAL IONIZATION CHAMBERS AS A FUNCTION OF BEAM QUALITY $TPR_{20,10}$ *(adapted from Andreo [20])*

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
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	[illegible]	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	[illegible]	[illegible]	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	[illegible]	[illegible]	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	[illegible]	[illegible]	0.983	0.980	0.975	0.970	0.963	0.956	0.949	0.937
PTW 23323 micro	1.003	1.003	1.000	0.999	0.997	0.993	[illegible]	[illegible]	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	[illegible]	[illegible]	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	[illegible]	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

interpolation

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Interpolacja

NE 2505 A Farmer		
0.70	0.74	0.73
0.982	0.974	0.9…

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Practice – measurements of absorbed dose conventional accelerators

Water is recommended as the reference medium for measurements
of absorbed dose and quality in photon beams.

The phantom should extend to at least 5 cm beyond
all sides of the field size.

Cylindrical chambers are recommended.

It is not recommended to use non-waterproof chambers.

Practice – measurements of absorbed dose conventional accelerators

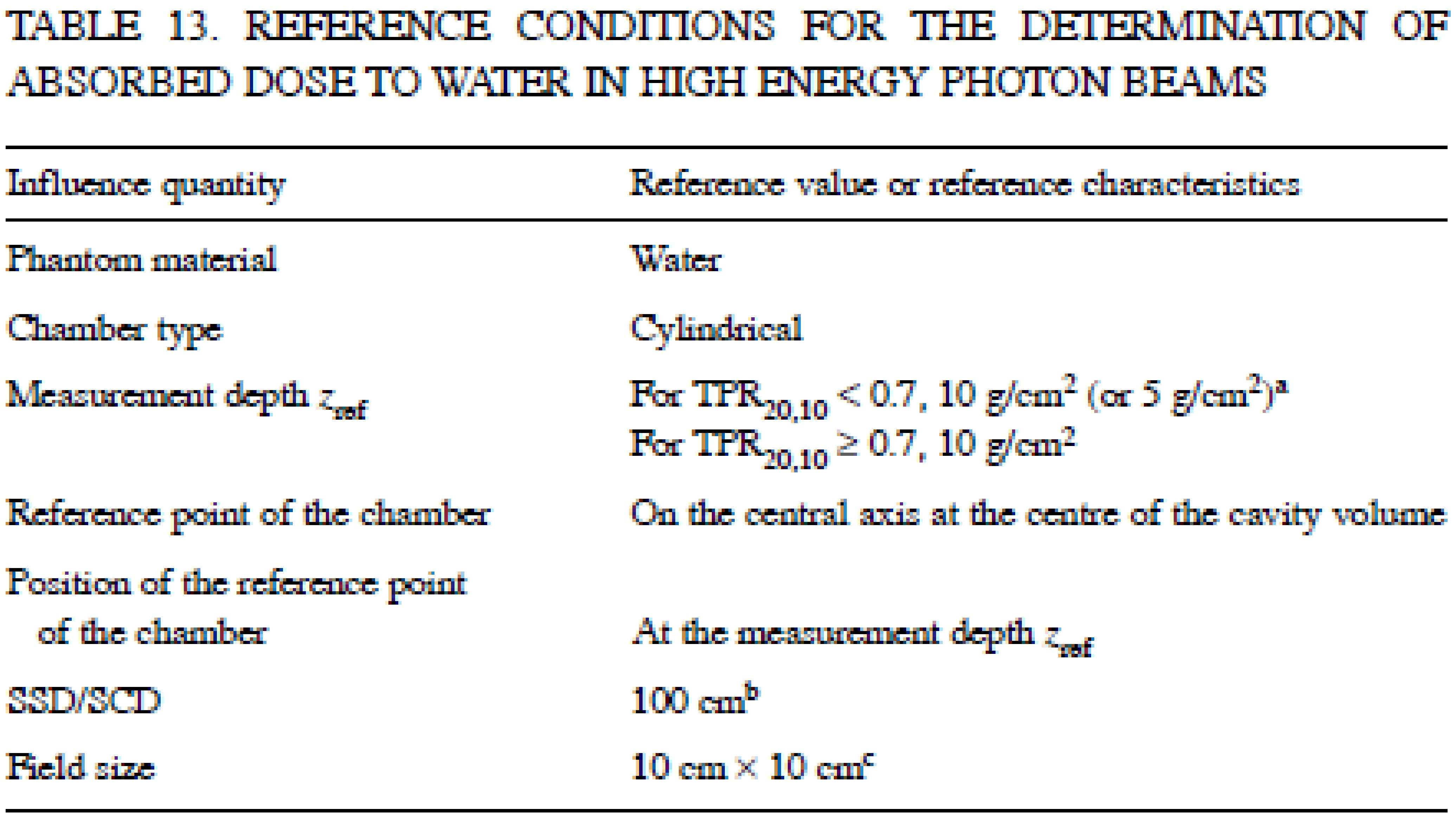

TABLE 13. REFERENCE CONDITIONS FOR THE DETERMINATION OF ABSORBED DOSE TO WATER IN HIGH ENERGY PHOTON BEAMS

Influence quantity	Reference value or reference characteristics
Phantom material	Water
Chamber type	Cylindrical
Measurement depth z_{ref}	For $TPR_{20,10} < 0.7$, 10 g/cm^2 (or 5 g/cm^2)[a] For $TPR_{20,10} \geq 0.7$, 10 g/cm^2
Reference point of the chamber	On the central axis at the centre of the cavity volume
Position of the reference point of the chamber	At the measurement depth z_{ref}
SSD/SCD	100 cm[b]
Field size	10 cm × 10 cm[c]

TRS 398

Why reference depth is 10 cm?

Practice – measurements of percent depth dose conventional accelerators

Water is recommended as the reference medium for measurements.

The phantom should extend to at least 5 cm beyond
all for sides of the field size.

Plane-paralel chambers are recommended. If cylindrical ionization chamber is used the effective measurement point should be taken into account.

Then complete PDD should be shifted towards the surface a distance equal to 0.6 internal cavity radius of the chamber. Usually we shift the chamber!

The chamber should be moved from the bottom to the surface!

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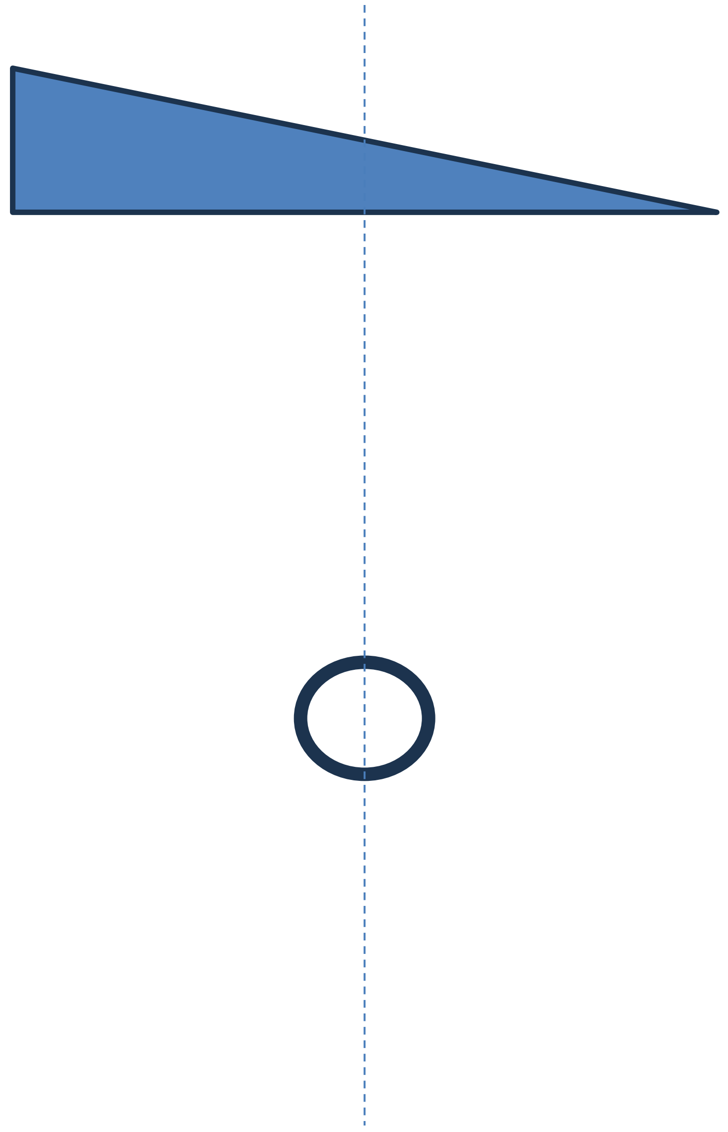
Wedge beam output factors measurements



The detector dimension in the wedge

direction should be

as small as possible.

Position of the chamber with respect

to central axis

should be checked carefully.

Cross calibration

It is allowed to calibrate a chamber with a claibrated chamber ref

in the secondary standard laboratory. Calibrated in quality Q_0.

The chambers are compared by alternately placing the chambers in a water phantom

with their reference points at reference depth (10 cm).

$$N_{D,w,Q_o}^{\text{field}} = \frac{M_{\text{ref}}}{M_{\text{field}}} N_{D,w,Q_o}^{\text{ref}}$$

Cross calibration in Q_0

Cross calibrated chamber factor is for Q_0 radiation quality!

To have calibration factor for Co60 we have to apply $k_{Q,Q0}$ factor.

From Q to Q_0 we use $k_{Q,Q0}$

From Q_0 to Q we use $1/k_{Q,Q0}$

$$\left(N_{D,water}\right)_Q = \left(N_{D,water}\right)_{Q0} \cdot k_{Q,Q_0}$$

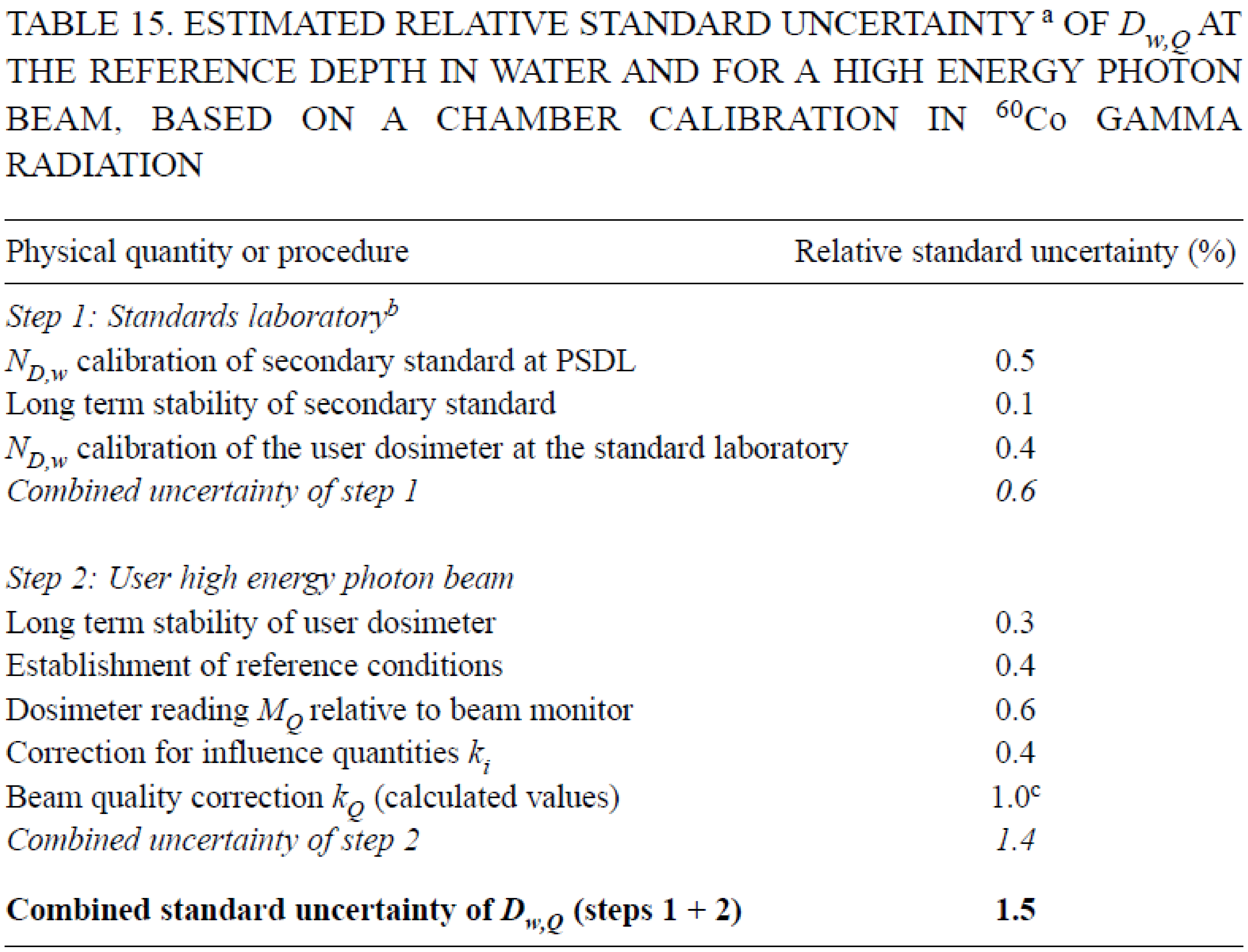
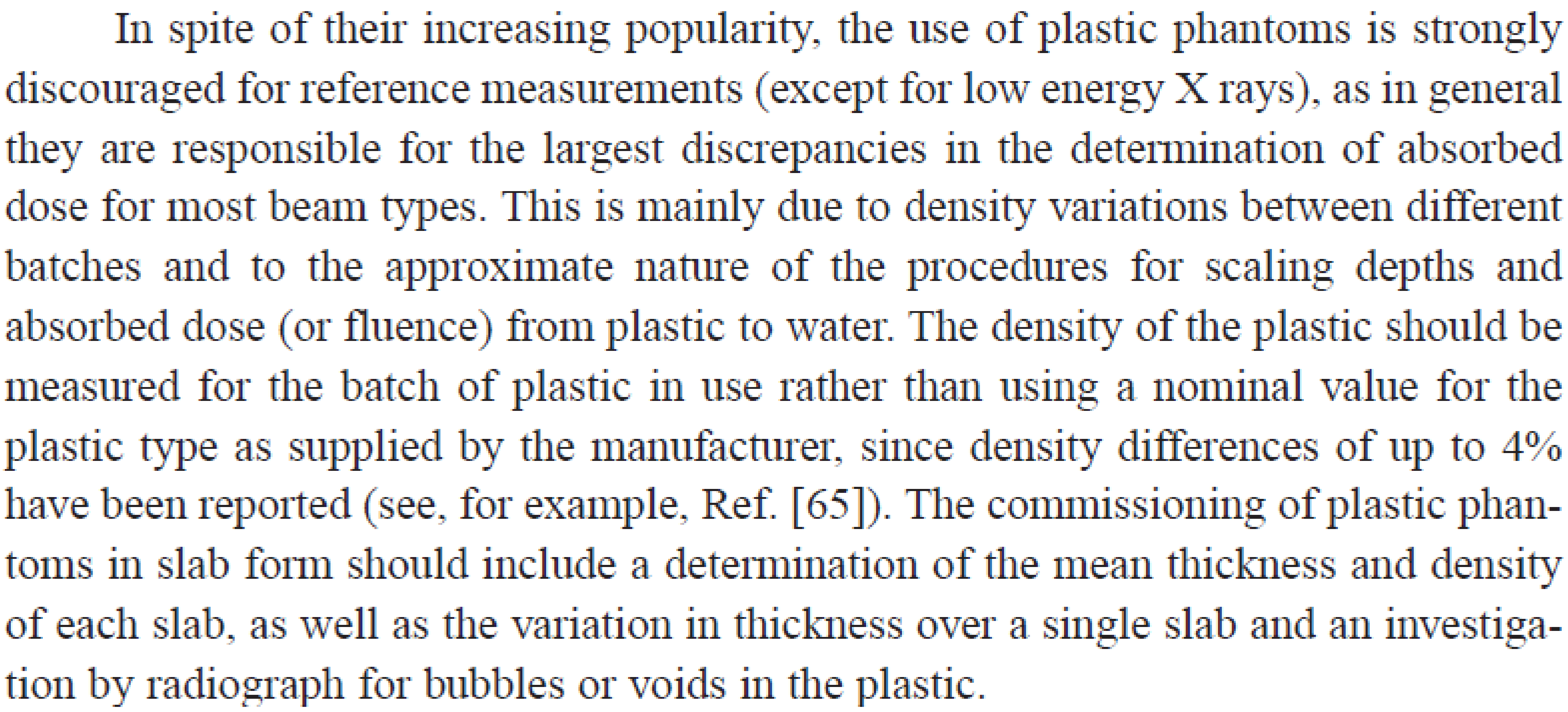


TABLE 15. ESTIMATED RELATIVE STANDARD UNCERTAINTY [a] OF $D_{w,Q}$ AT THE REFERENCE DEPTH IN WATER AND FOR A HIGH ENERGY PHOTON BEAM, BASED ON A CHAMBER CALIBRATION IN ^{60}Co GAMMA RADIATION

Physical quantity or procedure	Relative standard uncertainty (%)
Step 1: Standards laboratory[b]	
$N_{D,w}$ 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*
Step 2: User high energy photon beam	
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**

Solid phantoms



In spite of their increasing popularity, the use of plastic phantoms is strongly discouraged for reference measurements (except for low energy X rays), as in general they are responsible for the largest discrepancies in the determination of absorbed dose for most beam types. This is mainly due to density variations between different batches and to the approximate nature of the procedures for scaling depths and absorbed dose (or fluence) from plastic to water. The density of the plastic should be measured for the batch of plastic in use rather than using a nominal value for the plastic type as supplied by the manufacturer, since density differences of up to 4% have been reported (see, for example, Ref. [65]). The commissioning of plastic phantoms in slab form should include a determination of the mean thickness and density of each slab, as well as the variation in thickness over a single slab and an investigation by radiograph for bubbles or voids in the plastic.

Solid phantoms

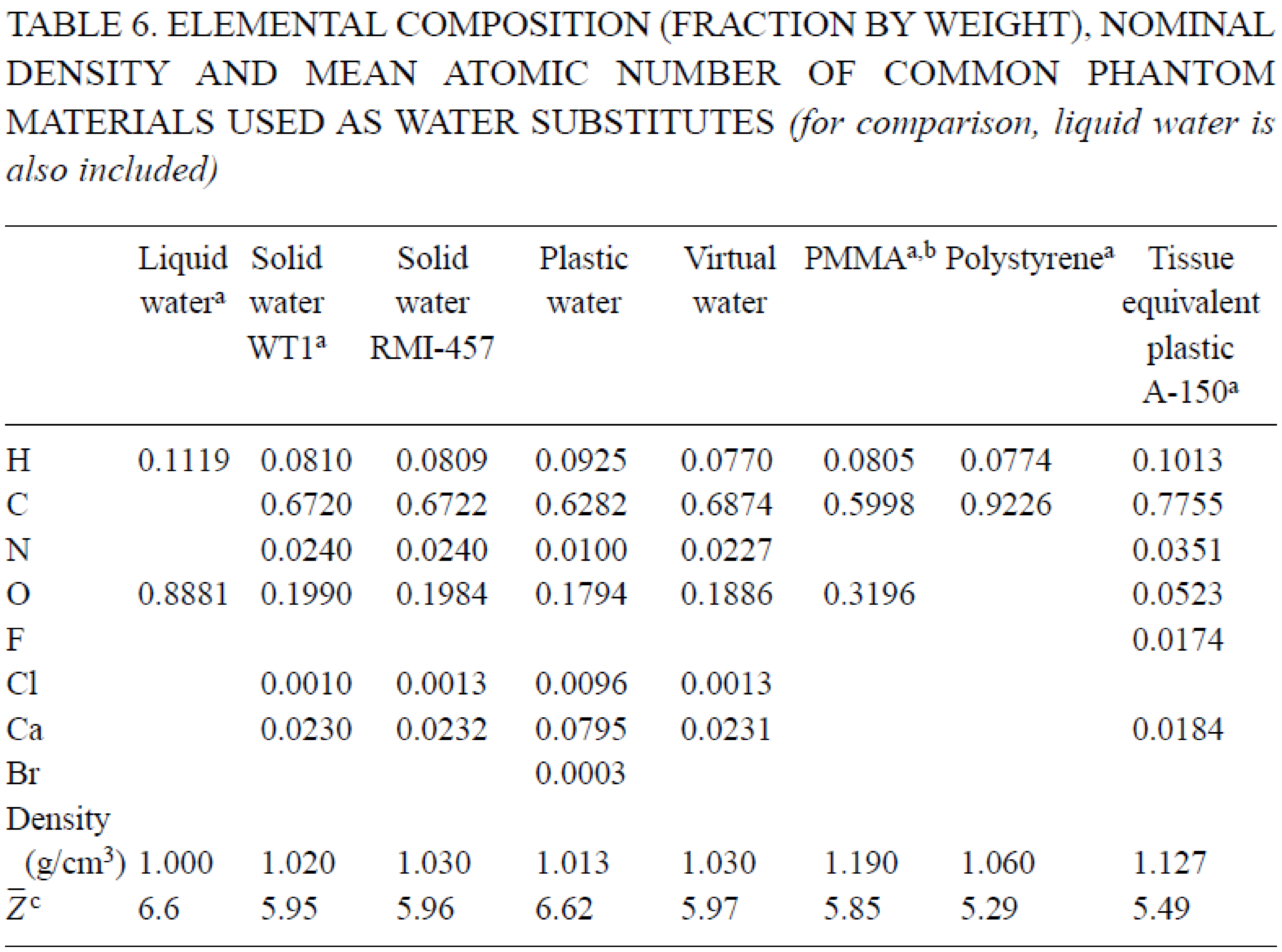


TABLE 6. ELEMENTAL COMPOSITION (FRACTION BY WEIGHT), NOMINAL DENSITY AND MEAN ATOMIC NUMBER OF COMMON PHANTOM MATERIALS USED AS WATER SUBSTITUTES *(for comparison, liquid water is also included)*

	Liquid water[a]	Solid water WT1[a]	Solid water RMI-457	Plastic water	Virtual water	PMMA[a,b]	Polystyrene[a]	Tissue equivalent plastic A-150[a]
H	0.1119	0.0810	0.0809	0.0925	0.0770	0.0805	0.0774	0.1013
C		0.6720	0.6722	0.6282	0.6874	0.5998	0.9226	0.7755
N		0.0240	0.0240	0.0100	0.0227			0.0351
O	0.8881	0.1990	0.1984	0.1794	0.1886	0.3196		0.0523
F								0.0174
Cl		0.0010	0.0013	0.0096	0.0013			
Ca		0.0230	0.0232	0.0795	0.0231			0.0184
Br				0.0003				
Density (g/cm^3)	1.000	1.020	1.030	1.013	1.030	1.190	1.060	1.127
$\overline{Z}$[c]	6.6	5.95	5.96	6.62	5.97	5.85	5.29	5.49

Thank you for your attention!