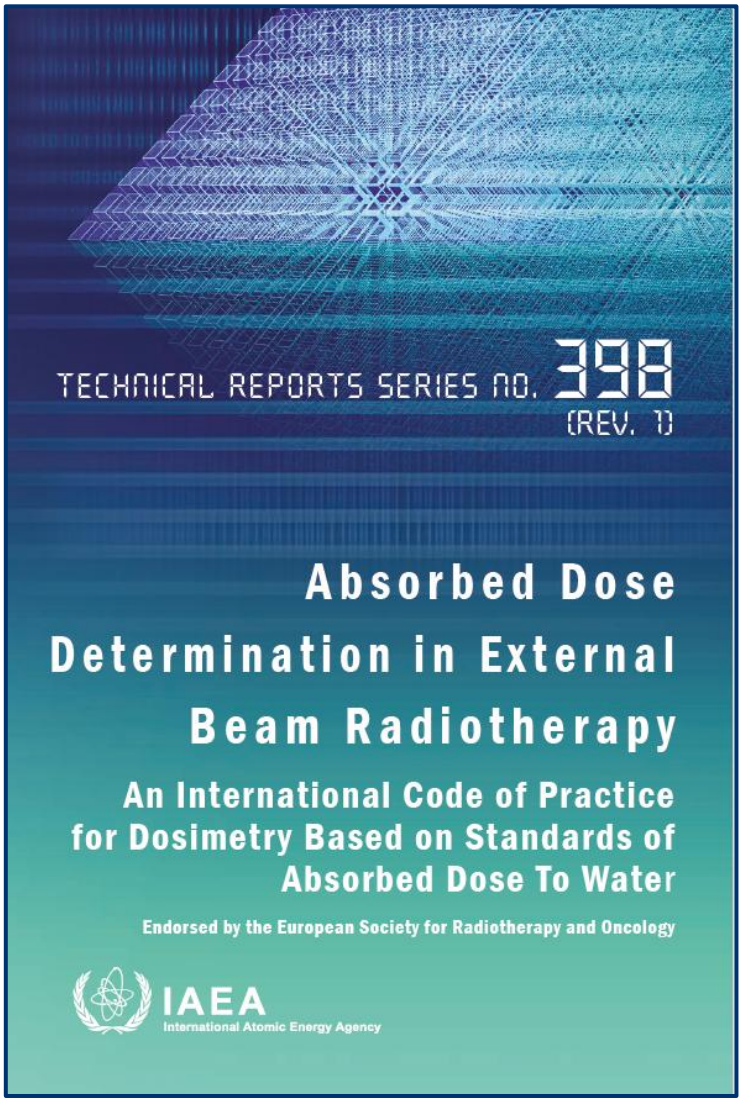

IAEA TRS-398 Rev. 1 Chapters 5&6 High-energy photons

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5-CODE OF PRACTICE FOR ^{60}Co BEAMS

1. General
2. Dosimetry equipment
   - Ionization chambers
   - Phantoms and chamber sleeves
3. Beam quality specification
   - Choice of beam quality index
   - Measurement of beam quality
4. Determination of absorbed dose to water
   - Reference conditions
   - Determination of D_w under reference conditions
   - ~~Values for k_{Q,Q_0}~~
5. Cross calibration of field ionization chambers
6. Measurements under non-reference conditions
   - Central-axis depth-dose distributions
   - Output factors
7. Estimated uncertainty in D_w under reference conditions
8. Worksheet

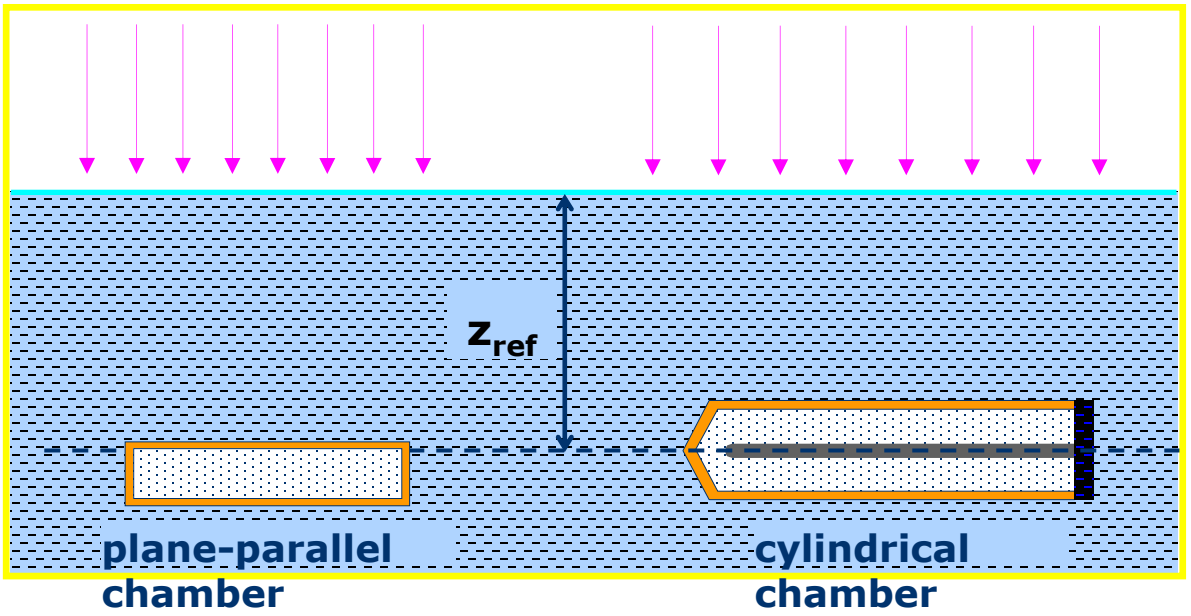
5.1. General

Simplest formalism: $D_{\mathrm{w}} = M\, N_{D,\mathrm{w}}$

No beam quality determination! $k_Q = 1$

5.2. Equipment

5.2.1. Ionization chambers: both cylindrical and plane-parallel



5.2. Equipment

5.2.2. Phantom and waterproof sleeves: see generic

Phantom: Water tank that extends > 5 cm beyond the field size, account for window water-equivalent thickness (~ρ.t) when using horizontal beam and at least 5 g/cm^2 beyond max depth measurement, consider window bending

Waterproof sleeve - PMMA (ρ = 1.19 g/cm^3), 1 mm max thickness, 0.3 mm air gap, also used for chamber calibration !

5.3. Beam quality

Simply ^{60}Co

5.4.1. Reference conditions for D_w in ^{60}Co

TABLE 12. REFERENCE CONDITIONS FOR THE DETERMINATION OF ABSORBED DOSE TO WATER IN ^{60}Co GAMMA RAY BEAMS

Influence quantity	Reference value or reference characteristic
Phantom material	Water
Chamber type	Cylindrical or plane parallel
Measurement depth, z_{ref}	5 g/cm^2 (or 10 g/cm^2)[a]
Reference point of chamber	For cylindrical chambers, on the central axis at the centre of the cavity volume
	For plane parallel chambers, on the inner surface of the front wall at its centre[b]
Position of reference point of chamber	For cylindrical and plane parallel chambers, at the measurement depth z_{ref}
Source–surface distance or source–chamber distance	80 cm or 100 cm [c]
Field size	10 cm × 10 cm [d]

5.4.2. Determination of D_w in reference conditions

$$D_{\mathrm{w}} = M\, N_{D,\mathrm{w}}$$

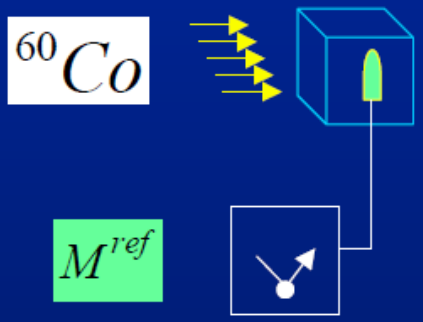
Remember: M corrected for elec, pressure&temperature, polarity, recombination

5.4.3. Determination of D_w at z_{max}

PDD for SSD setup, TPR for SAD setup

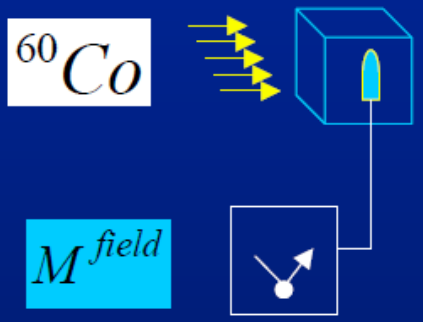
5.5. Cross calibration

reference chamber



same position

chamber to be calibrated



$$D_w^{ref} = M^{ref} N_{D,w}^{ref}$$

$$D_w^{field} = M^{field} N_{D,w}^{field}$$

as D_w has to be the same for both chambers:

$$N_{D,w}^{field} = N_{D,w}^{ref} \frac{M^{ref}}{M^{field}}$$

5.6. Measurements under non-reference conditions

CAX PDDs: for cylindrical chambers shift of PDDs over 0.6 * r_{cyl}

Attention to non-uniformities in smaller fields and wedged fields for OF

5.7. Uncertainty D_w in Co-60

TABLE 13. ESTIMATED RELATIVE STANDARD UNCERTAINTY[a] OF D_w AT THE REFERENCE DEPTH IN WATER FOR A ^{60}Co BEAM

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 standards laboratory	0.4
Combined uncertainty of step 1	0.6
Step 2: user ^{60}Co beam	
Long term stability of user dosimeter	0.2
Establishment of reference conditions	0.3
Dosimeter reading M_Q relative to timer or beam monitor	0.1
Correction for influence quantities k_i	0.3
Combined uncertainty of step 2	0.5
Combined standard uncertainty of D_w (steps 1 and 2)	0.8

5.8. Worksheet

5.8. WORKSHEET

Determination of the absorbed dose to water in a ^{60}Co gamma ray beam

User: _____ Date: _____

1. Radiation treatment unit and reference conditions for D_w determination

^{60}Co therapy unit: _____

Reference phantom: water Set-up: ☐ SSD ☐ SAD

Reference field size: 10 × 10 cm × cm Reference distance: _____ cm

Reference depth, z_{ref}: _____ g/cm^2

2. Ionization chamber and electrometer

Ionization chamber model: _____ Serial no.: Type: ☐ cyl ☐ pp

Chamber wall/window Material: _____ Thickness: _____ g/cm^2

Waterproof sleeve/cover Material: _____ Thickness: _____ g/cm^2

Phantom window Material: _____ Thickness: _____ g/cm^2

Absorbed dose to water cal. coefficient $N_{D,w}$ = _____ ☐ Gy/nC ☐ Gy/rdg

Reference conditions for calibration P_o = _____ kPa T_o = _____ °C Rel. humidity: ____%

Polarizing potential V_1: _____ V

Calibration polarity: ☐ positive ☐ negative ☐ corrected for polarity effect

User polarity: ☐ positive ☐ negative

Calibration laboratory: _____ Date: _____

Electrometer model: _____ Serial no.: _____

Calibrated separately from chamber: ☐ yes ☐ no Range setting: _____

If yes Calibration laboratory: Date: _____

3. Dosimeter reading[a] and correction for influence quantities

Uncorrected dosimeter reading at V_1 and user polarity: _____ ☐ nC ☐ rdg

Corresponding time: _____ min

Ratio of dosimeter reading and time[b]: M_1 = _____ ☐ nC/min ☐ rdg/min

(a) Pressure P = _____ kPa Temperature T = _____ °C Rel. humidity (if known): _____%

$$k_{TP} = \frac{(273.15+T)}{(273.15+T_o)}\frac{P_o}{P} = \_\_\_\_\_$$

(b) Electrometer calibration factor[c] k_{elec} = _____ ☐ nC/rdg ☐ dimensionless

(c) Polarity correction[d] Reading at $+V_1$: M_+ = _____ Reading at $-V_1$: M_- = _____

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

(d) Recombination correction (two voltage method)

Polarizing voltages: V_1 (normal) = _____ V V_2 (reduced) = _____ V

Readings[e] at V_1, V_2: M_1 = _____ M_2 = _____

Voltage ratio V_1/V_2 = _____ Ratio of readings M_1/M_2 = _____

$$k_s = \frac{(V_1/V_2)^2 - 1}{(V_1/V_2)^2 - (M_1/M_2)} = \_\_\_\_\_$$ [f]

Corrected dosimeter reading at the voltage V_1:

$M = M_1 k_{TP} k_{elec} k_{pol} k_s$ = _____ ☐ nC/min ☐ rdg/min

4. Absorbed dose rate to water at the reference depth, z_{ref}

$D_w(z_{ref}) = MN_{D,w}$ = _____ Gy/min

5. Absorbed dose rate to water at the depth of dose maximum, z_{max}

Depth of dose maximum: z_{max} = 0.5 g/cm^2

(a) SSD set-up

PDD at z_{ref} for a 10 cm × 10 cm field size: PDD(z_{ref} = ____ g/cm^2) = _____ %

Absorbed dose rate calibration at z_{max}:

$D_w(z_{max}) = 100 D_w(z_{ref})/\text{PDD}(z_{ref})$ = _____ Gy/min

(b) SAD set-up

TMR at z_{ref} for a 10 cm × 10 cm field size: TMR(z_{ref} = ____ g/cm^2) = _____

Absorbed dose rate calibration at z_{max}:

$D_w(z_{max}) = D_w(z_{ref})/\text{TMR}(z_{ref})$ = _____ Gy/min

---

[a] All readings should be checked for leakage current and corrected if necessary.

[b] The timer error should be taken into account. The correction at voltage V_1 can be determined according to the following process:

M_A is the integrated reading at time t_A M_A = _____ t_A = _____ min

M_B is the integrated reading for n short exposures of time t_B/n each ($2 \le n \le 5$) M_B = _____ t_B = _____ min n = ___

Timer error: $\tau = (M_B t_A - M_A t_B)/(nM_A - M_B)$ = _____ min (the sign of τ has to be taken into account)

$M_1 = M_A/(t_A + \tau)$ = _____ ☐ nC/min ☐ rdg/min

[c] If the electrometer is not calibrated separately, set $k_{elec} = 1$.

[d] M in the denominator of k_{pol} denotes the reading at the user polarity. Preferably, each reading in the equation should be the average of the ratios of M (or M_+ or M_-) to the reading of an external monitor, M_{em}.

[e] Strictly, readings should be corrected for polarity effect (average from both polarities). Preferably, each reading in the equation should be the average of the ratios of M_1 or M_2 to the reading of an external monitor, M_{em}.

[f] It is assumed that the calibration laboratory has performed a recombination correction. Otherwise the factor $k'_s = k_s/k_{s,Q_o}$ should be used instead of k_s. When Q_o is ^{60}Co, k_{s,Q_o} (at the calibration laboratory) will normally be close to unity, and the effect of not using this equation will be negligible in most cases.

Note: SAD: source–axis distance; SSD: source–surface distance; cyl: cylindrical; pp: plane parallel; PDD: percentage depth dose; TMR: tissue–maximum ratio.

6- CODE OF PRACTICE FOR HIGH-ENERGY PHOTON BEAMS

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   - Choice of beam quality index
   - Measurement of beam quality
4. Determination of absorbed dose to water
   - Reference conditions
   - Determination of D_w under reference conditions
5. Values for k_{Q,Q_0}
6. Cross calibration of field ionization chambers
7. Measurements under non-reference conditions
   - Central-axis depth-dose distributions
   - Output factors
8. Estimated uncertainty in D_w under reference conditions
9. Worksheet

6.1. General

WFF beams 1-25 MV

FFF beams ≤ 10 MV

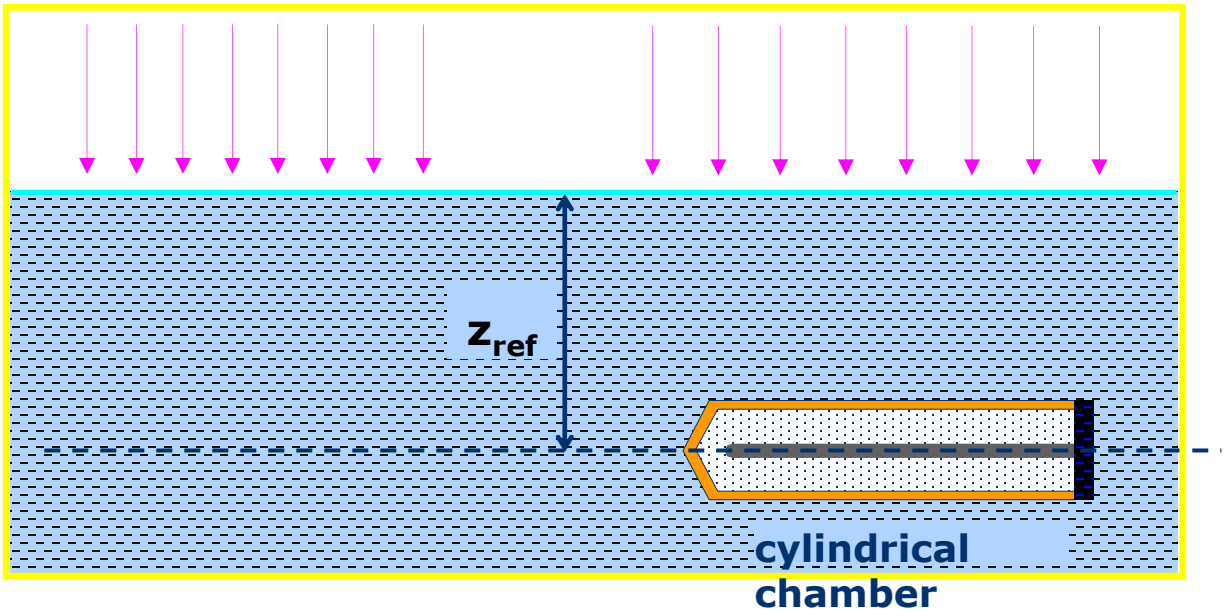
Special FFF beams (TomoTherapy, Radixact, CyberKnife, GammaKnife) → IAEA TRS-483

Formalism: $D_{w,Q} = M_Q N_{D,w,Q_0} k_{Q,Q_0}$

(if Q_0 = ^{60}Co → $D_{w,Q} = M_Q N_{D,w} k_Q$)

6.2. Equipment

6.2.1. Ionization chambers: only cylindrical



6.2. Equipment

6.2.2. Phantom and waterproof sleeves: see generic

Phantom: Water tank that extends > 5 cm beyond the field size, account for window water-equivalent thickness (~ρ.t) when using horizontal beam and at least 5 g/cm^2 beyond max depth measurement, consider window bending

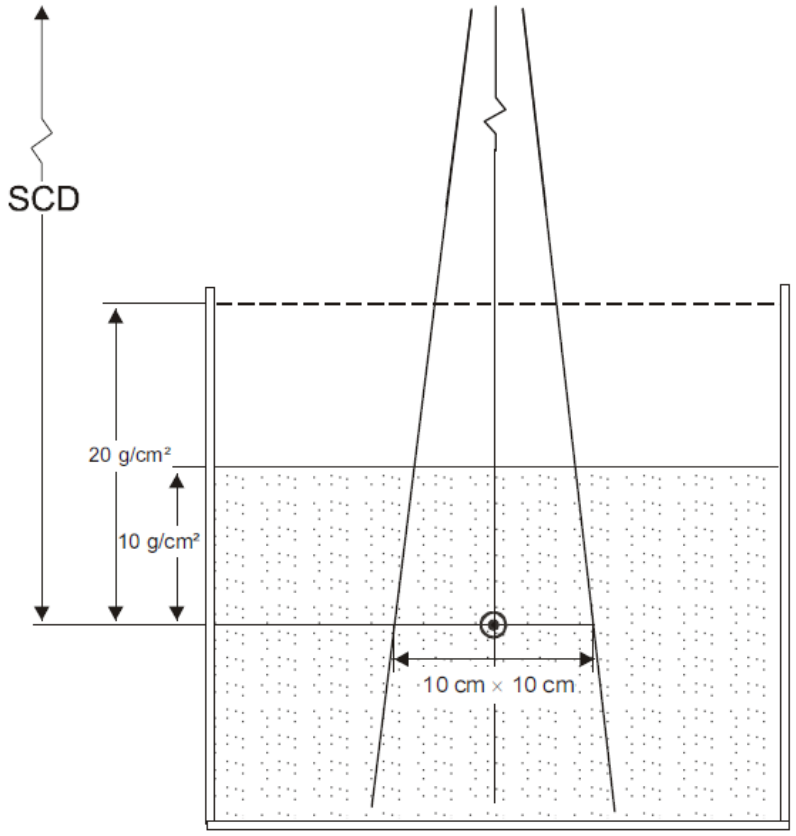
Waterproof sleeve - PMMA (ρ = 1.19 g/cm^3), 1 mm max thickness, 0.3 mm air gap, also used for chamber calibration !

6.3. Beam quality specification and measurement – $TPR_{20,10}$

TABLE 14. REFERENCE CONDITIONS FOR THE DETERMINATION OF THE PHOTON BEAM QUALITY ($TPR_{20,10}$)

Influence quantity	Reference value or reference characteristic
Phantom material	Water
Chamber type	Cylindrical or plane parallel
Measurement depths	20 g/cm² and 10 g/cm²
Reference point of the chamber	For cylindrical chambers, on the central axis at the centre of the cavity volume For plane parallel chambers, on the inner surface of the window at its centre
Position of the reference point of the chamber	For cylindrical and plane parallel chambers, at the measurement depths
Source–chamber distance	100 cm
Field size at source–chamber distance[a]	10 cm × 10 cm
Lateral beam profile	Homogeneous radial dose distribution over the sensitive volume of the ionization chamber

[a] The field size is defined at the plane of the reference point of the detector, at the recommended depths in the water phantom.



6.4.1. Reference conditions for D_w in high-energy photons

TABLE 15. REFERENCE CONDITIONS FOR THE DETERMINATION OF ABSORBED DOSE TO WATER IN HIGH ENERGY PHOTON BEAMS

Influence quantity	Reference value or reference characteristic
Phantom material	Water
Chamber type	Cylindrical
Measurement depth, z_{ref}	10 g/cm²
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 measurement depth z_{ref}
Source–surface distance or source–chamber distance[a]	100 cm
Field size[b]	10 cm × 10 cm
Lateral beam profile	Homogeneous radial dose distribution over the sensitive volume of the ionization chamber[c]

[a] If the reference dose has to be determined for an isocentric set-up, the source–axis distance (SAD) of the accelerator is to be used, even if this is not 100 cm.

[b] The field size is defined at the surface of the phantom for a source–surface distance type set-up, whereas for an SAD type set-up it is defined at the plane of the detector, placed at the reference depth in the water phantom at the isocentre of the machine.

[c] The radial dose distribution in the vicinity of the ionization chamber is mainly determined by the accelerator characteristics and cannot be easily modified by the user.

6.4.2. Determination of D_w in reference conditions

$$D_{w,Q} = M_Q N_{D,w,Q_0} k_{Q,Q_0}$$

(if Q_0 = ^{60}Co $\rightarrow$ $D_{w,Q} = M_Q N_{D,w} k_Q$)

Remember: M corrected for elec, pressure&temperature, polarity, recombination, volume averaging for FFF beams

6.4.3. Determination of D_w at z_{max}

PDD for SSD setup, TPR for SAD setup

6.5. Values of k_{Q,Q_0}

From a series of $N_{D,w,Q}$ coefficients

Generic values for a chamber type by a standards lab

From Bragg-Gray, Monte Carlo or experiment

Calculated $k_{Q,Q_0}\left(=\frac{N_{D,w,Q}}{N_{D,w,Q_0}}\right)$

$$D_{w,Q_0} = M_{Q_0} N_{D,air,Q_0} \left(s_{w,air}\right)_{Q_0} p_{Q_0} \text{ with } N_{D,air,Q_0} = \frac{(W_{air})_{Q_0}}{\rho_{air} V}$$

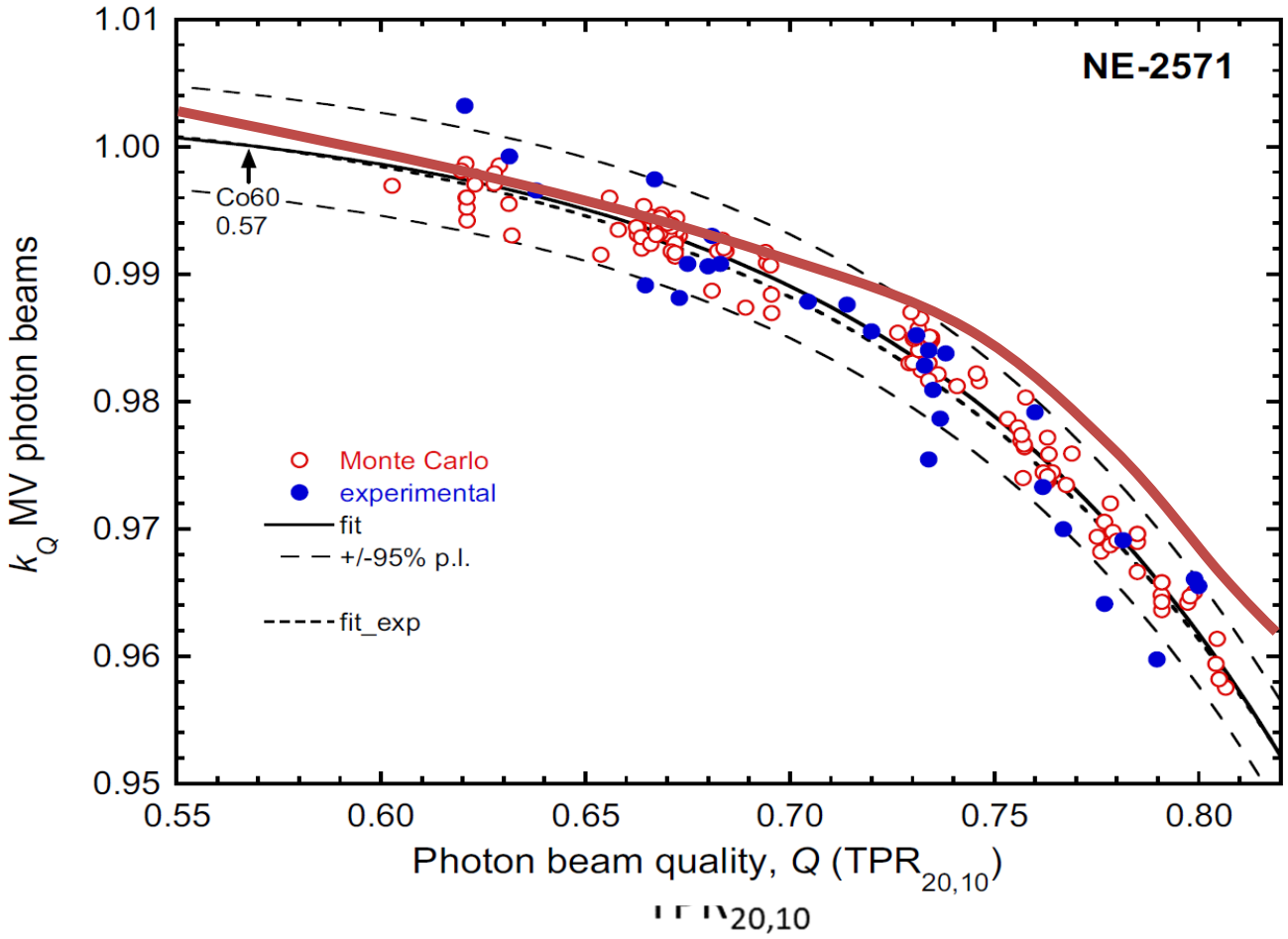
$$D_{w,Q} = M_Q N_{D,air,Q} \quad \left(s_{w,air}\right)_Q p_Q \text{ with } N_{D,air,Q} = \frac{(W_{air})_Q}{\rho_{air} V}$$

$$k_{Q,Q_0} = \frac{D_{w,Q}/M_Q}{D_{w,Q_0}/M_{Q_0}} = \frac{N_{D,air,Q}\left(s_{w,air}\right)_Q p_Q}{N_{D,air,Q_0}\left(s_{w,air}\right)_{Q_0} p_{Q_0}}$$

$$k_{Q,Q_0} = \frac{(W_{air})_Q \left(s_{w,air}\right)_Q p_Q}{(W_{air})_{Q_0} \left(s_{w,air}\right)_{Q_0} p_{Q_0}}$$

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

6.5. Values of k_Q (MC + experiment)



TRS-398u

From Andreo et al 2020 (Phys Med Biol 65:095011)

Addendum to AAPM TG-51

Addendum to the AAPM's TG-51 protocol for clinical reference dosimetry of high-energy photon beams

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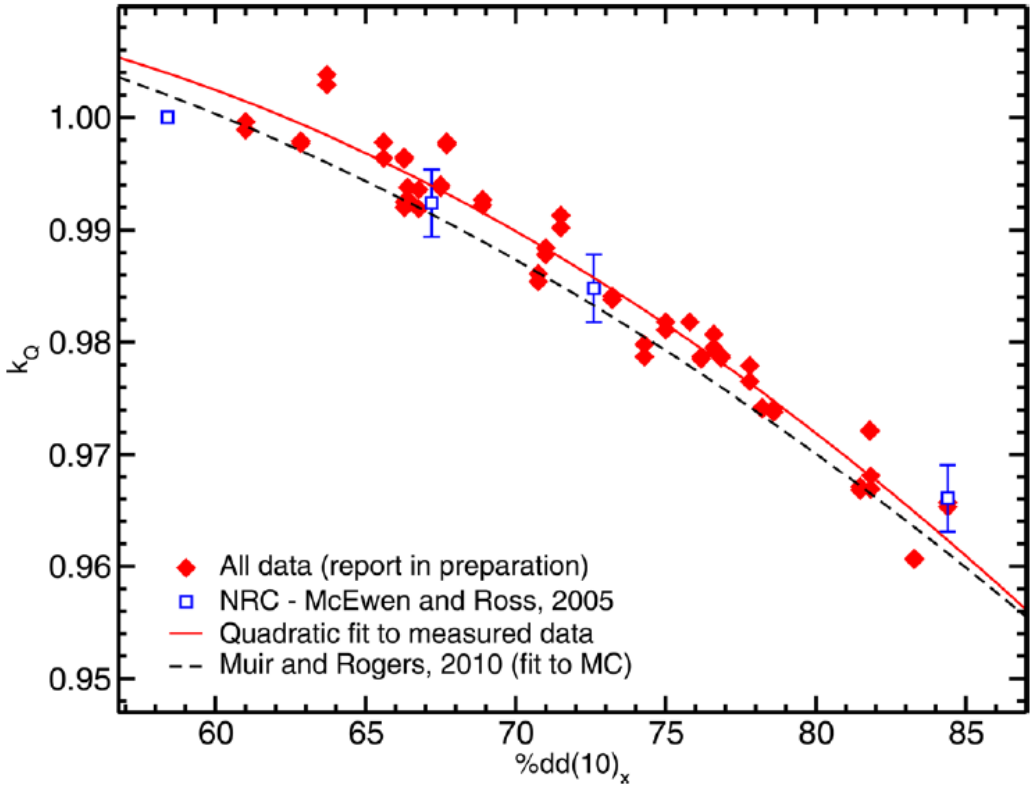
(Received 3 June 2013; revised 3 February 2014; accepted for publication 6 February 2014; published 12 March 2014)

An addendum to the AAPM's TG-51 protocol for the determination of absorbed dose to water in megavoltage photon beams is presented. This addendum continues the procedure laid out in TG-51 but new k_Q data for photon beams, based on Monte Carlo simulations, are presented and recommendations are given to improve the accuracy and consistency of the protocol's implementation.

Addendum to AAPM TG-51

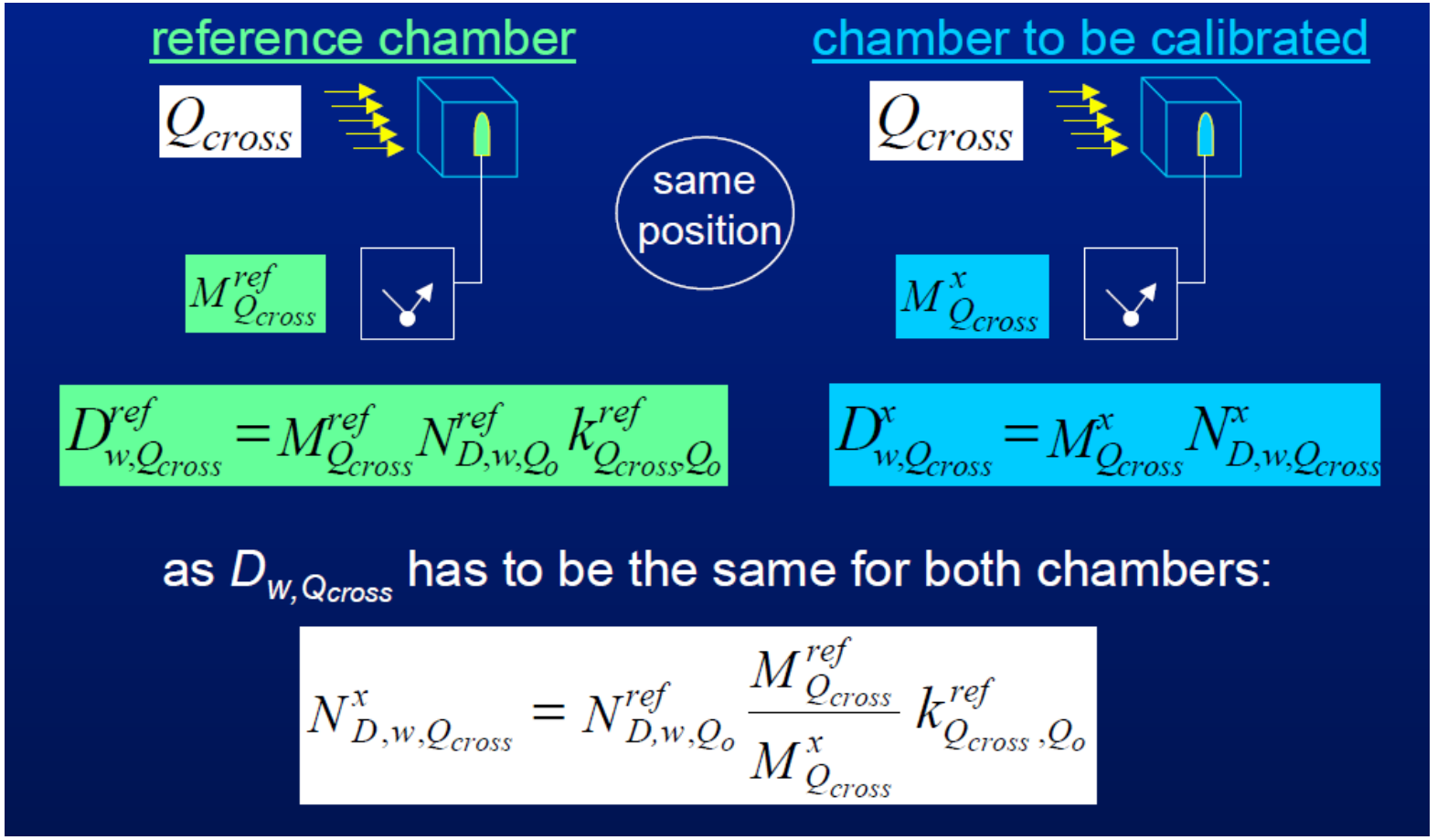
Use of Monte Carlo calculated overall k_Q values (verified with experimental data)



Muir et al. 2011
Med. Phys. 38:4604

FIG. 1. Comparison of the measured k_Q factors of Ref. 36 and those from a large comparison of primary standard laboratories [Stucki, G, private com-

6.6. Cross calibration



6.7. Measurements under non-reference conditions

CAX PDDs: for cylindrical chambers shift of PDDs over 0.6 * r_{cyl}

Attention to non-uniformities in smaller fields and wedged fields for OF

k_{pol} and k_s for every point!

6.8. Uncertainty D_w in HE photons

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 ^{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 standards laboratory	0.4
Combined uncertainty of step 1	0.6
Step 2: user's high energy photon beam	
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

[a] See Ref. [61] or Appendix IV for the expression of the uncertainty. The estimates given in the table should be considered typical values; these may vary depending on the uncertainty quoted by standards laboratories for calibration coefficients 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.

[c] For the dosimeter reading, a smaller uncertainty has been assumed than in the first edition

6.9. Worksheet

Determination of the absorbed dose to water in a high energy photon beam

User: _____ Date: _____

1. Radiation treatment unit and reference conditions for $D_{w,Q}$ determination

Accelerator: _____ Nominal accelerator potential: _____ MV

Nominal dose rate: _____ MU/min Beam quality, Q($TPR_{20,10}$): _____

Reference phantom: water Set-up ☐ SSD ☐ SAD

Reference field size: 10 × 10 cm × cm Reference distance: _____ cm

Reference depth, z_{ref} = _____ g/cm²

2. Ionization chamber and electrometer

Ionization chamber model: _____ Serial no.: _____

Chamber wall Material: _____ Thickness: _____ g/cm²

Waterproof sleeve Material: _____ Thickness: _____ g/cm²

Phantom window Material: _____ Thickness: _____ g/cm²

Absorbed dose to water calibration coefficient[a] N_{D,w,Q_o} = _____ ☐ Gy/nC ☐ Gy/rdg

Calibration quality Q_o: ☐ ^{60}Co ☐ photon beam Calibration depth: _____ g/cm²

If Q_o is photon beam, $TPR_{20,10}$ = _____

Reference conditions for calibration P_o = _____ kPa T_o = _____ °C Rel. humidity: _____ %

Polarizing potential V_1 = _____ V

Calibration polarity: ☐ positive ☐ negative ☐ corrected for polarity effect

User polarity: ☐ positive ☐ negative

Calibration laboratory: _____ Date: _____

Electrometer model: Serial no.: _____

Calibrated separately from chamber: ☐ yes ☐ no Range setting: _____

If yes, calibration laboratory: Date: _____

3. Dosimeter reading[b] and correction for influence quantities

Uncorrected dosimeter reading at V_1 and user polarity: _____ ☐ nC ☐ rdg

Corresponding accelerator monitor units: _____ MU

Ratio of dosimeter reading and monitor units: M_1 = _____ ☐ nC/MU ☐ rdg/MU

(a) Pressure P = _____ kPa Temperature T = _____ °C Rel. humidity (if known): _____ %

$$k_{TP} = \frac{(273.15+T)}{(273.15+T_o)}\frac{P_o}{P} = \_\_\_\_\_$$

(b) Electrometer calibration factor[c] k_{elec} = _____ ☐ nC/rdg ☐ dimensionless

(c) Polarity correction[d] Reading at $+V_1$: M_+ = _____ Reading at $-V_1$: M_- = _____

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

(d) Recombination correction[e] (two voltage method)

Polarizing voltages: V_1 (normal) = _____ V V_2 (reduced) = _____ V

Readings[f] at V_1, V_2: M_1 = _____ M_2 = _____

Voltage ratio V_1/V_2 = _____ Ratio of readings M_1/M_2 = _____

Use Table 10 for a beam of type: ☐ pulsed ☐ pulsed–scanned

a_0 = _____ a_1 = _____ a_2 = _____

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

(e) Volume averaging correction (in FFF beams)

SDD = _____ cm

Thimble length of ionization chamber L = _____ cm

$$k_{vol} = 1 + (0.0062\,Q - 0.0036)\left(\frac{100}{SDD}\right)^2 L^2 = \_\_\_\_\_$$

Corrected dosimeter reading at the voltage V_1:

$$M_Q = M_1 k_{TP} k_{elec} k_{pol} k_s k_{vol} = \_\_\_\_\_ \text{ ☐ nC/MU ☐ rdg/MU}$$

4. Absorbed dose to water at the reference depth, z_{ref}

Beam quality correction factor for user quality Q: k_{Q,Q_o} = _____

Taken from ☐ Table 16 ☐ other, specify: _____

$$D_{w,Q}(z_{ref}) = M_Q N_{D,w,Q_o} k_{Q,Q_o} = \_\_\_\_\_ \text{ Gy/MU}$$

5. Absorbed dose to water at the depth of dose maximum, z_{max}

Depth of dose maximum: z_{max} = _____ g/cm²

(a) SSD set-up

PDD at z_{ref} for a 10 cm × 10 cm field size: PDD(z_{ref}) = _____ g/cm²) = _____ %

Absorbed dose calibration of monitor at z_{max}:

$$D_{w,Q}(z_{max}) = 100\, D_{w,Q}(z_{ref})/PDD(z_{ref}) = \_\_\_\_\_ \text{ Gy/MU}$$

(b) SAD set-up

TMR at z_{ref} for a 10 cm × 10 cm field size: TMR(z_{ref} = _____ g/cm²) = _____

Absorbed dose calibration of monitor at z_{max}:

$$D_{w,Q}(z_{max}) = D_{w,Q}(z_{ref})/TMR(z_{ref}) = \_\_\_\_\_ \text{ Gy/MU}$$