Key comparisons of air kerma and absorbed dose to water standards in ^{Co}60radiation beam (EURAMET.RI(I)-K1.3 and EURAMET.RI(I)-K4.3)

Nylund, R.; de Prez, L.A. ; Hetland, P.O.; Andersen, C.E.; Aviles, P. ; Mulas, C.G.; Msimang, Z.; Czap, L.; Persson, L.

Publication date:
2023

Document Version
Publisher's PDF, also known as Version of record

Key comparisons of air kerma and absorbed dose to water standards in ^{60}Co radiation beam (EURAMET.RI(I)-K1.3 and EURAMET.RI(I)-K4.3)

Final report

R. Nylund[1], L.A. de Prez[2], P.O. Hetland[3], C.E. Andersen[4], P. Aviles[5], C.G. Mulas[5], Z. Msimang[6], L. Czap[6], L. Persson[7]

[1] STUK - Radiation and Nuclear Safety Authority, Vantaa, Finland
[2] VSL - National Metrology Institute, Delft, The Netherlands
[3] DSA - Norwegian Radiation and Nuclear Safety Authority, Østerås, Norway
[4] DTU - Technical University of Denmark, Risø, Denmark
[5]CIEMAT - Centre for Energy, Environmental and Technological Research, Madrid, Spain
[6] IAEA - International Atomic Energy Agency, Vienna, Austria
[7] SSM - Swedish Radiation Safety Authority, Stockholm, Sweden

Abstract

A key comparison of the standards for air kerma and absorbed dose to water of seven participating laboratories was carried out in the ^{60}Co radiation beam, therapy level, during October 2021 to November 2022. Six of the participating laboratories are secondary standards laboratories (SSM, DSA, STUK, DTU, CIEMAT, and IAEA) and VSL is a primary standards laboratory and acted as a linking laboratory to respective BIPM key comparisons. The comparison results are published in the BIPM key comparison database (KCDB) under the reference EURAMET.RI(I)-K1.3 and EURAMET.RI(I)-K4.3. The comparison was made indirectly using three thimble-type ionization chambers as transfer instruments. The results are analyzed and presented in terms of degrees of equivalence suitable for entry in the BIPM key comparison database.

1. Introduction

The national metrology laboratories for dosimetry quantities of the Netherlands (VSL, the Dutch National Metrology Institute), Sweden (SSM, Swedish Radiation Safety Authority), Norway (DSA, Norwegian Radiation and Nuclear Safety Authority), Finland (STUK, Radiation and Nuclear Safety Authority), Denmark (DTU, Technical University of Denmark), Spain (CIEMAT, Spanish National Metrology Institute for Ionising Radiation), and the International Atomic Energy Agency (IAEA) have performed a comparison in terms of air kerma and absorbed dose to water in ^{60}Co radiation therapy beams. VSL is a primary standards laboratory and acted as a linking laboratory to BIPM.RI(I)-K1 and BIPM.RI(I)-K4 comparisons. Other participating laboratories are secondary standards laboratories (SSDLs). SSM acted as a measuring pilot laboratory and STUK as a reporting pilot laboratory.

Three transfer ionization chambers (thimble-type) were circulated among participants. Each laboratory reported calibration coefficients in terms of air kerma and absorbed dose to water and uncertainty budgets for those chambers.

The objective of the comparison is to support the ionising radiation CMCs of SSM, DSA, STUK, DTU, CIEMAT, and IAEA in the dosimetry branch for the quantities of air kerma/rate and absorbed dose to water/rate from a ^{60}Co source at radiation therapy levels. Both STUK and VSL performed two sets of measurements in different timings during the comparison exercise in order to control possible variations arising from the changes in their facilities.

The detailed technical protocol is available in KCDB under the reference EURAMET.RI(I)-K1.3 and EURAMET.RI(I)-K4.3.

2. Comparison procedure

2.1 Participants and measurement schedule

Seven participants, listed in Table 1, were included in the comparison. VSL provided a comparison reference value. SSM and STUK shared responsibilities as pilot laboratory, SSM acting as a measuring pilot laboratory and STUK acting as a reporting pilot laboratory. SSM performed measurements at the beginning and at the end of the comparison to confirm the stability of the chambers. Both STUK and VSL performed two sets of comparison measurements since those laboratories had changes in their facilities. STUK relocated to completely new facilities and VSL updated their ^{60}Co facility and thus, the comparison measurements were performed in both locations/set-ups to confirm the measurement and calibration capability at both locations.

Table 1. Participants of the comparison, their traceability and measurement schedule in the order of the first-round measurements.

Institute, country	Contact person	Comment	^{60}Co traceability, type of standard	Measurement period, including the date of chambers shipment
VSL, The Netherlands	Leon de Prez	Linking	VSL, primary	1st 10/21- 5/11/21 2nd 09/22-1/10/22
SSM, Sweden	Linda Persson	Pilot, measurements	BIPM, secondary	1st 11/21-20/12/21 2nd 10/22-15/11/22
DSA, Norway	Per Otto Hetland		BIPM, secondary	01/22-4/2/22
STUK, Finland	Reetta Nylund	Pilot, reporting	BIPM, secondary	1st 02/22-18/3/22 2nd 08/22-1/9/22
DTU, Denmark	Claus E. Andersen		K_{air}: BIPM, secondary D_w: PTB, secondary	03/22-13/5/22
CIEMAT, Spain	Cristina García Mulas		BIPM, secondary	05/22-17/6/22
IAEA, International	Zakithi Msimang		BIPM, secondary	06/22-1/8/22

2.2 Transfer instruments

Three reference ionization chambers were used as transfer instruments for this comparison. Three chambers were selected to minimize the risk of comparison failure due to transfer instrument breakage during the comparison. The chambers are a property of three different laboratories participating in the comparison and have not been calibrated outside the laboratory before this comparison. The laboratories used their own electrometers and cables for performing the measurements during the comparison. The technical details of the transfer chambers are presented below (Table 2).

Table 2. Technical details of the transfer chambers (chamber characteristics according to IAEA TRS398).

Chamber type (owner of chamber)	**IBA FC65-G (SSM)**	**IBA FC65-G (STUK)**	**NE2571 (DTU)**
Serial number	4442	3578	3714
Geometry	thimble	thimble	thimble
Wall material	graphite	graphite	graphite
Wall thickness (g cm^{-2})	0.073	0.073	0.065
External (stem) diameter / mm	8.6	8.6	8.62
Cavity length/ mm	23.1	23.1	24.0
Cavity diameter or radius	Cavity radius 3.1 mm	Cavity radius 3.1 mm	Cavity radius 3.2 mm (thimble outside diameter 6.99)
Nominal volume / cm^3	0.65	0.65	0.69
Build-up cap for air kerma measurements	Chamber’s own build-up cap (3.9 mm; 0.560 g/cm^2)	Chamber’s own build-up cap (3.9 mm; 0.560 g/cm^2)	Chamber’s own build-up cap (0.551 g/cm^2)
Reference point for the air kerma measurements and absorbed dose measurements in water	On the central axis, 13 mm from the distal end of the chamber tip	On the central axis, 13 mm from the distal end of the chamber tip	On the central axis, 13 mm from the distal end of the chamber tip
Polarising voltage of a chamber	+300 V on collector (central) electrode, 0 V on chamber wall (collecting negative charge), optional: -300 V on wall, 0 V on collector	+300 V on collector (central) electrode, 0 V on chamber wall (collecting negative charge), optional: -300 V on wall, 0 V on collector	+250 V on collector (central) electrode, 0 V on chamber wall (collecting negative charge), optional: -250 V on wall, 0 V on collector
Connector type	TNC triaxial	TNC triaxial	TNC triaxial

Other remarks	Waterproof	Waterproof	NOT waterproof (laboratory's own sleeve is to be used for comparison)

2.3 Radiation quality and reference conditions

The radiation quality used in the comparison was ^{60}Co. The quantities for the comparison were air kerma and absorbed dose to water defined according to ICRU85a and in accordance to ICRU90 regarding the reference data for primary standards.

The distance from the source to the chamber's reference point for the ^{60}Co beams was 100 cm along the central beam axis. The reference field size at the reference point was 10 cm × 10 cm for both quantities. The reference points for chambers are described in Table 2. The marking on the stem of the chambers was oriented facing the radiation source. For absorbed dose to water the chambers were to be calibrated in such a manner that the reference point of the chamber was at the reference depth of 5 g/cm^2 in a water phantom, using a waterproof sleeve when appropriate. For air kerma the chambers were placed free in the air.

The calibration coefficients for the transfer chambers were corrected to standard conditions of air temperature and pressure; T = 293.15 K and p = 101.325 kPa. The reported values were not corrected to a relative humidity of 50 % RH as measurements were performed between 20 % RH and 80 % RH. No corrections for recombination were done. Each laboratory used their own equipment to measure environmental conditions.

2.4 Reference value

VSL as linking laboratory to BIPM.RI(I)-K1 and BIPM.RI(I)-K4 comparisons provided the reference value for this comparison. VSL proceeded according to the same procedures as for the latest BIPM comparisons. All results were compared to this value. None of the participating laboratories are traceable to VSL for the comparison quantities. As VSL performed two measurement sets, the first measurement set, which was performed at the beginning of the comparison, was used as a reference value for the comparison. Additionally, VSL performed another measurement set in the later phase of the comparison, which is reported but not used for calculating reference values for this comparison. This second measurement was performed after the change of ^{60}Co facility at VSL and serves as internal linking for VSL. The reference values were calculated and presented separately for each chamber.

VSL determined the reference air kerma rate and absorbed dose to water rate using their primary standards, respectively a cavity ion chamber and a water calorimeter, as described in the respective comparison reports, BIPM.RI(I)-K1and BIPM.RI(I)-K4 (Kessler C *et al*., 2017a and 2017b). For determining calibration factors of transfer chambers VSL proceeded accordingly to SSDLs (see below) excluding the procedure for determining the reference air kerma/dose rate.

2.5 Determination of the calibration coefficient at secondary standards laboratories

Each laboratory used their own procedure referring to international practices/ guidance followed when performing the calibration. Typically, for air kerma and absorbed dose to water, SSDL establishes a reference air kerma rate $\dot{K}_{air}$ and absorbed dose rate $\dot{D}_w$ at their facilities in accordance with their own procedure following an equation such as:

$$\dot{K}_{air} = N_{K,\mathrm{PSDL}} I_{\mathrm{SSDL}} \quad \text{or} \quad \dot{D}_w = N_{\mathrm{Dw,PSDL}} I_{\mathrm{SSDL}} \qquad (1)$$

where $N_{K,\mathrm{PSDL}}$ and $N_{Dw,\mathrm{PSDL}}$ are the calibration coefficients used by a given SSDL in order to reach traceability to a primary standards laboratory for air kerma or absorbed dose to water measurements in ^{60}Co beams, and where I_{SSDL} is the ionization current measured for the different set up by the SSDL. I_{SSDL} is corrected to standard conditions of air temperature and pressure, and if needed for relative humidity. For the other corrections to I_{SSDL} a laboratory proceeded according to their own procedure and may have included e.g. the electrometer correction factor, correction for leakage, correction for distance, correction for volume etc. All corrections used are reported in Appendix 1.

Each SSDL positions a transfer chamber at the reference point (see table 2), and the calibration coefficients for the transfer chamber N_K and N_{Dw} are calculated as:

$$N_K = \frac{\dot{K}_{air}}{I_M} \quad or \quad N_{Dw} = \frac{\dot{D}_w}{I_M} \tag{2}$$

where $\dot{K}_{air}$ and $\dot{D}_w$ is the reference air kerma rate and absorbed dose to water rate respectively from equation (1), and where I_{M} is the signal from the transfer chamber measured by the SSDL. Like I_{SSDL}, I_{M} is corrected to standard conditions of air temperature and pressure, and if needed for relative humidity. Similar corrections as for I_{SSDL} might have been applied to I_{M}.

2.6 Degrees of equivalence

The results were analyzed for a single chamber. Degrees of equivalence were calculated in terms of all comparison results (calibration coefficients and uncertainties) according to CCRI(I)/17-09 instructions. The degree of equivalence of each SSDL, with respect to the key comparison reference value, was evaluated as follows separately for each transfer chamber in terms of air kerma:

$$R_{SSDL} = \frac{N_{K,SSDL}}{N_{K,VSL}} R_{VSL,BIPM} \tag{3}$$

in which $R_{VSL,BIPM}$ represents the results of VSL in BIPM comparison BIPM.RI(I)-K1and BIPM.RI(I)-K4 (Kessler C *et al*, 2017a and 2017b).

The variance of R_{SSDL} is:

$$u_{R,SSDL}^2 = (u_{SSDL}^2 + u_{BIPM}^2 - \sum_j f_j^2 (u_{SSDL,j}^2 + u_{BIPM,j}^2)) + u_{tr}^2 + u_{VSL}^2 \tag{4}$$

in which f_j are weighting factors related to correlating components. In equation (4) u_{tr} combines the stability of the transfer chambers over the period of the comparison and the variation in the ratios for specific chambers. Measuring pilot laboratory SSM has performed several measurements for each transfer chamber. In this report, based on the results shown in Table 3, u_{tr} can be considered negligible as all chambers operated consistently during the comparison course. In equation (4) u_{VSL} represents the uncertainty of non-statistical components, which are not cancelling out via linking mechanism. To ease estimation of these, VSL’s measurement conditions in this comparison were as close as possible to those used in the VSL-BIPM key comparison.

In the case of three transfer chambers which were circulated in this comparison, R_{SSDL} can be derived using the following equation for a specific laboratory and specific quantity:

$$R_{SSDL} = R_{VSL,BIPM} \frac{1}{3} \sum_{j=1}^{3} \frac{N_{K,SSDL,j}}{N_{K,VSL,j}} \tag{5}$$

The degree of equivalence for SSDL was calculated as follows:

$$D_{SSDL} = R_{SSDL} - 1 \tag{6}$$

and its expanded uncertainty is $U_{\mathrm{SSDL}} = 2u_{\mathrm{R,SSDL}}$.

2.7 Correlated uncertainties for degrees of equivalence

For the analysis correlated uncertainties were analyzed and excluded from the calculation of expanded uncertainties for degrees of equivalence. All participating SSDLs are traceable to BIPM for air kerma, while DTU is traceable to PTB for absorbed dose to water. The whole type B component of the primary laboratory calibration was removed for the calculation of expanded uncertainties for degrees of equivalence in all cases, where SSDL is traceable to BIPM. For the absorbed dose to water expanded uncertainty no correlating components were removed for DTU, since it is traceable to PTB.

3.1 Transfer chamber stability

Transfer chambers were calibrated in terms of air kerma and absorbed dose to water by SSM at the beginning and at the end of the comparison. The ratio between the first measurement round (November 2021) and the second measurement round (November 2022) is presented below in Table 3.

Table 3. Transfer chamber stability check at SSM at the beginning (November 2021) and at the end (November 2022) of the comparison. The ratio of the measured calibration coefficients is presented.

Chamber	Quantity	Ratio: Nov 21/Nov22
FC65G-4442	D_w	1.0000
	K_{air}	1.0001
FC65G-3578	D_w	1.0000
	K_{air}	0.9999
NE2571-3714	D_w	1.0000
	K_{air}	1.0001

The results show clearly that the transfer chambers have remained stable during the comparison. Thus, there is no need to include components (referred as u_{tr}) related to transfer chamber stability to the analysis of degrees of equivalence.

3.2 Calibration coefficients and uncertainties

The calibration coefficients and respective uncertainties in terms of air kerma and absorbed dose to water are given in Tables 4-5 below. Detailed uncertainty budgets for each laboratory are given in Appendix 1.

During the transfer chamber stability check SSM noticed that they had performed measurements in terms of air kerma in November 2021 at an inaccurate distance, as a wrong calculation had been done for the air kerma set-up in 2021. SSM has separate set-up equations for the distances for measurements of absorbed dose to water and air kerma, and in 2021 measurements they had accidentally used the equation for absorbed dose to water instead of air kerma. Measurements in

2021 were performed 1.64 mm too close to the ^{60}Co source. The stability check measurements in 2022 were performed at two distances, the correct one and the one, which was used in 2021. The latter is used for the transfer chamber stability check. The results measured in November 2022 are reported here for the result of the comparison. All other participants of the comparison agreed that SSM may use the air kerma measurements of November 2022 with correct distance as a comparison result for this comparison.

Table 4. Reported calibration coefficients (Gy/µC) for transfer chambers in terms of air kerma and respective relative expanded uncertainty (%), *k*=2.

Institute*	FC65G-4442	FC65G-3578	NE2571-3714	U_c (%), *k*=2
VSL1	43.68	43.73	40.71	0.46
DSA	43.84	43.86	40.85	0.49
STUK1	43.84	43.86	40.81	0.45
DTU1	43.86	43.90	40.87	0.58
DTU2	43.83	43.87	40.83	0.58
CIEMAT	43.88	43.90	40.88	0.62
IAEA	43.83	43.87	40.84	0.6
STUK2	43.87	43.90	40.85	0.47
VSL2	43.70	43.73	40.72	0.46
SSM	43.84	43.87	40.85	0.42

* For VSL and STUK #1 indicates the first measurement round and #2 the second measurement round. For DTU #2 indicates results which are corrected for recombination and #1 is without correction for recombination.

Table 5. Reported calibration coefficients (Gy/µC) for transfer chambers in terms of absorbed dose to water and respective relative expanded uncertainty (%), *k*=2.

Institute*	FC65G-4442	FC65G-3578	NE2571-3714	U_c (%), *k*=2
VSL1	47.97	48.05	44.77	0.84
SSM1	48.19	48.26	44.93	0.50
DSA	48.26	48.30	44.97	0.60
STUK1	48.26	48.31	44.96	0.51
DTU1	48.23	48.28	44.93	0.67
DTU2	48.20	48.25	44.89	0.67
CIEMAT	48.15	48.21	44.89	0.75
IAEA1	48.10	48.15	44.85	0.7
IAEA2	48.15	48.19	-	0.7
STUK2	48.26	48.33	44.97	0.51
VSL2	48.02	48.05	44.77	0.84
SSM2	48.19	48.26	44.93	0.44

* For VSL, SSM and STUK #1 indicates the first measurement round and #2 the second measurement round. For DTU #2 indicates results which are corrected for recombination and #1 is without correction for recombination. For IAEA #2 indicates results which are measured without a sleeve, and #1 is measured with waterproof sleeve.

Data show that the laboratories are in good agreement with each other. The data show that the calibration coefficients for the comparison linking laboratory VSL are slightly lower than for other participating laboratories. However, this is explained by key comparisons between VSL and BIPM BIPM.RI(I)-K1and BIPM.RI(I)-K4 (Kessler C *et al*., 2017a and 2017b). These comparisons show that the degree of equivalence for VSL is -3.7 and -4.0 for air kerma and absorbed dose to water, respectively. The ICRU90 implementation has changed these D_i value for VSL to -3.4 and -3.0, respectively (Burns D and Kessler C, 2018).

3.3 Degrees of equivalence

The degrees of equivalence (D_i) and expanded uncertainties (U_i) were calculated according to equations 3-6. Results for D_i and U_i are expressed in mGy/Gy and are presented in Tables 6 and 7 for all participants. The result for VSL is shown for comparison, the values are the same as mentioned before.

Results shown in Tables 4 and 5 were used to calculate D_i and U_i. However, for final D_i and U_i shown in Tables 6 and 7 only the following results were used for the following laboratories: for STUK only from the second measurement round, for DTU only the results without recombination correction and, for IAEA for absorbed dose to water only the results obtained without a sleeve i.e. no duplicate measurement results were used for none of the laboratories.

Table 6. The degrees of equivalence (D_i) and expanded uncertainties (U_i) as mGy/Gy for participating laboratories in terms of air kerma.

Institute	D_i mGy/Gy	U_i mGy/Gy	previous D_i (and U_i) mGy/Gy
VSL*	-3.4	4.2	
SSM	0.0	5.7	1.0 (7.5)**
DSA	-0.1	6.2	5.1 (7.1)**
STUK	0.5	6.0	-2.3 (7.3)**
DTU	0.6	6.9	-
CIEMAT	0.8	7.3	0.7 (7.6)
IAEA	-0.1	7.1	0.0 (7.5)**

*for VSL the same as in BIPM.RI(I)-K1and BIPM.RI(I)-K4 (Kessler C *et al*, 2017a and 2017b)

** for SSM, DSA, STUK, and IAEA previous D_i are over 15 years old.

Table 7. The degrees of equivalence (D_i) and expanded uncertainties (U_i) as mGy/Gy for participating laboratories in terms of absorbed dose to water.

Institute	D_i mGy/Gy	U_i mGy/Gy	previous D_i (and U_i) mGy/Gy

VSL*	-3.0	10	
SSM	1.2	9.1	-1.4 (10.0)**
DSA	2.2	9.7	3.2 (8.8)**
STUK	2.4	9.1	-3.9 (8.5)**
DTU	1.6	11.5	-
CIEMAT	0.2	10.7	2.3 (11.1)
IAEA	-0.2	10.3	-0.4 (10.0)**

*for VSL the same as in BIPM.RI(I)-K1and BIPM.RI(I)-K4 (Kessler C *et al*, 2017a and 2017b)
** for SSM, DSA, STUK and IAEA previous D_i are over 15 years old.

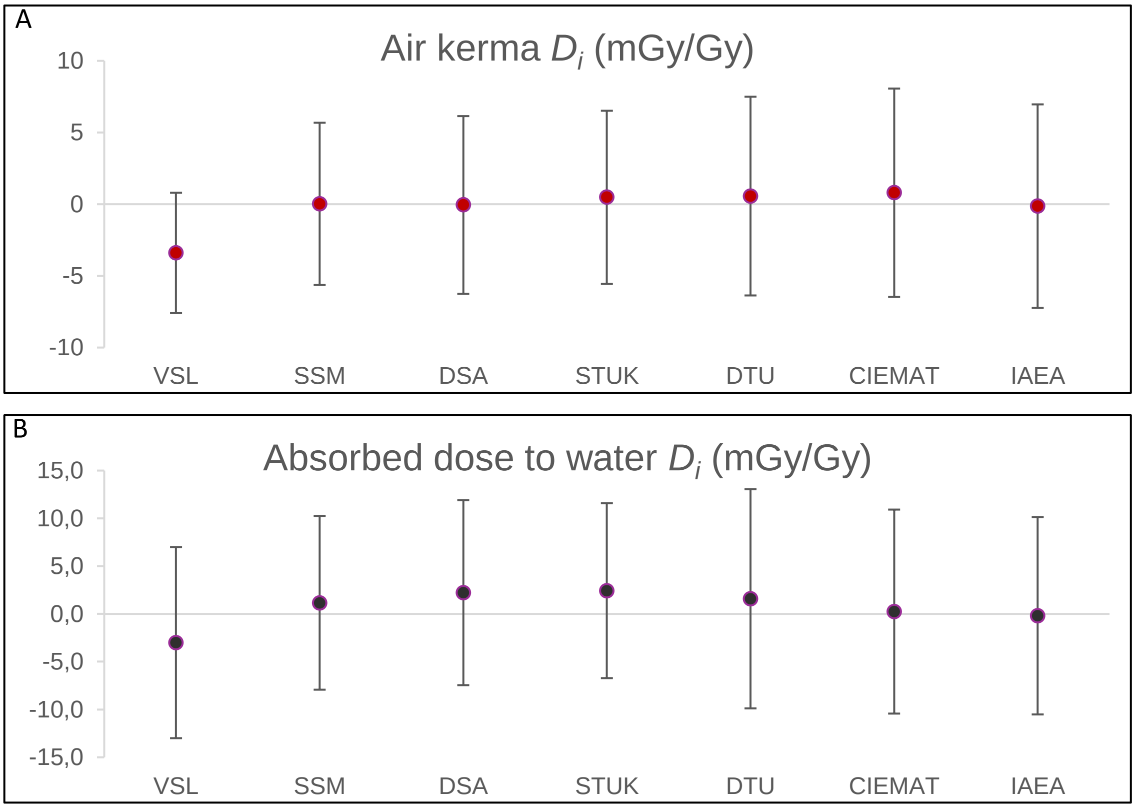

Figure 1. A) A graphical presentation of the degrees of equivalence (D_i) and expanded uncertainties (U_i) as mGy/Gy for participating laboratories in terms of air kerma. B) A graphical presentation of the degrees of equivalence (D_i) and expanded uncertainties (U_i) as mGy/Gy for participating laboratories in terms of absorbed dose to water.

As shown in figures 1A and 1B, deviations in D_i are within expanded uncertainties for all participating laboratories.

3 Discussion and conclusions

A key comparison in terms of air kerma and absorbed dose to water for ^{60}Co radiation has been carried out between seven laboratories using three ionization chambers as transfer standards. The results presented are well in line with each laboratory's measurement uncertainty and support the CMCs of the participating laboratories. The values presented here are in good agreement with earlier values of degrees of equivalence of the participating laboratories. The degrees of equivalence are already over 15 years old for several participating laboratories and thus, currently removed from the KCDB.

The results also support maintaining of the quality during STUK relocation as well as an update of the VSL facilities.

References

Burns D and Kessler C, Re-evaluation of the BIPM international dosimetry standards on adoption of the recommendations of ICRU Report 90, Metrologia 55 R21, 2018: DOI 10.1088/1681-7575/aacb01

CCRI(I)/17-09, Burns DT, Butler D, Updated report on the evaluation of degrees of equivalence in regional dosimetry comparisons, May 2017

IAEA, International Atomic Energy Agency. Absorbed dose determination in external beam radiation therapy. An international code of practice for dosimetry based on standards of absorbed dose to water. Technical Reports Series No. 398, V12, 05 June 2006.
http://www-naweb.iaea.org/nahu/DMRP/documents/CoP_V12_2006-06-05.pdf

ICRU85a, ICRU report 85a (revised), Fundamental Quantities and Units for Ionizing Radiation, https://www.icru.org/report/fundamental-quantities-and-units-for-ionizing-radiation-icru-report-85a-revised/

ICRU90, ICRU Report 90, Key Data For Ionizing-Radiation Dosimetry: Measurement Standards And Applications, https://www.icru.org/report/icru-report-90-key-data-for-ionizing-radiation-dosimetry-measurement-standards-and-applications/

KCDB, technical protocol
https://www.bipm.org/kcdb/comparison?id=1787
https://www.bipm.org/kcdb/comparison?id=1788

Kessler C, Burns D, Jansen BJ, de Pooter JA, de Prez LA, Key comparison BIPM.RI(I)-K1 of the air-kerma standards of VSL, The Netherlands, and the BIPM in ^{60}Co gamma radiation, 2017a

Kessler C, Burns D, Jansen BJ, de Pooter JA, de Prez LA, Comparison of the standards for absorbed dose to water of the VSL, The Netherlands, and the BIPM for ^{60}Co γ rays, 2017b

Appendix1

Measured results, uncertainty budgets + additional information for participating laboratories in the following order:

VSL (1st measurement round, comparison reference value)

SSM

DSA

STUK (2nd measurement round)

DTU

CIEMAT

IAEA

VSL

1st round

Chamber	IBA FC65-G (4442)		IBA FC65-G (3578)		NE2571 (3714)	
	N_{Dw}	N_{Kair}	N_{Dw}	N_{Kair}	N_{Dw}	N_{Kair}
Date of measurement	8.11.2021	5.11.2021	8.11.2021	5.11.2021	8.11.2021	8.11.2021
Calibration coefficient (Gy/µC)	*47.97*	*43.68*	*48.05*	*43.73*	*44.77*	*40.71*
u_c (k=2) (%)	*0.84*	*0.46*	*0.84*	*0.46*	*0.84*	*0.46*
Mean ionization current (I_{SSDL} or I_{PSDL}) (pA)	-98.31	-108.18	-98.13	-108.07	-105.33	-116.07
Measured leakage current (fA)	< ±10 fA	< ±10 fA	< ±10 fA	< ±10 fA	< ±10 fA	< ±10 fA
Environmental conditions (T, p, h), correction for humidity	T: 19.5 °C - 19.6 °C p: 100.11 kPa - 102.38 kPa RH: (47± 5) %	T: 19.8 °C - 19.9 °C p: 100.06 kPa - 102.27 kPa RH: (47± 5) %	T: 19.5 °C - 19.6 °C p: 100.11 kPa - 102.33 kPa RH: (47± 5) %	T: 19.8 °C - 19.9 °C p: 100.06 kPa - 102.27 kPa RH: (47 ± 5) %	T: 19.4 °C - 19.6 °C p: 100.11 kPa - 102.33 kPa RH: (47 ± 5) %	T: 19.8 °C - 19.9 °C p: 100.06 kPa - 102.27 kPa RH: (47 ± 5) %
Correction factors: k_{elec}	in VSL charge system	in VSL charge system	in VSL charge system	in VSL charge system	in VSL charge system	in VSL charge system
Correction factors: k_h	unity, i.e. n/a	unity, i.e. n/a	unity, i.e. n/a	unity, i.e. n/a	unity, i.e. n/a	unity, i.e. n/a
Correction factors: k_s	unity, i.e. n/a	unity, i.e. n/a	unity, i.e. n/a	unity, i.e. n/a	unity, i.e. n/a	unity, i.e. n/a
Correction factors: k_p	unity, i.e. n/a	unity, i.e. n/a	unity, i.e. n/a	unity, i.e. n/a	unity, i.e. n/a	unity, i.e. n/a
Description of sleeve used (material, thickness)	1 mm PMMA	n/a, standard build-up cap	1 mm PMMA	n/a, standard build-up cap	1 mm PMMA	n/a, standard build-up cap
Other remarks:	Certificate: 3320729.05 DUT: #15830, #15843, #15882, #15900, #15910 Field: #0	Certificate: 3320729.06 DUT: #15820, #15902 Field: #15803, #15811, #15819, #15919	Certificate: 3320729.07 DUT: #15827, #15883, #15897, #15909 Field: #0	Certificate: 3320729.08 DUT: #15815, #15903 Field: #15803, #15811, #15819, #15919	Certificate: 3320729.03 DUT: #15914, #15896, #15881, #15825 Field: #0	Certificate: 3320729.02 DUT: #15915, #15907, #15802 Field: #15919, #15819, #15811, #15803

Background information	D_w	K_{air}
Radiation source	^{60}Co	
Orientation of source relative to water phantom	vertical	vertical
Irradiator	Siemens Gammatron 3	
Field size	10.0 × 10.0 cm²	10.0 × 10.0 cm²
Dose rate (mGy/s)	4.23	4.24
SCD (cm)	100 cm	100 cm
Depth in water phantom	5 g/cm²	N/A
Reference standard (chamber + traceability)	VSL water calorimeter	VSL 5 cc cavity chamber
Electrometer (charge vs current, range + traceability)	Keithley 6517B - 1284818 Range: 20 nC	Keithley 6517B - 1284818 Range: 20 nC
other remarks	for all details, see text reports	for all details, see text reports

Equation/model See (Kessler C *et al.*, 2017a)

Computation method (analytic or MC) and program model: Analytical

Quantity Kair

Air kerma	**Type A**	**Type B**
	Uncertainty (%)	
1 Reference standard, set-up and radiation field		
Calibration coefficient by PSDL	0.01	0.20
Long term stability of reference standard		0.05
Spectral difference of SSDL and PSDL		0.00
Difference in radial non-uniformity of the beam and field size		0.00
Combined uncertainty of reference standard and setup	**0.01**	**0.21**
2 Use of reference standard		
Chamber and phantom positioning (distance. orientation)		0.02
Current/charge measurement including leakage		0.10
Air temperature correction		0.02
Air pressure correction		0.01
Others (e.g. humidity, field inhomogenity, half life correction)		-
Combined uncertainty in measuring with reference standard	**0.00**	**0.10**
Combined uncertainty in air kerma determination (1+2)	**0.01**	**0.23**
3 Use of transfer chamber		
Chamber and phantom positioning (distance, orientation)		-
Current/charge measurement including leakage		-
Air temperature correction		-
Air pressure correction		-
Others (e.g. humidity, decay of Co-60)		-
Combined uncertainty in measuring with transfer chamber	**0.00**	**0.00**
Relative combined standard uncertainty (1+2+3)	**0.01**	**0.23**
Total uncertainty for the air kerma calibration coefficient, *k*=1	**0.23**	
Expanded uncertainty, *k*=2	**0.46**	
Confidence level (%)	95	

Equation/model See (Kessler C *et al.*, 2017b)

Computation method (analytic or MC) and program model: Analytical

Quantity Dw

Absorbed dose	**Type A**	**Type B**
	Uncertainty (%)	
1 Reference standard, set-up and radiation field		
Calibration coefficient by PSDL	0.01	0.39
Long term stability of reference standard		0.05
Spectral difference of SSDL and PSDL		0.00
Difference in radial non-uniformity of the beam and field size		0.00
Combined uncertainty of reference standard and setup	**0.01**	**0.39**
2 Use of reference standard		
Chamber and phantom positioning (distance, orientation, water level)		0.10
Current/charge measurement including leakage		0.10
Air temperature correction		0.04
Air pressure correction		0.02
Others (e.g. humidity, water density, field inhomogenity, half life correction)		-
Combined uncertainty in measuring with reference standard	**0.00**	**0.15**
Combined uncertainty in absorbed dose determination (1+2)	**0.01**	**0.42**
3 Use of transfer chamber		
Chamber and phantom positioning (distance, orientation)		-
Current/charge measurement including leakage		-
Air temperature correction		-
Air pressure correction		-
Others (e.g. humidity, decay of Co-60)		-
Combined uncertainty in measuring with transfer chamber	**0.00**	**0.00**
Relative combined standard uncertainty (1+2+3)	**0.01**	**0.42**
Total uncertainty for the absorbed dose calibration coefficient, *k*=1	**0.42**	
Expanded uncertainty, *k*=2	**0.84**	
Confidence level (%)	95	

SSM

Chamber	IBA FC65-G (4442)		IBA FC65-G (3578)		NE2571 (3714)	
	N_{Dw}	N_{Kair}	NDw	N_{Kair}	N_{Dw}	N_{Kair}
Date of measurement	2021-11-17 - 2021-12-02	2022-10-18 - 2022-11-11	2021-11-16 - 2021-12-02	2022-10-20 - 2022-11-11	2021-11-16 - 2021-12-02	2022-10-18 - 2022-11-16
Calibration coefficient (Gy/µC)	48.19	43.84	48.26	43.87	44.93	40.85
u_c (k=2) (%)	0.44	0.42	0.44	0.42	0.44	0.42
Mean ionization current (I_{SSDL} or I_{PSDL}) (pA)	173.31653 (korr to 2021-12-02)	190.1032 (korr to 2021-12-01)	173.07075 (korr to 2021-12-02)	190.00333 (korr to 2021-12-01)	185.90602 (korr to 2021-12-02)	204.06026 (korr to 2021-12-01)
Measured leakage current (fA)	-1.8 - -6.7	-3.1 - -5.0	-0.7 - 7.3	-0.2 - -8.4	-7.5 - 2.4	-2.3 - 1.1
Environmental conditions (T, p, h), correction for humidity	T: 20.85 - 21.68 °C, p: 98.98 - 101.01 kPa, RH: 37-50% (no correction for humidity)	T: 20.98 - 21.42 °C, p: 100.64 - 102.20 kPa, RH: 41-55% (no correction for humidity)	T: 20.81 - 21.62 °C, p: 99.05 - 101.97 kPa, RH: 38-50% (no correction for humidity)	T: 21.07 - 21.38 °C, p: 100.70 - 102.24 kPa, RH: 41-59% (no correction for humidity)	T: 21.08 - 21.73 °C, p: 98.93 - 102.04 kPa, RH: 35-48% (no correction for humidity)	T: 21.08 - 21.33 °C, p: 100.60 - 102.24 kPa, RH: 38-50% (no correction for humidity)
Correction factors: k_{elec}	1.00	1.00	1.00	1.00	1.00	1.00
Description of sleeve used (material, thickness)	no watertight sleeve	-	no watertight sleeve	-	watertight sleeve: PMMA 1,0 mm	-

Background information	D_w	K_{air}
Radiation source	^{60}Co	
Orientation of source relative to water phantom	Horizontal	Horizontal
Irradiator	X200 Best Theratronics	
Field size	10 cm x 10 cm	10 cm x 10 cm
Dose rate (mGy/s)	8.352 mGy/s (2021-12-02)	8.335 mGy/s (2021-12-01)
SDD (cm)	100 cm	100 cm
Depth in water phantom	5 cm (water equivalent)	N/A
Reference standard (chamber + traceability)	FC65-G -3106, BIPM 10/2017	FC65-G -3106, BIPM 10/2017
Electrometer (charge vs current, range + traceability)	E3 ("SSM build"), measuring charge, RISE Sweden 05/2020	E3 ("SSM build"), measuring charge, RISE Sweden 05/2020

Equation

$\Delta K_{air}=\delta N_{k,sek}* \delta k_{stabilitet,sek}*\Delta I*\delta k_{fält,k}* \Delta k_{T,p}*\delta k_{rek}*\delta RH*\delta k_{inst.fält}*\delta k_{pos.jonk,k}*\delta k_{pos.strålk}*\delta A$

$\Delta N_{k,x}=\Delta K_{air}*\Delta I*\delta k_{pos.jonk,k}*\delta k_{inst.fält}* \Delta k_{T,p}*\delta RH*\delta A$

Analytical calculation in this document, analytical and MC in QMSys GUM Professional

Quantity Kair

Air kerma	ΔK_{air}	**Type A**	**Type B**	**Sensitivity coefficient for transfer chamber**	Effective degrees of freedom
		Uncertainty (%)			
1 Reference standard, set-up and radiation field					
Calibration coefficient by PSDL	$\delta N_{k,sek}$	0.020	0.130	1.00	100
Long term stability of reference standard	$\delta k_{stabilitet,sek}$		0.037	1.00	
Spectral difference of SSDL and PSDL	$\delta k_{fält,k}$		0.060	1.00	
Difference in radial non-uniformity of the beam and field size	$\delta k_{inst.fält}$		0.013	2.00	
Combined uncertainty of reference standard and setup		**0.020**	**0.148**		
2 Use of reference standard					
Chamber position	$\delta k_{pos.jonk,k}$		0.017	2.00	
Source position	$\delta k_{pos.strålk}$		0.003	2.00	
Current/charge measurement including leakage	ΔI	0.020	0.017	2.00	100
Pressure and temperature correction	$\Delta k_{T,p}$	0.006	0.059	2.00	100
Recombination	δk_{rek}		0.020	1.00	
Air humidity	δRH		0.012	2.00	
Half-life correction	δA		0.017	2.00	
Combined uncertainty in measuring with reference standard		**0.021**	**0.070**		
Combined uncertainty in air kerma determination (1+2)		**0.029**	**0.164**		
3 Use of transfer chamber					
Combined uncertainty in measuring with transfer chamber		**0.046**	**0.202**		
Total uncertainty for the air kerma calibration coefficient, *k*=1	***ΔNk,x***	**0.208**			
Expanded uncertainty, *k*=2		**0.415**			
Confidence level (%)	95.45				

Equation

$\Delta D_w = \delta N_{D,w,sek} * \delta k_{stabilitet,sek} * \Delta I * \Delta k_{T,p,vatten} * \delta k_{rek} * \delta A * \delta k_{fält,w} * \delta RH * \delta k_{pos.fantom} * \delta k_{pos.jonk,w} * \delta \rho_{vatten} * \delta k_{inst.fält} * \delta k_{pos.strålk}$

$\Delta N_{D,W,x} = \Delta D_w * \Delta I * \Delta k_{T,p,vatten} * \delta A * \delta k_{fält,w} * \delta RH * \delta k_{pos.fantom} * \delta k_{pos.jonk,w} * \delta \rho_{vatten} * \delta k_{inst.fält} * \delta k_{pos.strålk}$

Analytical calculation in this document, analytical and MC in QMSys GUM Professional

Quantity Dw

Absorbed dose	ΔD_w	**Type A**	**Type B**	**Sensitivity coefficient for transfer chamber**	Effective degrees of freedom
		Uncertainty (%)			
1 Reference standard, set-up and radiation field					
Calibration coefficient by PSDL	$\delta N_{D,w,sek}$	0.05	0.19	1.00	100
Long term stability of reference standard	$\delta k_{stabilitet,sek}$		0.037	1.00	
Spectral difference of SSDL and PSDL	$\delta k_{fält,w}$		0.004	1.00	
Difference in radial non-uniformity of the beam and field size	$\delta k_{inst.fält}$		0.013	2.00	
Combined uncertainty of reference standard and setup		**0.05**	**0.19**		
2 Use of reference standard					
Chamber position	$\delta k_{pos.jonk,w}$		0.014	2.00	
Phantom position	$\delta k_{pos.fantom}$		0.002	2.00	
Source position	$\delta k_{pos.strålk}$		0.003	2.00	
Current/charge measurement including leakage	ΔI	0.020	0.017	2.00	100
Pressure and temperature correction for water	$\Delta k_{T,p,vatten}$	0.01	0.018	2.00	100
Water density	$\delta \rho_{vatten}$		0.010	2.00	
Recombination	δk_{rek}		0.020	1.00	
Air humidity	δRH		0.012	2.00	
Half-life correction	δA		0.017	2.00	
Combined uncertainty in measuring with reference standard		**0.02**	**0.04**		
Combined uncertainty in absorbed dose determination (1+2)		**0.05**	**0.20**		
3 Use of transfer chamber					
Combined uncertainty in measuring with transfer chamber		**0.065**	**0.210**		
Total uncertainty for the absorbed dose calibration coefficient, *k*=1	$\Delta N_{D,w,x}$	**0.220**			
Expanded uncertainty, *k*=2		**0.439**			
Confidence level (%)		95.45			

DSA

Chamber	IBA FC65-G (4442)		IBA FC65-G (3578)		NE2571 (3714)	
	N_{Dw}	N_{Kair}	N_{Dw}	N_{Kair}	N_{Dw}	N_{Kair}
Date of measurement	12.1.2022	14.1.2022	12.1.2022	17.1.2022	13.1.2022	17.1.2022
Calibration coefficient (Gy/µC)	48.26	43.84	48.30	43.86	44.97	40.85
u_c (k=2) (%)	0.60	0.49	0.60	0.49	0.60	0.49
Mean ionization current (I_{SSDL} or I_{PSDL}) (pA)	-430	-472	-430	-471	-462	-506
Measured leakage current (fA)	-4	0,3	-3	0,4	-8	-8
Environmental conditions (T, p, h), correction for humidity	T = 293.57 K (20.42 °C), p = 100.68 kPa, rh = 33%	T = 294.50 K (21.35 °C), p = 100.24 kPa, rh = 35%	T = 293.58 K (20.43 °C), p = 100.67 kPa, rh = 34%	T = 294.46 K (21.31 °C), p = 99.81 kPa, rh = 33%	T = 293.52 K (20.37 °C), p = 99.82 kPa, rh = 32%	T = 294.57 K (21.42 °C), p = 99.96 kPa, rh = 34%
Correction factors: k_{elec}	NA (range: 2 nA)	NA (range: 2 nA)	NA (range: 2 nA)	NA (range: 2 nA)	NA (range: 2 nA)	NA (range: 2 nA)
Description of sleeve used (material, thickness)	PMMA sleeve, 8.2 mm outer diameter, secondary standard calibrated in sleeve at the primary lab	-	PMMA sleeve, 8.2 mm outer diameter, secondary standard calibrated in sleeve at the primary lab	-	PMMA sleeve, 8.2 mm outer diameter, secondary standard calibrated in sleeve at the primary lab	-

Background information	D_w	K_{air}
Radiation source	^{60}Co	
Orientation of source relative to water phantom	horizontal	horizontal
Irradiator	Best Theratronics GBX-200	
Field size	10 cm x 10 cm	10 cm x 10 cm
Dose rate (mGy/s)	20.8 mGy/s	20.7 mGy/s
SCD (cm)	100 cm	100 cm
Depth in water phantom	5 g/cm^2 water	N/A
Reference standard (chamber + traceability)	Exradin A19 XAQ170232, BIPM (61/2018)	Exradin A19 XAQ170232, BIPM (61/2018)
Electrometer (charge vs current, range + traceability)	**Keithley 6517A #0863876, range: 2 nA, Justervesenet (NMI)**	**Keithley 6517A #0863876, range: 2 nA, Justervesenet (NMI)**

Equation/model

NDw * kstab * kspec * kref * [kpos * (I-delta*I) * kelec * kt * kp * kothers]ref / [kpos * (I-delta*I) * kelec * kt * kp * kothers]uut

Computation method (analytic or MC) and program model: Analytical

Quantity Kair

Air kerma	**Type A**	**Type B**	degrees of freedom
	Uncertainty (%)		
1 Reference standard, set-up and radiation field			
Calibration coefficient by PSDL		0.13	∞
Long term stability of reference standard		0.10	∞
Spectral difference of SSDL and PSDL		0.00	∞
Difference in radial non-uniformity of the beam and field size		0.10	∞
Combined uncertainty of reference standard and setup	**0.00**	**0.19**	
2 Use of reference standard			
Chamber and phantom positioning (distance, orientation)		0.05	∞
Current/charge measurement including leakage	0.01	0.05	99 (Type A) and ∞ (Type B)
Air temperature correction		0.06	∞
Air pressure correction		0.02	∞
Others (e.g. humidity, field inhomogenity, half life correction)		0.05	∞
Combined uncertainty in measuring with reference standard	**0.01**	**0.11**	
Combined uncertainty in air kerma determination (1+2)	**0.01**	**0.22**	
3 Use of transfer chamber			
Chamber and phantom positioning (distance, orientation)		0.05	∞
Current/charge measurement including leakage	0.01	0.05	∞
Air temperature correction		0.06	∞
Air pressure correction		0.02	∞
Others (e.g. humidity, decay of Co-60)		0.05	∞
Combined uncertainty in measuring with transfer chamber	**0.01**	**0.11**	
Relative combined standard uncertainty (1+2+3)	**0.01**	**0.25**	
Total uncertainty for the air kerma calibration coefficient, *k*=1	**0.25**		
Expanded uncertainty, *k*=2	**0.49**		99
Confidence level (%)	95 %		

Equation/model

Nk * kstab * kspec * kref * [kpos * (I-delta*I) * kelec * kt * kp * kothers]ref / [kpos * (I-delta*I) * kelec * kt * kp * kothers]uut

Computation method (analytic or MC) and program model: Analytical

Quantity Dw

Absorbed dose	**Type A**	**Type B**	degrees of freedom
	Uncertainty (%)		
1 Reference standard, set-up and radiation field			
Calibration coefficient by PSDL		0.19	∞
Long term stability of reference standard		0.10	∞
Spectral difference of SSDL and PSDL		0.00	∞
Difference in radial non-uniformity of the beam and field size		0.10	∞
Combined uncertainty of reference standard and setup	**0.00**	**0.24**	
2 Use of reference standard			
Chamber and phantom positioning (distance, orientation, water level)		0.09	∞
Current/charge measurement including leakage	0.01	0.05	99 (Type A) and ∞ (Type B)
Air temperature correction		0.06	∞
Air pressure correction		0.02	∞
Others (e.g. humidity, water density, field inhomogenity, half life correction)		0.05	∞
Combined uncertainty in measuring with reference standard	**0.01**	**0.13**	
Combined uncertainty in absorbed dose determination (1+2)	**0.01**	**0.27**	
3 Use of transfer chamber			
Chamber and phantom positioning (distance, orientation)		0.09	∞
Current/charge measurement including leakage	0.01	0.05	∞
Air temperature correction		0.06	∞
Air pressure correction		0.02	∞
Others (e.g. humidity, decay of Co-60)		0.05	∞
Combined uncertainty in measuring with transfer chamber	**0.01**	**0.13**	
Relative combined standard uncertainty (1+2+3)	**0.01**	**0.30**	
Total uncertainty for the absorbed dose calibration coefficient, *k* =1	**0.30**		
Expanded uncertainty, *k*=2	**0.60**		99
Confidence level (%)	95 %		

STUK

2nd round

Chamber	IBA FC65-G (4442)		IBA FC65-G (3578)		NE2571 (3714)	
	N_{Dw}	N_{Kair}	N_{Dw}	N_{Kair}	N_{Dw}	N_{Kair}
Date of measurement	3.-5.8.2022	15.-19.8.2022	3.-5.8.2022	15.-22.8.2022	3.-5.8.2022	18.-24.8.2022
Calibration coefficient (Gy/µC)	48.26	43.87	48.33	43.90	44.97	40.85
u_c (k=2) (%)	0.51	0.47	0.51	0.47	0.51	0.47
Mean ionization current (I_{SSDL} or I_{PSDL}) (pA)	-123.5	-136.2	-123.3	-136.2	-132.5	-146.3
Measured leakage current (fA)	< 5 fA	< 5 fA	< 5 fA	< 5 fA	< 5 fA	< 5 fA
Environmental conditions (T, p, h), correction for humidity	T:18.2-18.5 C p: 101.39-101.45 kPa h: 50% +/-5 %rh, no correction for humidity	T: 20.0-20.5 C p: 101.19-101.65 kPa h: 50% +/-5 %rh, no correction for humidity	T: 18.1-18.3 C p: 101.34-101.47 kPa h: 50% +/-5 %rh, no correction for humidity	T: 19.8-20.5 C p: 101.17-101.62 kPa h: 50% +/-5 %rh, no correction for humidity	T: 18.1-18.4 C p: 101.39-101.47 kPa h: 50% +/-5 %rh, no correction for humidity	T: 19.9-20.4 C p: 101.34-102.10 kPa h: 50% +/-5 %rh, no correction for humidity
Correction factors: k_{elec}	1.00183 (20 nC, ref current -100 pA)					
Correction factors: k_{pT}	Simultaneous k_{pT} correction during measurement					
Description of sleeve used (material, thickness)	no sleeve	-	no sleeve	-	PMMA, 1 mm	-
Other remarks:	average of several measurements, environmental conditions are corrected for each measurement and vary between measurements					

Background information	D_w	K_{air}
Radiation source	^{60}Co	
Orientation of source relative to water phantom	Horizontal	
Irradiator	Best Theratronics GBX-200	
Field size	10 cm x 10 cm (50% 9.98 x 9.98 cm)	
Dose rate (mGy/s)	5.97 mGy/s	5.98 mGy/s
SCD (cm)	100 cm	
Depth in water phantom	50 mm (incl. the wall of the water phantom)	N/A
Reference standard (chamber + traceability)	FC65G-3360, BIPM 12/2019	
Electrometer (charge vs current, range + traceability)	Keithley 6157B-4045533, measuring charge, 20 nC range, VTT MIKES (11/2021)	
other remarks	Water phantom material: PMMA, wall thickness: 10 mm (no window in phantom)	

Equation/model

$$N_{K,transfer} = \frac{\dot{K}_{air}}{[I k_{pT} k_{rec} k_{pol} k_{stem} k_{other}]_{transfer}} = \frac{[I k_{pT} k_{rec} k_{pol} k_{stem} k_{other} N_K]_{ref}}{[I k_{pT} k_{rec} k_{pol} k_{stem} k_{other}]_{transfer}}$$

Computational method: Analytical

Quantity Kair

Air kerma	**Type A**	**Type B**	DoF
	Uncertainty (%)		
1 Reference standard, set-up and radiation field			
Calibration coefficient by PSDL	0.02	0.13	100
Long term stability of reference standard		0.08	100
Spectral difference of SSDL and PSDL		0.00	30
Difference in radial non-uniformity of the beam and field size		0.06	10
Combined uncertainty of reference standard and setup	**0.02**	**0.16**	
2 Use of reference standard			
Chamber and phantom positioning (distance, orientation)		-	
Current/charge measurement including leakage	0.03	0.023	10
Air temperature correction		0.03	10
Air pressure correction		0.01	10
Others (e.g. humidity of the measurement environment, potential unstability of the chamber)		0.06	10
Combined uncertainty in measuring with reference standard	**0.03**	**0.07**	
Combined uncertainty in air kerma determination (1+2)	**0.04**	**0.175**	
3 Use of transfer chamber			
Chamber and phantom positioning (distance, orientation)		0.13	10
Current/charge measurement including leakage	0.03	0.015	10
Air temperature correction		0.03	10
Air pressure correction		0.01	10
Difference in radial non-uniformity of the beam and field size		0.03	10
Decay of Co-60		0.01	100
Others (e.g. humidity in measurement environment, potential unstability of the chamber)		0.06	10
Combined uncertainty in measuring with transfer chamber	**0.03**	**0.15**	
Relative combined standard uncertainty (1+2+3)	**0.05**	**0.23**	
Total uncertainty for the air kerma calibration coefficient, *k* =1	**0.234**		
Relative expanded uncertainty, *k*=2	**0.47**		%
Confidence level (%)	95.3		

Equation/model

$$N_{Dw,transfer} = \frac{\dot{D}_w}{[Ik_{pT}k_{rec}k_{pol}k_{stem}k_{other}]_{transfer}} = \frac{[Ik_{pT}k_{rec}k_{pol}k_{stem}k_{other}N_{Dw}]_{ref}}{[Ik_{pT}k_{rec}k_{pol}k_{stem}k_{other}]_{transfer}}$$

Computational method: Analytical

Quantity	Dw		
Absorbed dose	**Type A**	**Type B**	DoF
	Uncertainty (%)		
1 Reference standard, set-up and radiation field			
Calibration coefficient by PSDL	0.05	0.19	100
Long term stability of reference standard		0.08	30
Spectral difference of SSDL and PSDL		0.00	30
Difference in radial non-uniformity of the beam and field size		0.06	10
Combined uncertainty of reference standard and setup	**0.05**	**0.21**	
2 Use of reference standard			
Chamber and phantom positioning (distance, orientation, water level)		-	
Current/charge measurement including leakage	0.03	0.023	10
Air temperature correction		0.02	10
Air pressure correction		0.01	10
Others (e.g. humidity of the measurement environment, potential unstability of the chamber)		0.06	10
Combined uncertainty in measuring with reference standard	**0.03**	**0.06**	
Combined uncertainty in absorbed dose determination (1+2)	**0.06**	**0.22**	
3 Use of transfer chamber			
Chamber and phantom positioning (distance, orientation)		0.08	10
Current/charge measurement including leakage	0.03	0.015	10
Air temperature correction		0.02	10
Air pressure correction		0.01	10
Difference in radial non-uniformity of the beam and field size		0.01	10
Decay of Co-60		0.01	100
Others (e.g. humidity in measurement environment, potential unstability of the chamber)		0.06	10
Combined uncertainty in measuring with transfer chamber	**0.03**	**0.10**	
Relative combined standard uncertainty (1+2+3)	**0.07**	**0.24**	
Total uncertainty for the absorbed dose calibration coefficient, *k*=1	**0.252**		
Relative expanded uncertainty, *k*=2	**0.51**		%
Confidence level (%)	95.3 %		

DTU

Chamber	**IBA FC65-G (4442)**		**IBA FC65-G (3578)**		**NE2571 (3714)**	
	N_{Dw}	**N_{Kair}**	**N_{Dw}**	**N_{Kair}**	**N_{Dw}**	**N_{Kair}**
Date of measurement	**April 20 – May 4, 2022**	**April 7-12, 2022**	**April 20 – May 4, 2022**	**April 7-12, 2022**	**April 20 - May 04, 2022**	**April 7 -12, 2022**
(A) Calibration coefficient (Gy/µC), no correction for recombination	48.227	43.862	48.284	43.897	44.934	40.869
(B) Calibration coefficient (Gy/µC) with correction for recombination	48.196	43.834	48.250	43.866	44.893	40.831
u_c (k=2) (%)	0.67	0.58	0.67	0.58	0.67	0.58
Mean ionization current (I_{SSDL} or I_{PSDL}) (pA)	-190	-200	-190	-200	-200	-220
Measured leakage current (fA)	1	3	1	3	1	4
Environmental conditions (T, p, h), correction for humidity	22.1 ± 0.5 degC, 1009.7 - 1024.6 hPa, 43 ± 5% RH	22.2 ± 0.5 degC, 970.6-1019.9 hPa, 43 ± 5% RH	22.1 ± 0.5 degC, 1009.7 – 1024.6 hPa, 43 ± 5% RH	22.2 ± 0.5 degC, 970.6 - 10193.9 hPa, 43 ± 5% RH	22.1 ± 0.5 degC, 1009.7 - 1024.6 hPa, 43 ± 5% RH	22.2 ± 0.5 degC, 970.6 - 1019.9 hPa, 43 ± 5% RH
Correction factors: k_{elec}	1	1	1	1	1	1
Correction factors: ks	1.000645	1.000645	1.000708	1.000708	1.000921	1.000921
Correction factors: kpol (not applied)	1.000818	1.000818	1.000803	1.000803	1.000997	1.000997
Description of sleeve used (material, thickness)	None	None	None	None	PTW 41023-1-100 (PMMA 1 mm)	None
Other remarks:	Cert. DTU-276701	Cert. DTU-276801	Cert. DTU-276702	Cert. DTU-276802	Cert. DTU-276703	Cert. DTU-276803

Background information	**D_w**	**K_{air}**
Radiation source	^{60}Co	
Orientation of source relative to water phantom	Horizontal	Horizontal
Irradiator	Terabalt T-100 (UJP Praha)	
Field size	10 cm x 10 cm	10 cm x 10 cm
Dose rate (mGy/s)	9	9
SCD (cm)	100	100
Depth in water phantom	5.00	N/A
Reference standard (chamber + traceability)	Several (PTB)	NPL2611-1019, BIPM-34/2020 + FC65G-3362, BIPM-35/2020
Electrometer (charge vs current, range + traceability)	**Keithley 6517B-1341729 with external air capacitor, 20 V calibrated by DTU using electrical and time standards from Trescal, DK.**	**Keithley 6517B-1341729 with external air capacitor, 20 V calibrated by DTU using electrical and time standards from Trescal, DK.**

Equation/model

$$N_{K,Q_0}(j) = \frac{\frac{1}{N}\sum_i \frac{1}{K_i}\sum_k N_{K,Q_0}(i)\, M(i,k)}{\frac{1}{K_j}\sum_k M(j,k)}$$

Where j is index for the chamber to be calibrated and i is index for the N reference chambers needed to establish the kerma rate at the reference point in the air at the reference time for the calibration session. K_i and K_j are the number of repeat set-ups (full positioning) for each chamber, M are the corrected readings and $N_{K,Qo}$ is the cobalt calibration coefficients.

Computation method (analytic or MC) and program model Analytical

Quantity Kair

Air kerma	**Type A**	**Type B**
	Uncertainty (%)	
1 Reference standard, set-up and radiation field		
Calibration coefficient by PSDL		0.14
Long term stability of reference standard		-
Spectral difference of SSDL and PSDL		0.12
Difference in radial non-uniformity of the beam and field size		-
Combined uncertainty of reference standard and setup	**0.00**	**0.18**
2 Use of reference standard		
Chamber and phantom positioning (distance, orientation)	0.03	-
Current/charge measurement including leakage		-
Air temperature correction		-
Air pressure correction		-
Others (e.g. humidity, field inhomogenity, half life correction)		
Combined uncertainty in measuring with reference standard	**0.03**	**0.00**
Combined uncertainty in air kerma determination (1+2)	**0.03**	**0.18**
3 Use of transfer chamber		
Chamber and phantom positioning (distance, orientation)		-
Current/charge measurement including leakage		-
Air temperature correction		-
Air pressure correction		-
Others (e.g. humidity, decay of Co-60)		0.22
Combined uncertainty in measuring with transfer chamber	**0.00**	**0.22**
Relative combined standard uncertainty (1+2+3)	**0.03**	**0.29**
Total uncertainty for the air kerma calibration coefficient, *k* =1	**0.29**	
Expanded uncertainty, *k*=2	**0.58**	
Confidence level (%)	95	

Equation/model

$$N_{D,W,Q_0}(j) = \frac{\frac{1}{N}\sum_i \frac{1}{K_i}\sum_k N_{D,W,Q_0}(i)\, M(i,k)}{\frac{1}{K_j}\sum_k M(j,k)}$$

Where j is index for the chamber to be calibrated and i is index for the N reference chambers needed to establish the dose rate at the reference point in the water phantom at the reference time for the calibration session. K_i and K_j are the number of repeat set-ups (full positioning) for each chamber, M are the corrected readings and N_{D,W,Q_0} is the cobalt calibration coefficients.

Computation method (analytic or MC) and program model Analytical

Quantity Dw

Absorbed dose	**Type A**	**Type B**
	Uncertainty (%)	
1 Reference standard, set-up and radiation field		
Calibration coefficient by PSDL		0.25
Long term stability of reference standard		-
Spectral difference of SSDL and PSDL		0.05
Difference in radial non-uniformity of the beam and field size		-
Combined uncertainty of reference standard and setup	**0.00**	**0.25**
2 Use of reference standard		
Chamber and phantom positioning (distance, orientation, water level)	0.03	-
Current/charge measurement including leakage		-
Air temperature correction		-
Air pressure correction		-
Others (e.g. humidity, water density, field inhomogenity, half life correction)		-
Combined uncertainty in measuring with reference standard	**0.03**	**0.00**
Combined uncertainty in absorbed dose determination (1+2)	**0.03**	**0.25**
3 Use of transfer chamber		
Chamber and phantom positioning (distance, orientation)	0.03	-
Current/charge measurement including leakage		-
Air temperature correction		-
Air pressure correction		-
Others (e.g. humidity, decay of Co-60)		0.21
Combined uncertainty in measuring with transfer chamber	**0.03**	**0.21**
Relative combined standard uncertainty (1+2+3)	**0.04**	**0.33**
Total uncertainty for the absorbed dose calibration coefficient, *k*=1	**0.33**	
Expanded uncertainty, *k*=2	**0.67**	
Confidence level (%)	95	

CIEMAT

Chamber	IBA FC65-G (4442)		IBA FC65-G (3578)		NE2571 (3714)	
	N_{Dw}	N_{Kair}	N_{Dw}	N_{Kair}	N_{Dw}	N_{Kair}
Date of measurement	05/11/22 to 06/08/2022	05/17/22 to 06/06/2022	05/12/22 to 06/08/2022	05/17/22 to 06/06/2022	05/10/22 to 06/10/2022	05/17/22 to 06/06/2022
Calibration coefficient (Gy/µC)	48.15	43.88	48.21	43.90	44.89	40.88
u_c (k=2) (%)	0.75	0.62	0.75	0.62	0.75	0.62
Mean ionization current (I_{SSDL}) corrected for T, p, leakage, kelec and fnon lin elec (pA)	103.42	112.75	103.27	112.76	110.89	121.08
Measured leakage current (fA)	-22.26	-21.46	-21.15	-20.56	-27.10	-22.98
Environmental conditions (T, p, h), correction for humidity	T= 292.95 K (19.80 C), p= 94.119 kPa, rh=45.86%, no correction for humidity	T= 293.25 K (20.10C), p= 94.062 kPa, rh=50.33%, no correction for humidity	T= 292.95 K (19.80 C), p= 94.151 kPa, rh=46.06%, no correction for humidity	T= 293.27 K (20.12 C), p= 94.017 kPa, rh=48.24%, no correction for humidity	T= 292.99 K (19,84 C), p= 94.151 kPa, rh=44.08%, no correction for humidity	T= 293.15 K (20,00 C), p= 94.024 kPa, rh=47.19%, no correction for humidity
Correction factors: k_{elec}	1.001	1.001	1.001	1.001	1.001	1.001
Correction factors: $f_{non\ lin\ elec}$	1.000	1.000	1.000	1.000	1.000	1.000
Correction factors: $k_{distance}$	1.000	1.0007	0.9995	1.0006	0.9995	1.0005
Correction factors: k_{depth}	1.000	-----	1.000	-----	1.000	-----
Correction factors: $k_{P,T}$	1.076	1.078	1.075	1.078	1.073	1.078
Correction factors: $k_{h,50}$	1.000	1.000	1.000	1.000	1.000	1.000
Description of sleeve used (material, thickness)	PMMA, 1 mm	-----	PMMA, 1 mm	-----	PMMA, 1 mm	-----

Background information	D_w	K_{air}
Radiation source	^{60}Co	
Orientation of source relative to water phantom	Horizontal	Horizontal
Irradiator	Best theratronics, Theratron 780, n/s:183R	
Field size	10 cm x 10 cm	10 cm x 10 cm
Dose rate (mGy/s)	4.98	4.95
SCD (cm)	100	100
Depth in water phantom	5 g/cm^2	N/A
Reference standard (chamber + traceability)	FC65G-935, BIPM (08/2021) NE2571-3526,BIPM (09/2020)	FC65G-935, BIPM (08/2021) NE2571-3526,BIPM (09/2020)
Electrometer (charge vs current, range + traceability)	Wellhöfer Dose 1-10908, measuring charge, 0-10 nA range, NPL (07/2020)	Wellhöfer Dose 1-10908, measuring charge,0-10 nA range, NPL (07/2020)

Equation/model

$$N_{Kair,transfer} = \frac{\dot{K}_{\mathrm{air,ref}}}{I_{\mathrm{transfer}}} = \frac{[I\, N_{Kair}^{\mathrm{BIPM}}\; k_{\mathrm{est}}\, k_{\mathrm{spec}}\, k_{\mathrm{rn}}\, k_{\mathrm{s}}\, k_{\mathrm{st}}\, k_{\mathrm{pos}}\, k_{\mathrm{elec}}\, k_{\mathrm{TP}}\, k_{\mathrm{others}}]_{ref}}{[I\, k_{TP}\, k_{\mathrm{pos}}\, k_{\mathrm{elec}}\, k_{\mathrm{others}}]_{transfer}}$$

Computation method (analytic or MC) and program model Analytical

Quantity Kair

Air kerma	**Type A**	**Type B**	degrees of freedom
	Uncertainty (%)		
1 Reference standard, set-up and radiation field			
Calibration coefficient of the ref standard (uncertainties are similar for both chambers NE 2571 3526 or FC65G 935)	0.02	0.13	>1E4
Long term stability of reference standard	---	0.02	17
Spectral difference of SSDL and PSDL	---	0.10	>1E4
Difference in radial non-uniformity of the beam and field size u(k_{rn})(Ciemat)/u(k_{rn})(BIPM)	---	0.08	>1E4
u(ks) (Ciemat)/u(ks)(BIPM)	---	0.04	>1E4
u(k_{st}) (Ciemat)/u(k_{st}) (BIPM)	---	0.01	>1E4
Combined uncertainty of reference standard and setup	**0.02**	**0.19**	**>1E4**
2 Use of reference standard			
Chamber and phantom positioning (distance, orientation)	0.004	0.06	>1E4
Current/charge measurement including leakage	0.004	0.16	>1E4
Air temperature correction	---	0.03	>1E4
Air pressure correction	---	0.01	>1E4
Others (k_h humidity, k_{at} air attenuation, k_{dec} half life correction, source positioning k_{source})	---	0.06	>1E4
Combined uncertainty in measuring with reference standard	**0.01**	**0.18**	**>1E4**
Combined uncertainty in air kerma determination (1+2)	**0.02**	**0.26**	
3 Use of transfer chamber			
Chamber and phantom positioning (distance, orientation)	0.004	0.04	>1E4
Current/charge measurement including leakage	0.005	0.01	>1E4
Air temperature correction	---	0.02	>1E4
Air pressure correction	---	0.005	>1E4
Others (k_h humidity, k_{at} air attenuation)	---	0.05	>1E4
Combined uncertainty in measuring with transfer chamber	**0.01**	**0.07**	**>1E4**
Relative combined standard uncertainty (1+2+3)	**0.02**	**0.27**	
Total uncertainty for the air kerma calibration coefficient, *k* =1	**0.27**		**>1E4**
Expanded uncertainty, *k*=2	**0.54**		
Confidence level (%)	95.4		

Equation/model

$$N_{Dw,transfer} = \frac{\dot{D}_{\mathrm{w,ref}}}{I_{\mathrm{transfer}}} = \frac{\left[I\, N_{D\mathrm{w}}^{\mathrm{BIPM}}\; k_{\mathrm{est}}\, k_{\mathrm{spec}}\, k_{\mathrm{rn}}\, k_{\mathrm{s}}\, k_{\mathrm{st}}\, k_{\mathrm{pf}}\, k_{\mathrm{pos}}\, k_{\mathrm{elec}}\, k_{TP}\, k_{\mathrm{others}}\right]_{ref}}{\left[I\, k_{TP}\, k_{\mathrm{pos}}\, k_{\mathrm{elec}}\, k_{\mathrm{others}}\right]_{transfer}}$$

Computation method (analytic or MC) and program model Analytical

Quantity Dw

Absorbed dose	**Type A**	**Type B**	degrees of freedom
	Uncertainty (%)		
1 Reference standard, set-up and radiation field			
Calibration coefficient of the ref standard (uncertainties are similar for both chambers NE 2571 3526 or FC65G 935)	0.05	0.19	>1E4
Long term stability of reference standard	---	0.02	32
Spectral difference of SSDL and PSDL	---	0.10	>1E4
Difference in radial non-uniformity of the beam and field size u(k_{rn})(Ciemat)/u(k_{rn})(BIPM)	---	0.05	>1E4
u(ks) (Ciemat)/u(ks)(BIPM)	---	0.04	>1E4
u(k_{st}) (Ciemat)/u(k_{st}) (BIPM)	---	0.01	>1E4
Non equivalence to water of the PMMA window of the CIEMAT phanton. k_{pf}	---	0.07	>1E4
Combined uncertainty of reference standard and setup	**0.05**	**0.24**	**>1E4**
2 Use of reference standard			
Chamber and phantom positioning (distance, orientation)	0.004	0.06	>1E4
Current/charge measurement including leakage (scale factor, measurement time)	0.003	0.16	>1E4
Air temperature correction	---	0.01	>1E4
Air pressure correction	---	0.01	>1E4
Others (k_h humidity, k_{at} air attenuation, k_{dec} half life correction, source positioning k_{source})	---	0.06	>1E4
Combined uncertainty in measuring with reference standard	**0.01**	**0.18**	**>1E4**
Combined uncertainty in absorbed dose determination (1+2)	**0.05**	**0.30**	
3 Use of transfer chamber			
Chamber and phantom positioning (distance, orientation)	0.004	0.06	>1E4
Current/charge measurement including leakage	0.006	0.02	>1E4
Air temperature correction	---	0.005	>1E4
Air pressure correction	---	0.004	>1E4
Others (k_h humidity, k_{at} air attenuation)	---	0.05	>1E4
Combined uncertainty in measuring with transfer chamber	**0.01**	**0.08**	**>1E4**
Relative combined standard uncertainty (1+2+3)	**0.05**	**0.31**	
Total uncertainty for the absorbed dose calibration coefficient, *k* =1	**0.31**		**>1E4**
Expanded uncertainty, *k*=2	**0.62**		
Confidence level (%)	95.4		

IAEA

Chamber	IBA FC65-G (4442)		IBA FC65-G (3578)		NE2571 (3714)	
	N_{Dw}	N_{Kair}			N_{Dw}	N_{Kair}
Date of measurement	16 June to 20 July 2022	22 June to 18 July 2022	15 June to 20 July 2022	21 June to 18 July 2022	15 June to 20 July 2022	21 June to 18 July 2022
Calibration coefficient (Gy/µC)	*48.10*	*43.83*	*48.15*	*43.87*	*44.85*	*40.84*
Calibration coefficient (gy/µC) without sleeve	*48.15*		*48.19*			
u_c (*k*=2) (%)	0.7	0.6	0.7	0.6	0.7	0.6
Mean ionization current (I_{SSDL} or I_{PSDL}) (pA)	~ 185 pA	~ 200 pA	~ 185 pA	~ 200 pA	~ 185 pA	~ 200 pA
Measured leakage current (fA)	<10 fA	<10 fA	<10 fA	<10 fA	<14 fA	<10 fA
Environmental conditions (T, p, h), correction for humidity	T= 22.2±0.3 °C, P= 995±5 hPa, rh=50%, no correction for humidity	T= 22.0±0.5 °C, P= 998±5 hPa, rh=50%, no correction for humidity	T= 22.3±0.3 °C, P= 994±3 hPa, rh=50%, no correction for humidity	T= 22.6±0.3 °C, P= 998±5 hPa, rh=50%, no correction for humidity	T= 21.0±0.4 °C, P= 995±5 hPa, rh=50%, no correction for humidity	T= 21.5±0.5 °C, P= 997±5 hPa, rh=50%, no correction for humidity
Correction factors: k_{elec}	0.9988	0.9988	0.9988	0.9988	0.9988	0.9988
Correction factors: k_{sat} ref. standard	1.0009	1.0009	1.0009	1.0009	1.0009	1.0009
Correction factors: k_{sat} chamber	1.0007	1.0007	1.0007	1.0007	1.0008	1.0008
Description of sleeve used (material, thickness)	1 mm PMMA	-	1 mm PMMA	-	1 mm PMMA	-
Other remarks:	For each point of measurement for current temperature and pressure is measured and is individually corrected. No correction was applied for k_{sat}. Also, measurements were performed with and without sleeve. Provided calibration coefficients refer to air temperature T = 20°C, air pressure P = 101.325 kPa.					

Background information	D_w	K_{air}
Radiation source	^{60}Co	
Orientation of source relative to water phantom	Horiz. beam	
Irradiator	Gammabeam X200	
Field size	10 cm x 10 cm	10 cm x 10 cm
Dose rate [mGy/s]	19.00	19.00
SCD [cm]	100.00	100.00
Depth in water phantom	5 g/cm²	N/A
Reference standard (chamber + traceability)	NE2611 / BIPM 2022	NE2611 / BIPM 2022
Electrometer (charge vs current, range + traceability)	K6517 / 200 nC / BEV	K6517 / 200 nC / BEV
other remarks	200 nC range	200 nC range

Equation/model

$$N_k^{user} = N_k^{ref} k_{stab}^{ref} k_{Q,Q_0} k_{rad} \left(1 - 2\left(\partial d^{ref} - \partial d^{user}\right)\right) \frac{M_{raw}^{ref}}{M_{raw}^{user}} \left(\frac{273.15 + T^{ref}}{273.15 + T^{user}}\right) \left(\frac{p^{user}}{p^{ref}}\right) \left(\frac{k_{other}^{ref}}{k_{other}^{user}}\right)$$

Computation method (analytic or MC) and program model Analytical

Quantity Kair

Air kerma	**Type A**	**Type B**	Effective degrees of freedom
	Uncertainty (%)		
1 Reference standard, set-up and radiation field			
Calibration coefficient by PSDL		0.13	30
Long term stability of reference standard		0.02	100
Spectral difference of SSDL and PSDL		-	
Difference in radial non-uniformity of the beam and field size		-	
Combined uncertainty of reference standard and setup	**0.00**	**0.13**	
2 Use of reference standard			
Chamber and phantom positioning (distance, orientation)		0.02	100
Current/charge measurement including leakage		0.10	100
Air temperature correction		0.08	100
Air pressure correction		0.11	100
Others (e.g. humidity, field inhomogenity, half life correction)		-	
Combined uncertainty in measuring with reference standard	**0.00**	**0.17**	
Combined uncertainty in air kerma determination (1+2)	**0.00**	**0.21**	
3 Use of transfer chamber			
Chamber and phantom positioning (distance, orientation)		0.02	100
Current/charge measurement including leakage		0.10	100
Air temperature correction		0.08	100
Air pressure correction		0.11	100
Others (e.g. humidity, decay of Co-60)		-	
Combined uncertainty in measuring with transfer chamber	**0.00**	**0.17**	
Relative combined standard uncertainty (1+2+3)	**0.00**	**0.27**	
Total uncertainty for the air kerma calibration coefficient, *k*=1	**0.27**		
Expanded uncertainy, *k*=2	**0.55**		
Confidence level (%)	95		

Equation/model

$$N_{D_w}^{user} = N_{D_w}^{ref} k_{stab}^{ref} k_{Q,Q_0} k_{rad} \left(1 - 2\left(\delta d^{ref} - \delta d^{user}\right)\right) \frac{M_{raw}^{ref}}{M_{raw}^{user}} \left(\frac{273.15 + T^{ref}}{273.15 + T^{user}}\right) \left(\frac{p^{user}}{p^{ref}}\right) \left(\frac{k_{other}^{ref}}{k_{other}^{user}}\right)$$

Computation method (analytic or MC) and program model Analytical

Quantity Dw

Absorbed dose	**Type A**	**Type B**	Effective degrees of freedom
	Uncertainty (%)		
1 Reference standard, set-up and radiation field			
Calibration coefficient by PSDL		0.20	30
Long term stability of reference standard		0.02	100
Spectral difference of SSDL and PSDL		-	
Difference in radial non-uniformity of the beam and field size		-	
Combined uncertainty of reference standard and setup	**0.00**	**0.20**	
2 Use of reference standard			
Chamber and phantom positioning (distance, orientation, water level)		0.06	100
Current/charge measurement including leakage		0.10	100
Air temperature correction		0.08	100
Air pressure correction		0.11	100
Others (e.g. humidity, water density, field inhomogenity, half life correction)		-	
Combined uncertainty in measuring with reference standard	**0.00**	**0.18**	
Combined uncertainty in absorbed dose determination (1+2)	**0.00**	**0.27**	
3 Use of transfer chamber			
Chamber and phantom positioning (distance, orientation)		0.06	100
Current/charge measurement including leakage		0.10	100
Air temperature correction		0.08	100
Air pressure correction		0.11	100
Others (e.g. humidity, decay of Co-60)		-	
Combined uncertainty in measuring with transfer chamber	**0.00**	**0.18**	
Relative combined standard uncertainty (1+2+3)	**0.00**	**0.32**	
Total uncertainty for the absorbed dose calibration coefficient, *k*=1	**0.32**		
Expanded uncertainty, *k*=2	**0.65**		
Confidence level (%)	95		