Key comparison BIPM.RI(I)-K1 of the air-kerma standards of the PTB, Germany, and the BIPM in ^{60}Co gamma radiation

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Abstract

A new direct key comparison of the standards for air kerma of the Physikalisch-Technische Bundesanstalt (PTB), Germany, and the Bureau International des Poids et Mesures (BIPM) was carried out in the ^{60}Co radiation beam of the BIPM in February 2024. The comparison result, evaluated as a ratio of the PTB and the BIPM standards for air kerma, is 1.0004 with a combined standard uncertainty of 2.5 parts in 10^3. The results for an indirect comparison made at the same time are consistent with the direct comparison result at the level of 3.4 parts in 10^3. The result of the direct comparison agrees with the direct comparison carried out in 2014 at the level of the combined standard uncertainty, when updated with the changes implemented to the standards at each laboratory. The results are analysed and presented in terms of degrees of equivalence, suitable for entry in the BIPM key comparison database.

1. Introduction

A direct comparison of the standards for air kerma of the Physikalisch-Technische Bundesanstalt (PTB), Germany, and the Bureau International des Poids et Mesures (BIPM) was carried out in February 2024 in the ^{60}Co radiation beam at the BIPM to update the previous comparison result of 2014 (Kessler *et al.* 2014) published in the BIPM key comparison database (KCDB 2026) under the reference BIPM.RI(I)-K1. An indirect comparison was also made using two ionization chambers as transfer instruments.

The comparison was carried out after the implementation of the recommendations of the ICRU Report 90 (ICRU 2016) at both laboratories.

The PTB took part in the direct comparison using a new primary standard that had not been adopted as the national standard at the time of the measurements. The final results were submitted by the PTB in July 2025; however, the publication of this report was deferred until the new primary standard was officially adopted as the national standard in December 2025.

2. Details of the standards and the transfer chambers

At the time of the comparison, the PTB was in the process of adopting a new ^{60}Co air-kerma primary standard, a spherical cavity ionization chamber constructed at the PTW (Freiburg, Germany), identified as PS-10/1. Since December 2025, this standard has replaced the standard used for the previous comparison, which consisted of six graphite-walled cavity ionization chambers, as described by Kessler *et al*. (2014). A detailed description of the new primary standard can be found in Pojtinger and Büermann (2021). The BIPM primary standard, identified as CH6.2, is a graphite-walled parallel-plate cavity ionization chamber described in

Boutillon and Niatel (1973), Burns *et al.* (2007) and Burns and Kessler (2018). The main characteristics of the BIPM primary standard and the new PTB primary standard are given in Table 1. Two cylindrical chambers belonging to the PTB, still considered as part of the national standard for air kerma measurements until the adoption of the new chamber, were used as transfer instruments for the indirect comparison. The transfer chambers were calibrated against the PS-10/1. Their main characteristics are given in Table 2.

Table 1. Characteristics of the BIPM and the PTB standards

Dimensions		BIPM standard CH6.2	PTB standard PS-10/1
Cavity	Diameter / mm	45.01	26.82
	Thickness / mm	5.16	–
	Measuring volume / cm^3	6.8749	10.003
Electrode	Shape	disc	cylindrical
	Diameter / mm	41.03	3
	Thickness / mm	1.005	–
	Height / mm	–	14.45
Wall	Thickness / mm	2.90	3.5
	Material	graphite	graphite
	Density / g cm^{-3}	1.85	1.84
Voltage applied to outer electrode / V		± 80	± 500

Table 2. Characteristics of the PTB transfer chambers

Nominal values		PTB HRK2-1	PTB HRK2-2
Chamber	Outer diameter / mm	14	
	Outer length / mm	24	
Electrode	Diameter / mm	2	
	Length / mm	16	
Cavity	Nominal volume / cm^3	1.5190	1.5157
Wall*	Thickness / mm	2	
	Material	Graphite	
	Density / g cm^{-3}	1.775	
Voltage applied to outer electrode / V		+ 200	

* build-up cap of thickness 1 mm was used

3. Determination of the air kerma

For a cavity chamber with measuring volume V, the air-kerma rate is determined by the relation

$$\dot{K} = \frac{I}{\rho_{\mathrm{air}} V} \frac{W}{e} \frac{1}{1-\bar{g}} \left(\frac{\mu_{\mathrm{en}}}{\rho}\right)_{\mathrm{a,c}} \bar{s}_{\mathrm{c,a}} \prod k_i \qquad (1)$$

where

ρ_{air} is the density of air under reference conditions,

I is the ionization current under the same conditions,

W is the average energy spent by an electron of charge e to produce an ion pair in dry air,

$\bar{g}$ is the fraction of electron energy lost by bremsstrahlung production in air,

$(\mu_{en}/\rho)_{a,c}$ is the ratio of the mean mass energy-absorption coefficients of air and graphite,

$\bar{s}_{c,a}$ is the ratio of the mean mass stopping powers of graphite and air,

$\prod k_i$ is the product of the correction factors to be applied to the standard.

Physical data and correction factors

The values used for the physical constants, the correction factors, the volume of the primary standards entered into equation (1) and the associated uncertainties for the BIPM ^{60}Co radiation beam are given in Table 3.

Table 3. Physical constants, correction factors and relative standard uncertainty components of the BIPM and PTB standards for the ^{60}Co radiation beam at the BIPM

		BIPM CH6.2			PTB PS-10/1		
		values	uncertainty(1)		values	uncertainty(1)	
			100 u_{iA}	100 u_{iB}		100 u_{iA}	100 u_{iB}
Physical Constants							
ρ_{air}	dry air density(2) / kg m^{-3}	1.2930	–	0.01	1.2930	–	0.01
$(\mu_{en}/\rho)_{a,c}$	ratio of mass energy-absorption coefficients	0.9989	0.01	0.04	0.9988	–	0.05
$s_{c,a}$	ratio of mass stopping powers	0.9928	–	0.08(3,4)	0.9945	–	0.08(3)
W/e	mean energy per charge / J C^{-1}	33.97			33.97		
$\bar{g}$	fraction of energy lost in radiative processes	0.0031	–	0.02	0.0032	–	0.02
Correction factors and uncertainty components							
k_h	relative humidity	0.9970	–	0.03	0.9970	–	0.03
k_g	re-absorption of radiative loss	0.9996	–	0.01	–	–	–
k_s	recombination losses	1.0019	0.01	0.02	1.0031(6)	–	0.04
k_{st}	stem scattering	1.0000	0.01	–	0.9982	0.02	0.05
k_{wall}	wall attenuation and scattering	1.0011	–	– (5)	1.0241	0.02	0.15
k_{an}	axial non-uniformity	1.0020	–	– (5)	1.0000	0.02	0.05
k_{rn}	radial non-uniformity	1.0015	–	0.02	1.0003(6)	–	0.02
k_{sa}	Spencer-Attix correction	–	–	–	0.9997	0.02	0.10
Measurement of *I* / *V*							
V	chamber volume / cm^3	6.8749	–	0.08(5)	10.003	0.08	0.10
I	ionization current / pA	–	0.01	0.02	–	0.01	0.02
Relative standard uncertainty							
quadratic summation			0.02	0.13		0.09	0.25
combined uncertainty			**0.13**			**0.26**(6)	

(1) Expressed as one standard deviation

u_{iA} represents the type A relative standard uncertainty estimated by statistical methods,

u_{iB} represents the type B relative standard uncertainty estimated by other means

(2) At 101.325 kPa and 273.15 K at the BIPM (traditionally, the BIPM corrects the current measured using primary standards to these conditions of P and T)

(3) Combined uncertainty for the product of $s_{c,a}$ and W/e adopted from ICRU Report 90 recommendations (ICRU 2016)

(4) Adopted from January 2019 (Burns and Kessler 2018)

(5) The uncertainties for k_{wall} and k_{an} are included in the determination of the effective volume (Burns *et al.* 2007)

(6) At the PTB, k_s = 1.0095 (4), k_{rn} = 1.0000 (20) and the relative combined standard uncertainty is 0.33

For the PS-10/1, these values were provided by the PTB (Pojtinger and Büermann 2021). The ion recombination and radial non-uniformity correction factors were evaluated for the BIPM beam. For the BIPM standard, these values are given in Kessler and Burns (2024).

Reference conditions and beam characteristics

The reference conditions for the air-kerma determination at the BIPM (Kessler and Burns 2024) and at the PTB are the following:

– the distance from source to reference plane is 1 m,
– the field size in air at the reference plane is 10 cm × 10 cm, defined by the photon fluence rate at the centre of each side of the square being 50 % of the photon fluence rate at the centre of the square.

The characteristics of the BIPM and PTB beams are given in Table 4.

Table 4. Characteristics of the ^{60}Co beams at the PTB and the BIPM

^{60}Co beam	Nominal $\dot{K}$ / mGy s^{-1}	Source dimensions / mm		Scatter contribution in terms of energy fluence	Field size at 1 m
		diameter	length		
PTB	12.9	23.6	36.9	– [a]	10 cm × 10 cm
BIPM Theratron 1000	3.8	20	14	21 %	10 cm × 10 cm

[a] Not determined

Reference values

The BIPM reference air-kerma rate, $\dot{K}_{\text{BIPM}}$, is taken as the mean of the four measurements made around the period of the comparison. The $\dot{K}_{\text{BIPM}}$ values refer to an evacuated path length between source and standard, corrected to the reference date of 2024-01-01, 0 h UTC. The correction for air attenuation between source and standard used the ambient air density at the time of the measurement and the air attenuation coefficient 0.0078 m^{-1} for ^{60}Co. The half-life of ^{60}Co used for the decay correction was taken as 1925.21 days (u = 0.29 days) (Bé *et al.* 2006). At the PTB, no air attenuation correction was applied and the reference value $\dot{K}_{\text{PTB}}$ is given at the reference date of 2024-01-11, 10:30 h UTC using the same half-life value for the decay correction.

4. Experimental method

The BIPM and the PTB experimental method for measurements is described in the following paragraphs.

Positioning

At each laboratory the standard and the transfer chambers were positioned with the stem perpendicular to the beam direction and with the appropriate marking on the stem facing the source.

Applied voltage and polarity

A collecting voltage of 500 V (both polarities) and 200 V (positive polarity) was applied to the outer electrode of the PTB standard and the transfer chambers, respectively, at least 40 min before any measurements were made.

Charge and leakage measurements

The charge Q collected by the PTB standard and transfer chambers was measured at the BIPM using a Keithley electrometer model 642. The source was exposed during the entire measurement series and the charge was collected for the appropriate, electronically controlled, time interval. A pre-irradiation was made for at least 40 min before any measurements (~10 Gy). The measurements were corrected by the mean leakage current measured before and after each series of measurements. The leakage correction, estimated as the ratio of the leakage current relative to the ionization current, was less than 1 part in 10^4 for all the chambers.

At the PTB, a pre-irradiation was made for 40 min before any measurements. The ionization current I was measured using a Keithley electrometer model 616. The relative leakage correction for each chamber was less than 1 part in 10^4.

Radial non-uniformity correction

At the BIPM, the correction applied for the radial non-uniformity of the beam for the PTB standard was 1.0003; for the transfer chambers the correction was estimated to be 2 parts in 10^4 and a similar correction at the PTB. No radial non-uniformity correction was applied to the current measured using the transfer chambers and a relative uncertainty component of 2 parts in 10^4 is included in Table 11.

Ion recombination

Primary standard. At the time of the comparison, the PTB assumed that the ion recombination correction for the primary standard was dominated by the initial component providing a correction of 1.0010 (7).

Ion recombination was determined at the BIPM during the comparison period using the Niatel method, as described in Boutillon (1998), demonstrating that volume recombination was not negligible, as assumed by the PTB. After the comparison, the PTB determined ion recombination using the same method. The initial and volume recombination components determined at both laboratories are presented in Table 5, including the ion recombination correction calculated for the currents measured at each laboratory using both determinations.

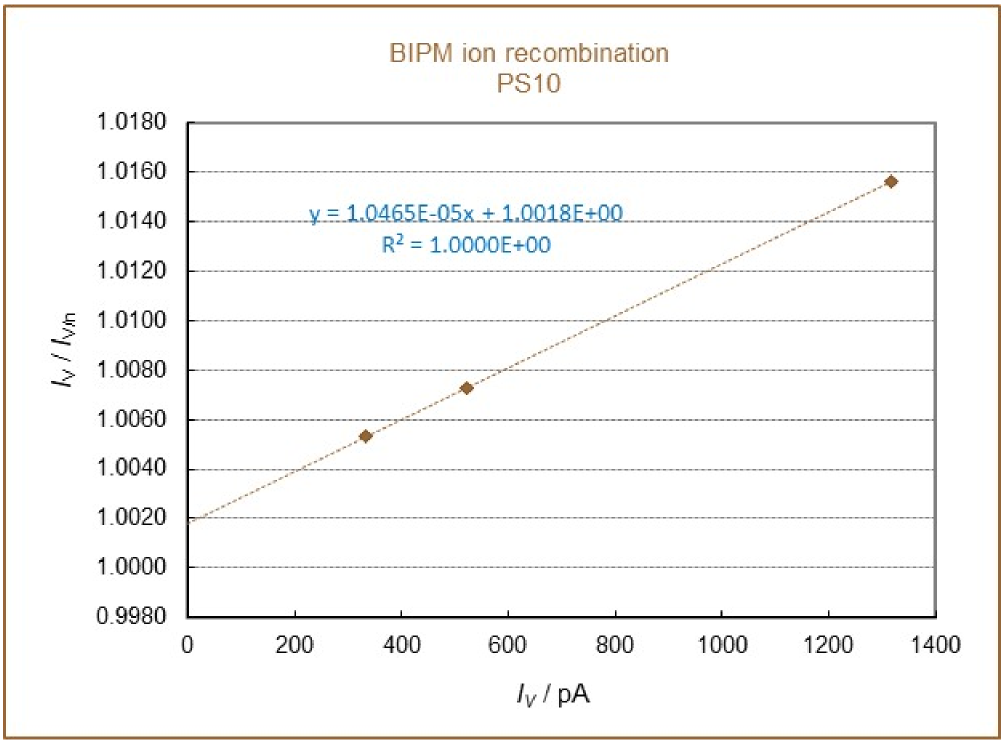
Table 5. Ion recombination correction for the PS-10/1 primary standard

Ion recombination determined at each laboratory	PTB pre-BIPM	BIPM	PTB post-BIPM
Initial recombination and diffusion, k_{init}	1.0×10^{-3}	1.21×10^{-3}	4.39×10^{-4}
Volume recombination factor, k_{vol} / pA	–	1.99×10^{-6}	2.03×10^{-6}
k_s for $I = 1.3 \times 10^3$ pA (BIPM beam)	1.0010	1.0038	1.0031
k_s for $I = 4.5 \times 10^3$ pA (PTB beam)	1.0010	1.0102	1.0096
Relative standard uncertainty	7×10^{-4}	2×10^{-4}	4×10^{-4}

The final PTB results agree with the BIPM determination at the level of 7 parts in 10^4. The ion recombination correction determined by the PTB was used to calculate $\dot{K}_{PTB}$. A graphical representation of the method with the BIPM results is shown in Figure 1.

Transfer chambers. The PTB determined also the ion recombination for the transfer instruments used for the indirect comparison. The results showed that the correction is only due to initial recombination. No ion recombination correction was applied to the currents measured using the transfer chambers and a relative standard uncertainty of 2 parts in 10^4 is included in Table 11.

Figure 1. Graphical representation of the ion recombination method



Plot of ratio of currents at two polarizing voltages (V = 500 V and V / n = 200 V) vs current at the working polarizing voltage 500 V. A linear fit is used to evaluate the initial and volume recombination for the PS-10/1

Ambient conditions

During a series of measurements, the air temperature was measured for each current measurement and was stable to better than 0.05 °C at the BIPM. At the PTB, the air temperature was also measured for each current measurement and was stable to better than 0.3 °C. At the BIPM the current measured using the primary standard is corrected to 273.15 K and 101.325 kPa. For the transfer chambers, the calibration coefficients are normalized at both laboratories to the reference conditions of 293.15 K and 101.325 kPa.

At the BIPM, the relative humidity is controlled in the range from 45 % to 55 %. At the PTB, relative humidity is controlled in the range from 30 % to 70 %; no correction for humidity was applied to the ionization current measured.

5. Results of the comparison

Direct comparison

The PTB primary standard was set-up and measured in the BIPM ^{60}Co beam on two separate occasions. The results were reproducible to better than 1 part in 10^4. The values of the ionization currents measured by the BIPM using the PTB standard are given in Table 6.

The result of the direct comparison, R_K , is expressed in the form

$$R_K = \dot{K}_{\mathrm{PTB}}/\dot{K}_{\mathrm{BIPM}} \qquad (2)$$

where $\dot{K}_{\mathrm{PTB}}$ and $\dot{K}_{\mathrm{BIPM}}$ are the kerma rate values measured by the BIPM using the PTB PS-10/1 and the BIPM CH6.2 primary standards, respectively; the results are presented in Table 7.

Table 6. The experimental results using the PTB standard in the BIPM beam

PTB standard	I_+ and I_- / pA		I_{mean} / pA
PS-10/1	1424.39	-1424.21	1424.30
	1424.51	-1424.08	1424.30
Mean current			1424.30

Table 7. Final result of the PTB/BIPM comparison of standards for ^{60}Co air kerma

Direct comparison PS-10/1 and CH6.2	$\dot{K}_{PTB}$ / µGy s^{-1}	$\dot{K}_{BIPM}$ / µGy s^{-1}	R_K	u_c
	3.8112	3.8096	1.0004	0.0025

Note that at the time of the comparison, using the value 1.0010 informed by the PTB for the ion recombination correction, the comparison result was 0.9983.

The combined standard uncertainty u_c for the comparison result R_K is presented in Table 8.

The ratio of the air kerma rate values determined by the BIPM using the PTB and the BIPM standards is 1.0004 with a combined standard uncertainty u_c of 0.0025. Some of the uncertainties in $\dot{K}$ that appear in both the BIPM and the PTB determinations (such as air density, *W/e*, μ_{en}/ρ, $\bar{g}$, $\bar{s}_{c,a}$ and k_h) cancel each other when evaluating the uncertainty of R_K.

Table 8. Uncertainties associated with the comparison result

Relative standard uncertainty	100 u_{iA}	100 u_{iB}
$\dot{K}_{PTB}/\dot{K}_{BIPM}$	0.09	0.24$^{(1)}$
Combined standard uncertainty of R_K	u_c = 0.0025	

(1) Takes account of correlation in type B uncertainties.

Indirect comparison

The transfer chambers were set up and measured in the BIPM ^{60}Co beam on two separate occasions. The results were reproducible to around 2 parts in 10^4. The result of the indirect comparison is evaluated as the ratio of the calibration coefficients $N_{K,lab}$ determined at each laboratory. The calibration coefficient is given by

$$N_{K,\text{lab}} = \dot{K}_{\text{lab}}/I_{\text{lab}} \tag{3}$$

where $\dot{K}_{lab}$ is the air kerma rate at each lab and I_{lab} is the ionization current of a transfer chamber measured at each laboratory. Table 9 lists the relevant values of N_K at the stated reference conditions (293.15 K and 101.325 kPa) and the final results $N_{K,\text{PTB}}/N_{K,\text{BIPM}}$ of the indirect comparison. The uncertainties associated with the calibration of the transfer chambers at each laboratory and with the indirect comparison are presented in Table 10 and Table 11, respectively.

As mentioned in the paragraph on ion recombination in Section 4, the PTB assumed that the loss of charges due to recombination for the primary standard PS-10/1 was dominated by the initial component, a correction of 1 part in 10^3 included in the determination of the air kerma rate $\dot{K}_{\text{PTB}}$. After re-evaluating this factor, a correction of 9 parts in 10^3 was introduced in equation (1), representing a change of 8 parts in 10^3 in the air kerma rate determination, and thus, in the calibration coefficients N_K. The values $N_{K,\mathrm{PTB}}$ provided by the PTB at the time of the comparisons are also included in Table 9.

The revised calibration coefficients measured before and after the measurements at the BIPM give rise to a relative standard deviation for each chamber, whose root mean squared (rms) value is taken as a representation of the stability of the transfer instruments. The short-term stability was estimated to be 2 parts in 10^3. Table 11 includes a component of 1 part in 10^4 for the difference in the comparison results between the two transfer chambers.

Table 9. Results of the indirect comparison

Transfer chamber	$N_{K,\mathrm{PTB}}$/ Gy µC^{-1}				$N_{K,\mathrm{BIPM}}$ / Gy µC^{-1}	R_K	u_c
	pre-BIPM	Revised pre-BIPM	post-BIPM	overall mean			
HRK2-1	18.57	18.72	18.68	18.70	18.63	1.0038	0.0039
HRK2-2	18.60	18.76	18.70	18.73	18.66	1.0038	0.0039
					Mean value	1.0038	0.0039

Table 10. Uncertainties associated with the transfer chamber calibration

	BIPM		PTB	
Relative standard uncertainty	100 u_{iA}	100 u_{iB}	100 u_{iA}	100 u_{iB}
Air-kerma rate	0.02	0.13	0.09	0.32
Ionization current	0.01	0.02	0.01	0.02
Source to Detector Distance	0.01	–	0.01	–
Reproducibility	0.02	–	–	–
Air density	–	–	0.04	–
Decay correction	–	–	–	0.01
$N_{K,\mathrm{lab}}$	0.03	0.13	0.10	0.32

Table 11. Uncertainties associated with the indirect comparison

Relative standard uncertainty	100 u_{iA}	100 u_{iB}
$N_{K,\mathrm{PTB}}$ / $N_{K,\mathrm{BIPM}}$ [(1)]	0.10	0.31
Ion recombination	–	0.02
Radial non-uniformity	–	0.02
Stability of the chambers	0.20	–
Different chambers	0.01	–
Combined standard uncertainty of R_K	u_c = 0.0039	

(1) The combined standard uncertainty u_c of the comparison result R_K takes into account correlation in the type B uncertainties in the determination of the air kerma rate associated with the physical constants and the humidity correction

The mean ratio of the air-kerma calibration coefficients of the transfer chambers determined by the PTB and the BIPM taken from Table 9 is 1.0038 with a combined standard uncertainty u_c of 0.0039.

Discussion about the direct and indirect comparisons

The previous comparison run in 2014 was done using four primary standards, two HRK3 chambers and the two HRK2 chambers that were used as transfer instruments for the present indirect comparison. However, it is possible to do primary determinations of air kerma, $\dot{K}_{\mathrm{PTB}}$ using the HRK2 chambers and compare with the BIPM reference value $\dot{K}_{\mathrm{BIPM}}$. The individual comparison results using the HRK2 chambers are summarized in Table 12, updated with the changes adopted by each laboratory since 2014.

Table 12. Results using the HRK2 chambers as primary standards

Direct comparison	$\dot{K}_{\mathrm{PTB}}/\dot{K}_{\mathrm{BIPM}}$ (1)	
	2014 (1)	2024
HRK2-1	1.0024	1.0016
HRK2-2	1.0029	1.0020
Mean values	1.0026(17)	1.0018(17)

(1) For this analysis, the PTB and BIPM results were decreased by 0.9916 and 0.9918, respectively, to consider the adoption of the ICRU 90 recommendations; uncertainties were evaluated using the data for the HRK2 standards described in Kessler *et al*. (2014)

It can be seen from Table 12 that the 2014 and 2024 comparison results agree at the level of 8 parts in 10^4, within the combined standard uncertainty of 1.7 parts in 10^3. Using the HRK chambers as primary standards, the direct comparison result would be 1.0018 (17), in agreement at the level of 1.4 parts in 10^3 with the direct comparison result of 1.0004 (25) using the PS10/1.

At the PTB, the determinations of air kerma using the PS10/1 and the six HRK chambers (mean value) agree at the level of 8 parts in 10^4.

As mentioned in Section 2, the HRK2 chambers were calibrated against the PS-10/1 and the calibration coefficients determined at each laboratory give an indirect comparison result of 1.0038 (39), as presented in Table 9.

The direct and indirect comparison results agree at the level of 3.4 parts in 10^3, which is within the expanded uncertainty when all the correlations are taken into account. No other explanation than the calibration process itself was found to describe the discrepancy between both results.

6. Degrees of equivalence

Following a decision of the CCRI(I), the BIPM determination of the dosimetric quantity, here K_{BIPM}, is taken as the key comparison reference value (KCRV) (Allisy *et al.* 2009). It follows that for each NMI, *i*, having a BIPM comparison result x_i with combined standard uncertainty u_i, the degree of equivalence with respect to the reference value is the relative difference $D_i = (K_i - K_{\mathrm{BIPM},i}) / K_{\mathrm{BIPM},i} = x_i - 1$ and its expanded uncertainty $U_i = 2\, u_i$.
The results for D_i and U_i are usually expressed in mGy/Gy. Table 13 gives the values for D_i and U_i for each NMI, *i*, taken from the KCDB of the CIPM MRA (1999) and this report. These data are presented graphically in Figure 2.

Table 13. **Degrees of equivalence**

For each laboratory i, the degree of equivalence with respect to the key comparison reference value is the difference D_i and its expanded uncertainty U_i. Tables formatted as they appear in the BIPM key comparison database

BIPM.RI(I)-K1

Lab i	D_i	U_i
	/ (mGy / Gy)	
ININ	3.5	4.2
LNE-LNHB	-0.6	3.6
ENEA-INMRI	-0.1	4.4
NIM	-0.3	5.4
IST/ITN	2.6	3.4
SCK-CEN	2.1	5.2
SMU	4.2	5.4
NPL	-0.4	6.0
VSL	-3.4	4.2
BEV	3.0	5.0
GUM	3.9	6.0
ARPANSA	-1.4	5.4
NRC	2.2	4.4
BFKH	2.9	4.4
NMIJ	1.3	4.4
KRISS	0.6	3.6
NIST	4.4	6.8
PTB	0.4	5.0

APMP.RI(I)-K1.1 (2009 to 2012)

Lab i	D_i	U_i
	/ (mGy / Gy)	
DMSC	-4.5	8.8
NIS	-12.1	15.0

EURAMET.RI(I)-K1.1 (2013-2015)

Lab i	D_i	U_i
	/ (mGy / Gy)	
METAS	0.1	10.5

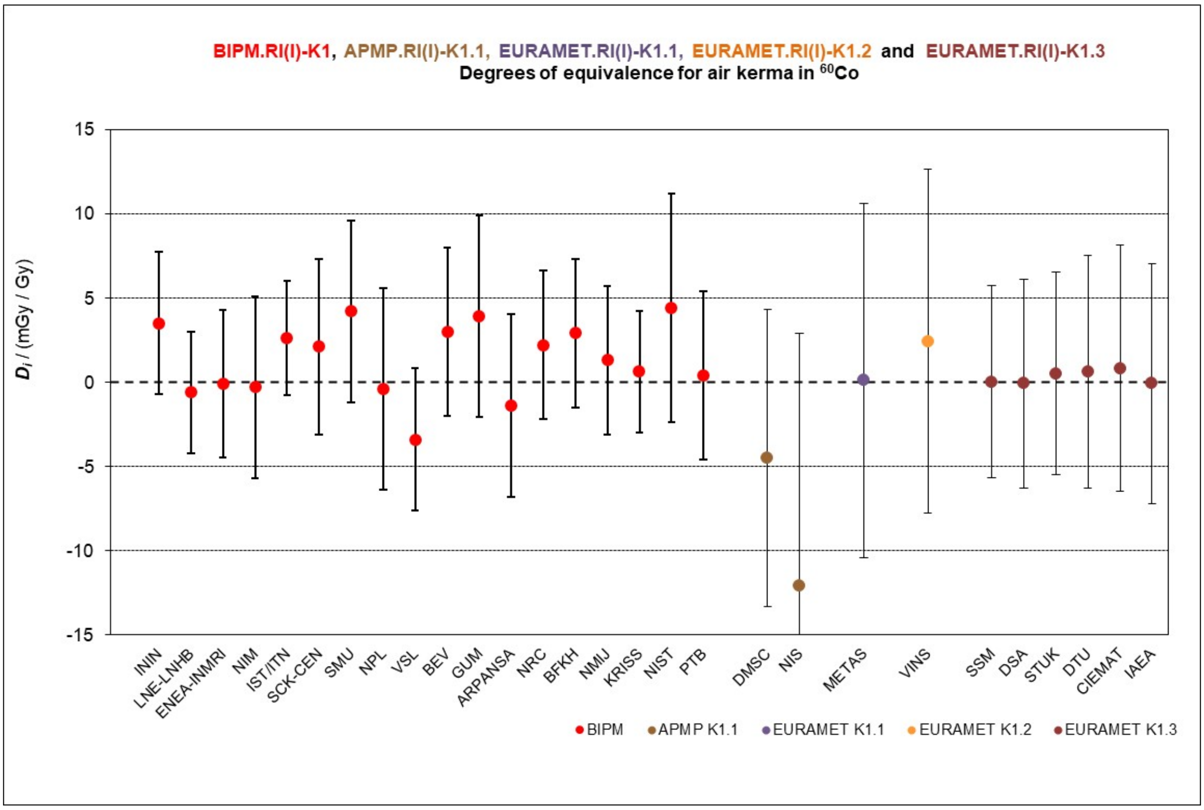
EURAMET.RI(I)-K1.2 (2017)

Lab i	D_i	U_i
	/ (mGy / Gy)	
VINS	2.4	10.2

EURAMET.RI(I)-K1.3 (2022)

Lab i	D_i	U_i
	/ (mGy / Gy)	
SSM	0.0	5.7
DSA	-0.1	6.2
STUK	0.5	6.0
DTU	0.6	6.9
CIEMAT	0.8	7.3
IAEA	-0.1	7.1

Figure 2. **Graph of degrees of equivalence with the KCRV**



Note that the data presented in Table 13, while correct at the time of publication of the present report, becomes out-of-date as NMIs make new comparisons. In addition, revised validity rules for comparison data have been agreed by the CCRI(I) so that any results older than 15 years are no longer considered valid and are removed from the KCDB. The formal results under the CIPM MRA are those available in the key comparison database.

7. Conclusion

The result of the direct comparison of the air-kerma standards for ^{60}Co gamma radiation of the PTB and the BIPM is 1.0004 (25), in agreement within the expanded uncertainties with the result of the indirect comparison of 1.0038 (39).

The previous comparison of the air-kerma standards for ^{60}Co gamma radiation of the PTB and the BIPM was made directly in 2014 using four primary standards, two HRK3 chambers and the two HRK2 used for the present indirect comparison. The comparison result evaluated as the mean of the four individual results was 1.0036 (17). Since the previous comparison, both laboratories implemented some changes in the standards following the recommendations of the ICRU 90. For the PTB and for the BIPM, this resulted in a reduction of 8.4 parts in 10^3 and 8.2 parts in 10^3 in the determination of air kerma, respectively. Adopting these changes, the 2014 comparison result becomes 1.0034 (17), in close agreement with the indirect comparison result of 1.0038 (39) and in agreement within the uncertainties with the result of the direct comparison.

The new PTB primary standard PS-10/1 agrees within the expanded uncertainty with all the NMIs having taken part in the BIPM.RI(I)-K1 ongoing key comparison for air-kerma standards in ^{60}Co gamma-ray beams.

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