COMPARISON OF ABSORBED DOSE TO WATER AT HIGH PHOTON ENERGIES AT A REFERENCE FACILITY

BIPM Key Comparison BIPM.RI(I)-K6

PROTOCOL 3.0

CCRI(I)

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ABSTRACT

This comparison protocol outlines the procedure to be followed during a series of bi-lateral comparisons of the absorbed dose to water in high-energy photon beams, where the BIPM is the pilot laboratory. The comparisons are carried out at a reference facility in the outskirts of Paris. The NMI may either bring their calorimeter to make a direct comparison with the BIPM, or may bring a transfer standard for an indirect comparison.

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BACKGROUND

High-energy photon facilities such as linear accelerators have almost completely replaced ^{60}Co sources for radiotherapy in industrialized countries. Beams of 6 MV to 20 MV are now being used routinely in hospitals, often in combination with intensity-modulated techniques. Consequently, the National Metrology Institutes (NMIs) face a need to demonstrate dosimetric equivalence and traceability in this energy region.

In 2005, the CCRI encouraged the BIPM to consider the possibility of setting up a high-energy facility, dedicated to comparisons and calibrations for Member States of the Metre Convention. It was decided in 2008 to make a series of bi-lateral comparisons piloted by the BIPM as an interim solution by taking its primary calorimetric standard to each NMI having a primary standard and facility for high-energy photon beams. As decided at the 24th meeting of the CCRI, the linking of the NMIs for equivalence is achieved through the BIPM standard [1 - 3]. The BIPM carried out ten comparisons with this approach from 2009 until 2016 [4 - 13].

In 2017, the BIPM obtained access to a medical linear accelerator on the outskirts of Paris at which the BIPM may define and determine their own conditions for reference dosimetry. The BIPM can hence now offer a fixed reference source for high energy photon dosimetry.

This new approach does not modify the choice of the key comparison reference value of BIPM.RI(I)-K6 and future results may therefore be linked to the same reference value.

This protocol describes the frame for comparisons in high energy photon beams of absorbed dose to water at a reference facility. The NMI, expected to have a primary standard, may either bring their primary instrument to make a direct comparison with the BIPM, or a transfer standard for an indirect comparison.

1. MEASURAND, KEY COMPARISON REFERENCE VALUE AND COMPARISON RESULT

The BIPM.RI(I)-K6 is a continuous series of bi-lateral comparison between an Institute[1] (NMI) and the BIPM where the BIPM determination is adopted as the key comparison reference value. The comparison is based on the determination of absorbed dose to water in a high-energy photon beam made by each partner. The NMI is expected to have a primary standard.

Using this procedure, the determination of $D_{\mathrm{w,BIPM}}$ based on the BIPM primary standard will be accompanied by a corresponding estimate of the NMI absorbed dose to water, $D_{\mathrm{w,NMI}}$.

The comparison will result in the determination of the ratio

$$R_{\mathrm{NMI}} = \frac{D_{\mathrm{w,NMI}}}{D_{\mathrm{w,BIPM}}} . \qquad (1)$$

and its associated uncertainty, $u_{\mathrm{c}}(R_{\mathrm{NMI}})$, including the uncertainty contribution arising from the monitor calibration procedure described in Appendix I. The method to determine $D_{\mathrm{w,BIPM}}$ is summarized in Appendix II.

[1] For simplicity the institute is from now on labelled « NMI ».

The comparison result will be subject for inclusion as a Degree of Equivalence into the KCDB.

2. PARTICIPANTS

NMIs that already have participated, or will participate, in the BIPM.RI(I)-K6 comparison are listed in the BIPM Key Comparison Database (KCDB) .

Registration for a comparison should be communicated to the BIPM.RI(I)-K6 contact person (cf. KCDB).

3. COMPARISON TECHNIQUE AND TRANSFER INSTRUMENT

The comparison can be carried out in two different ways:

a) The NMI has previously determined the absorbed dose to water at its institute and brings a transfer standard to the BIPM in form of a calibrated ionization chamber. For practical reason, a maximum of 3 transfer instruments is suggested.

b) The NMI brings its primary standard to the BIPM and makes a determination of the absorbed dose to water in the BIPM reference beam.

The BIPM will determine the absorbed dose to water before the comparison activity, and will use an ionization chamber during the comparison that has been calibrated against the BIPM primary standard.

4. REFERENCE CONDITIONS

The reference accelerator beams are established on an ELEKTA Versa HD System.

All measurements will be carried out in a horizontal beam. The ambient temperature and pressure will be monitored, and the level of relative humidity will be kept within a range from 20 % to 80 %.

Three beam qualities are available, represented by the tissue-phantom ratio $TPR_{20,10}$ as listed in Table 1, where the nominal accelerator energy is indicated as well as the approximate value of the percentage depth dose PDD(10).

Variations in beam intensity cannot be neglected and a reliable beam monitor must be used. The BIPM has realized a monitoring system for which both short- and long-term stability will be assessed using a thimble ionization chamber in combination with a transmission monitor. All measurements made by the BIPM or the NMI will be referenced to the beam monitoring.

Although a reference depth of 10 g cm^{-2} and a source to detector distance (SDD) of 100 cm are internationally recommended [14], the NMI participants are recommended to use their usual reference conditions (e.g. in some cases a larger SDD is applied for bulky instruments) for the measurements at the BIPM facility if this is possible to realize on site.

Table 1. Measured $TPR_{20,10}$ and PDD(10) used for comparison. The uncertainty in the last digit(s) is indicated within parenthesis.

$TPR_{20,10}$	PDD(10)	$C_{w,c}$	Nominal accelerator energy / MV
0.6862(15)	68.61	1.1225(28)	6
0.7330(4)	73.66	1.1306(28)	10
0.7735(6)	78.62[2]	1.1378(28)	18

The beam height is 125 cm. A support table (that cannot be removed) is available with an adjustable height from 64 cm to 173 cm. The available distance from the front face of the accelerator head to a virtual reference plane at 100 cm from the source is 334 mm. The minimum cable length from the support table to the control room is 10 m. The ON/OFF of the beam can presently only be controlled manually. The electric network provides AC 220 V at 50 Hz and all plugs are of European standard Type E.

5. COMPARISON PROCEDURE

a) The NMI and the BIPM agree upon the start date well in advance, the duration of the comparison, the number of beam qualities, the type of comparison and the number of ionization chambers to be employed.

b) The NMI must fulfil the requests as listed in Appendix III in order to carry out the comparison under the best conditions;

c) Knowing the $TPR_{20,10}$ of the accessible beam qualities on the BIPM accelerator facility, the NMI shall provide an interpolated value for the calibration coefficient at each $TPR_{20,10}$ available and its associated uncertainty. The NMI shall also provide the value(s) of the associated correction factor(s) (see Appendix IV). This information is to be communicated well in advance before the comparison.

d) The NMI shall provide a complete uncertainty budget well in advance of the comparison.

e) The beam qualities will be alternated as frequently as possible.

f) The beam intensity will be monitored continuously by the BIPM and the beam monitor will be calibrated – at least – at the start and end of the day.

g) The correction factor for radial non-uniformity will be provided by the BIPM. The approximate dose-per-pulse may be communicated by the BIPM for correction of recombination.

h) When necessary, a determination of the recombination effect using the two-voltage method may be carried out for each chamber involved.

i) The BIPM will provide the instruments necessary to determine the ionization charge.

j) The NMI is requested to bring the associate sleeve(s) used for the calibration of the chamber(s).

[2] Not filtered, may contain electron contribution.

k) The dose determination for each ionization chamber at each beam quality will be subject to repeats and the position of the chamber will be reproduced at least twice.

l) On return to its institute, the NMI will carry out a quality control of their travelling standard(s). When the BIPM has received feedback, the BIPM will prepare a Draft A Report for circulation to all participants for comment and discussion.

m) The results of each bi-lateral comparison with a given NMI, subject to the approval of the CCRI, will be reported in the open literature and published in the key comparison database (KCDB). The usual publication route is as a Technical Supplement in *Metrologia*, but the NMI and the BIPM may agree to publish elsewhere.

In case of configuration **3b)**

n) The NMI will bring all equipment needed to carry out its measurements.

I should be noted that the BIPM cannot yet provide the phase space files of the beams.

6. COSTS, TRANSPORT, INSURANCE, SAFETY, AND OTHER PRACTICAL DETAILS

The NMI is requested to pay for transport and potential customs clearance operations [15].

NMIs shall make their own "door to door" arrangements for the costs of transport of their equipment to or from the BIPM. The BIPM contact person must be contacted well in advance to allow adequate time for administrative arrangements if necessary.

Insurance for the NMI staff and equipment is arranged and paid by the NMI.

The participants shall bring their own personal dosemeters.

Some practical details are listed in Appendix VI.

7. FAILURES AND BREAKDOWNS

In case of a serious failure or breakdown of the BIPM or NMI equipment during the measurement phase, the BIPM should decide on the actions after having consulted the NMI.

References

[1] Consultative Committee for Ionizing Radiation, Report of the 24th meeting (2013)

[2] Establishment of degrees of equivalence of national primary standards for absorbed dose to water in accelerator photon beams, S. Picard, D. T. Burns and J. M. Los Arcos, *Metrologia* **50** *Tech. Suppl.* (2013) 06016.

[3] Key Comparison BIPM.RI(I)-K6 / BIPM Key Comparison Database *http://kcdb.bipm.org/*

[4] Picard S, Burns D T, Roger P, Allisy-Roberts P J, McEwan M, Cojocaru C, Ross C 2010 Comparison of the standards for absorbed dose to water of the NRC and the BIPM for accelerator photon beams *Metrologia* **47** *Tech. Suppl.* 06025, 22 pp.

[5] Picard S, Burns D T, Roger P, Allisy-Roberts P J, Kapsch R P and Krauss A 2011b Key comparison BIPM.RI(I)-K6 of the standards for absorbed dose to water of the PTB, Germany and the BIPM in accelerator photon beams *Metrologia* **48** *Tech. Suppl.* 06020, 21 pp.

[6] Picard S, Burns D T, Roger P, Bateman F B, Tosh R E and Chen-Mayer H 2013b Key comparison BIPM.RI(I)-K6 of the standards for absorbed dose to water of the NIST, USA and the BIPM in accelerator photon beams *Metrologia* **50** *Tech. Suppl.* 06004, 22 pp.

[7] Picard S, Burns D T, Roger P, Delaunay F, Le Roy M, Ostrowsky A, Sommier L and Vermesse D 2013c Key comparison BIPM.RI(I)-K6 of the standards for absorbed dose to water of the LNE-LNHB, France and the BIPM in accelerator photon beams *Metrologia* **50** *Tech. Suppl.* 06015, 24 pp.

[8] Picard S, Burns D T, Roger P, Harty P D, Ramanathan G, Lye J E, Wright T, Butler D J, Cole A, Oliver C and Webb D V D 2014 Key comparison BIPM.RI(I)-K6 of the standards for absorbed dose to water of the ARPANSA, Australia and the BIPM in accelerator photon beams *Metrologia* **51** *Tech. Suppl.* 06006, 29 pp.

[9] Picard S, Burns D T, Roger P, Duane S, Bass G A, Manning J W and Shipley D R 2015a Key comparison BIPM.RI(I)-K6 of the standards for absorbed dose to water at 5 g cm^{-2} and 7 g cm^{-2} of the NPL, United Kingdom and the BIPM in accelerator photon beams, *Metrologia*, **52**, *Tech. Suppl.*, 06010 27 pp.

[10] Picard S, Burns D T, Roger P, Duane S, Bass G A, Manning J W and Shipley D R 2015b Key comparison BIPM.RI(I)-K6 of the standards for absorbed dose to water at 10 g cm^{-2} of the NPL, United Kingdom and the BIPM in accelerator photon beams, *Metrologia*, **52**, *Tech. Suppl.*, 06021 23 pp.

[11] Picard S, Burns D T, Roger P, de Prez L. and Jansen B 2017 Key comparison BIPM.RI(I)-K6 of the standards for absorbed dose to water of the VSL, Netherlands and the BIPM in accelerator photon beams, *in preparation*.

[12] Picard S, Burns D T, Roger P, Shimizu M, Morishita Y, Kato M, Tanaka T, Kurosawa T and Saito N 2016 Key comparison BIPM.RI(I)-K6 of the standards for absorbed dose to water at 10 g cm^{-2} of the NMIJ, Japan and the BIPM in accelerator photon beams *Metrologia*, **53**, *Tech. Suppl.*, 06012 25 pp.

[13] Picard S, Burns D T, Roger P, … N 2017 Key comparison BIPM.RI(I)-K6 of the standards for absorbed dose to water at 10 g cm^{-2} of the NIMJ, China and the BIPM in accelerator photon beams, *in preparation*.

[14] *Absorbed Dose Determination in External Beam Radiotherapy: An International Code of Practice for Dosimetry based on Standards of Absorbed Dose to Water*, P. Andreo, D. T. Burns, K. Hohfeld, M. Saiful Huq, T. Kanai, F. Laitano, V. Smyth, S. Vynckier, IAEA TRS-398 (2004) IAEA, Vienna.

[15] DIR-P-01 "BIPM measurement and consultancy services policy" 2.1 - 26 June 2012.

[16] Construction of an Absorbed Dose Graphite Calorimeter, S. Picard, D. T. Burns and P. Roger, *Rapport BIPM-09/01*.

[17] Picard S, Burns D T, Roger P 2011a The BIPM Graphite Calorimeter Standard for Absorbed Dose to Water, abstract to International Symposium on Standards, Applications and Quality Assurance in Medical Radiation Dosimetry in Standards, Applications and Quality Assurance in Medical Radiation Dosimetry (IDOS), 2010, vol. 1 55-65, Proceedings Series – International Atomic Energy Agency 2011

[18] Determination of the Specific Heat Capacity of a Graphite Sample Using Absolute and Differential Methods, S. Picard, D. T. Burns and P. Roger, *Metrologia* **44** (2007) 294-302.

APPENDIX I: Beam Monitoring Procedure for Accelerator Comparisons

The principle is to use a parallel-plate transmission monitor to determine daily stability and a thimble chamber to provide a reference over the duration of a comparison. Both chambers are supplied by the BIPM. In the following, irradiations of a nominally fixed duration are assumed and all readings are integrals for a given irradiation. All charge readings Q are corrected to a reference air density and for any deviation of relative humidity outside the range from 20 % to 80 %. The BIPM transmission monitor is positioned sufficiently close to the beam exit that the entire beam is measured. Note that when the thimble chamber is used in conjunction with the measurement of D_c, a tungsten block is inserted to avoid heating the calorimeter. It follows that this block must also be in position to provide the same degree of backscatter into the thimble and transmission monitors when used in conjunction with the measurement of Q_c.

i) The first step is to position the BIPM transmission monitor between the exit plane of the accelerator and the calibrated NMI transfer standard in the BIPM water phantom. This gives the monitor dose calibration

$$N_D = D_{w,NMI} / Q_{mon,D} \qquad \text{(AI-1)}$$

where $D_{w,NMI}$ is the dose estimate resulting from the reading of the NMI transfer standard and $Q_{mon,D}$ is the monitor reading for this dose calibration. In practice mean values determined from series of irradiations will be used.

ii) Around the same time the BIPM thimble chamber is positioned on the monitor support, keeping the phantom in place, and a charge calibration of the monitor is determined (the effects of scatter into the monitor from the thimble chamber will cancel, following the procedure). This is defined as the daily charge calibration $f_{Q,day}$ and is given by

$$f_{Q,day} = Q_{thim,day} / Q_{mon,day}. \qquad \text{(AI-2)}$$

where $Q_{thim,day}$ is the thimble chamber reading and $Q_{mon,day}$ is the monitor reading for this reference charge calibration. If time permits, the dependence of $f_{Q,day}$ on the different backscatter from the NMI and BIPM phantoms should be assessed. $D_{w,NMI}$ may hence be expressed as

$$D_{w,NMI} = Q_{mon,D}\ N_D\ (Q_{thim,day} / Q_{mon,day}), \qquad \text{(AI-3)}$$

i.e. the dose measurements are now referenced to the thimble monitor.

iii) On subsequent days (and at least twice per day) the thimble chamber is positioned on the monitor support[3], as in ii), to determine a daily charge calibration of the monitor. For these measurements, the BIPM phantom will remain in place.

iv) Similarly, the dose estimate resulting from the reading of the BIPM transfer standard becomes

[3] The monitor and thimble chamber can be removed if necessary, but need to be positioned reproducibly.

$$D_{\mathrm{w,BIPM}} = Q_{\mathrm{mon},D'} \ N_{D'} \ f_{Q,\mathrm{day}'}, \qquad \text{(AI-4)}$$

where the comparison result R_{NMI} hence may be expressed as

$$R_{\mathrm{NMI}} = \frac{Q_{\mathrm{mon},D} \, N_D \, f_{Q,\mathrm{day}}}{Q_{\mathrm{mon},D'} \, N_{D'} f_{Q,\mathrm{day}'}} \qquad \text{(AI-5)}$$

APPENDIX II: BIPM Determination of Absorbed Dose to Water

A-II.1. The BIPM Graphite Calorimeter

The BIPM has designed and constructed an absorbed dose graphite calorimeter described in detail elsewhere [16, 17]. It consists of a graphite core 45 mm in diameter and 6.7 mm thick placed in a graphite jacket with outer diameter 60 mm. The core is equipped with three thermistor pairs connected to three independent bridges. This core and jacket are placed in a cubic PMMA vacuum phantom with side length 300 mm. The specific heat capacity of the core is determined in a separate apparatus [18]. The absorbed dose in the graphite core can hence be determined by measuring the temperature rise when the calorimeter is exposed to a photon beam.

A-II.2. BIPM Determination of Absorbed Dose to Water

A graphite-walled parallel-plate ionization chamber (similar to the existing BIPM standard for absorbed dose to water) is used as the transfer device from graphite to water. When positioned in the graphite jacket, replacing the core, the calibration coefficient $N_{D,\mathrm{c}}$ for graphite absorbed dose can be written as

$$N_{D,\mathrm{c}} = \frac{D_\mathrm{c}}{Q_\mathrm{c}}, \qquad \text{(AII-1)}$$

,

where D_c is the mean absorbed dose rate to the graphite core and Q_c is the ionization charge. The absorbed dose to water D_w at the reference point in a homogeneous water phantom can be written as

$$D_\mathrm{w} = N_{D,\mathrm{w}} Q_\mathrm{w} k_\mathrm{rn} \ , \qquad \text{(AII-2)}$$

where $N_{D,\mathrm{w}}$ is the transfer chamber calibration coefficient for water, Q_w is the ionization charge measured in water and k_rn repreents the correction for the radial non-uniformity. Through the use of Monte Carlo simulations of the complete graphite and water geometries, $N_{D,\mathrm{w}}$ is obtained using

$$N_{D,\mathrm{w}} = N_{D,\mathrm{c}} \left(\frac{N_{D,\mathrm{w}}}{N_{D,\mathrm{c}}} \right)^{\mathrm{MC}} . \qquad \text{(AII-3)}$$

where MC indicates Monte Carlo simulations of the corresponding parameters (ionization charges are represented in the Monte Carlo calculations by the absorbed dose to the air of the cavity). It follows that

(AII-4a)

$$D_{\mathrm{w}} = D_{\mathrm{c}} \frac{I_{\mathrm{w}}}{I_{\mathrm{c}}} k_{rn} \left(\frac{D_{\mathrm{w}}}{D_{\mathrm{c}}}\right)^{\mathrm{MC}} \left[\left(\frac{I_{\mathrm{w}}}{I_{\mathrm{c}}}\right)^{\mathrm{MC}}\right]^{-1},$$

which may also be expressed as

$$D_{\mathrm{w}} = D_{\mathrm{c}} \frac{I_{\mathrm{w}}}{I_{\mathrm{c}}} k_{\mathrm{rn}} C_{\mathrm{w,c}}. \quad \text{(AII-4b)}$$

Thus, to determine the absorbed dose rate to water using the BIPM graphite calorimeter, three different measurement arrangements must be realized (Figure 1-a, 1-b and 1-c); the corresponding parameters and a simulation of D_{w} (Figure 1-d) have to be determined using Monte Carlo calculations.

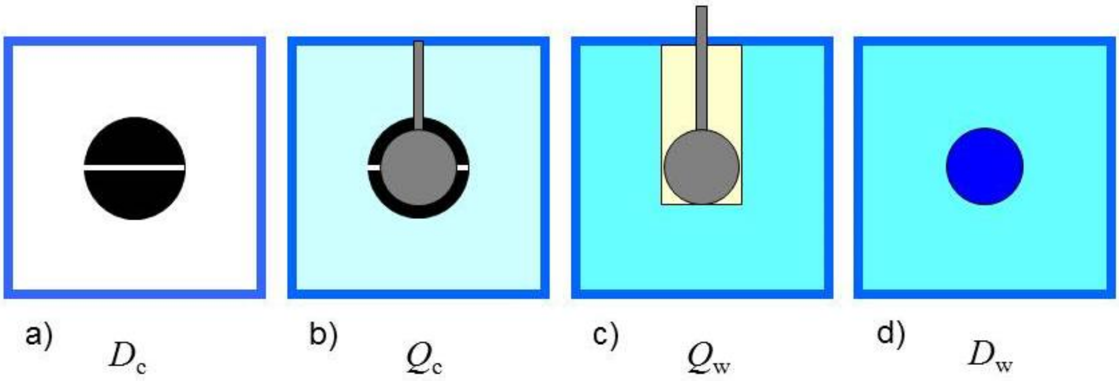

Figure 1. Schematic representation of the three different measurement situations (1-a, 1-b and 1-c) and Monte Carlo models (1-a, 1-b, 1-c and 1-d).

The measurements are all made in the cubic PMMA phantom, here represented by the dark blue square.

a) The calorimeter is used in vacuum, and the jacket containing the core is represented by the sectioned black disc. The absorbed dose rate to graphite, D_{c}, is both measured and calculated.

b) The graphite core is replaced by the transfer ionization chamber and the assembly is at atmospheric pressure. The ionization charge in graphite, Q_{c}, is measured and a corresponding cavity dose rate calculated.

c) The same ionization chamber is placed in a waterproof envelope inside an identical phantom filled with water. The ionization charge in water, Q_{w}, is measured and the corresponding cavity dose rate calculated. The dose rate to water, D_{w}, in the absence of the chamber and envelope is also calculated.

In an accelerator facility, variations in beam intensity cannot be neglected and a reliable beam monitor must be used. The BIPM has purchased a commercial transmission chamber to use in these comparisons as a short-term stability monitor, and is therefore not reliant on the performance of any existing accelerator beam monitor. Furthermore, long-term stability (throughout a given bi-lateral comparison) will be assessed using a thimble ionization chamber in combination with the transmission monitor. A thimble chamber monitor is also provided by the BIPM. This procedure is described in Appendix I.

A-II.3. Determination of Calculated Dose Conversion Factor

Twenty complete determinations of $C_{w,c}$ were generated between 2009 and 2015, plotted as a function of *calculated* $TPR_{20,10}$ in Figure 2 (these are the results re-evaluated for the new chamber envelope adopted in 2013). A quadratic fit to these data, weighted with the statistical uncertainty of each point, shows the deviations to be consistent with the typical statistical standard uncertainty of 5 parts in 10^4. The dose conversion factor for a given comparison is taken to be that corresponding to the *measured* $TPR_{20,10}$ and is obtained from this fit using the following equation:

$$C_{w,c}(TPR_{20,10}) = 1.0534 + 0.0343\ TPR_{20,10} + 0.0968\ (TPR_{20,10})^2 \qquad \text{(AII-5)}$$

The values for $C_{w,c}$ used for the comparison are evaluated from equation (AII-5) and are given in Table 1.

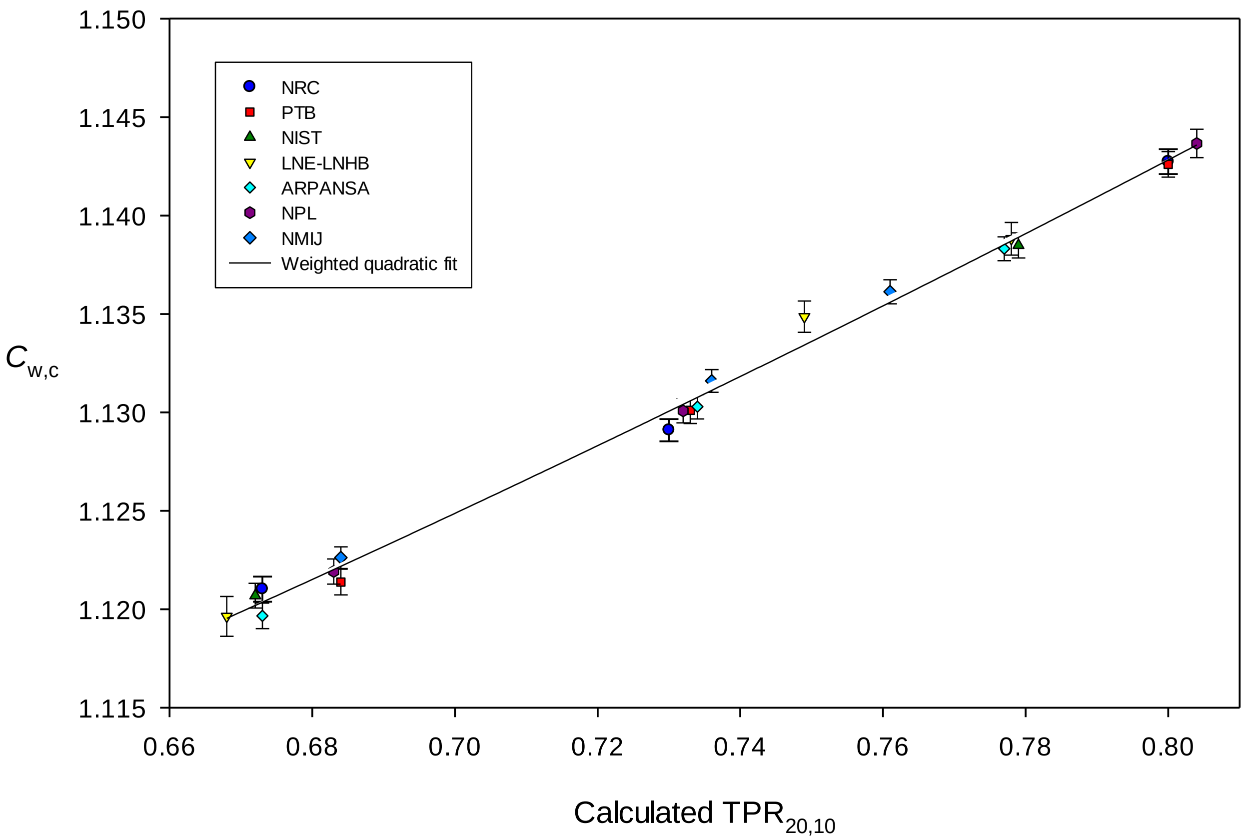

Figure 2. The dose conversion factor $C_{w,c}$ for the BIPM standard, calculated using the phase-space files supplied by participating NMIs. The line is a weighted quadratic fit to the data; the deviations about this line are consistent with the typical statistical uncertainty of 5 parts in 10^4.

APPENDIX III: Request for information and actions before the comparison

The following information will be requested before the comparison (list not exhaustive):

1. Provide a list of equipment describing the item, manufacturer, model, serial number, value (Appendix V).

2. Provide a list of participants (Appendix V).

3. Provide information on

a) the calibration coefficient, associated uncertainty and correction factors for each chamber (Appendix IV);

b) the reference depth used (g/cm^2) and SDD (cm)[4];

c) whether or not a determination at the BIPM facility of the recombination effect is necessary[3];

d) the field size at the reference distance (cm $\times$ cm) (Appendix IV)[3].

[4] By e-mail to the BIPM contact person.

APPENDIX IV

This form shall be completed for each chamber and beam quality and returned to the BIPM contact person.

The form may be downloaded using the following link: https://kcdb.bipm.org/AppendixB/appbresults/BIPM.RI(I)-K6/Information_on_Reference_Chamber_FORM_TP_3.0.docx

Information on reference chamber

NMI			
Manufacturer		**Model**	
S/N		**Calibration date**	

$$D_w = Q\ N_{Dw}\ k_1\ \ k_2\ k_3\ \ldots \qquad \text{(AIV-1)}$$

Expressing the absorbed dose D_w (AIV-1) as a function of charge Q where N_{Dw} is the calibration coefficient and k represent associated correction factors, please give below the value and estimated uncertainty of the calibration coefficient and all associated correction factors.

Information on measured calibration factor and correction factors of reference chamber

parameter	nature of correction	value	uncertainty
Type of beam			N/A
$TPR_{20,10}$			
N_{Dw} (Gy/µC)			
k_1			
k_2			
k_3			
k_4			
k_5			
k_6			
k_7			
k_8			

APPENDIX V: List of equipment and participants

Below is an example for a list of material.

#	Item	Manufacturer	Model	Serial Number	Value (€)
1	Voltmeter	Keithley	2002	123456789	2500
2					
3					

Below is an example for a list of participants.

#	First name	Family name	Nationality	Passport number	Date of birth
1	Michael	Jackson	American	123456789	1 January 2000
2					
3					

APPENDIX VI: Practical details

The measurement will be carried out at the BIPM accelerator facility BAF/DOSEO in Saclay, 17 km south of the BIPM headquarters.

Public buses are available from the RER B station Massy Palaiseau, directly linked to the city of Paris. Several hotels are also available in Massy-Palaiseau, close to the RER station (e.g. Residhome Paris-Massy, Aparthotel Adagio). It is possible to have lunch at the staff restaurant. There is no individual internet connection possible at the reference facility.

The estimated duration for the comparison will depend on the comparison technique and the number of beam qualities required. The official working hours are from 8:30 to 17:00.

D446
Hotel Novotel Paris Saclay
LE CHRIST
D36
D306
N118
Etandex
Commissariat à l'énergie atomique et aux...
CEA Saclay - Porte Est
I.N.S.T.N
Allée Iseult
DOSEO

Paris
Bois de Boulogne
Issy-les-Moulineaux
Sèvres
Clamart
Jouy-en-Josas
Buc
Palaiseau
Aéroport de Paris-Orly
Paray-Vieille-Post
DOSEO