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of the OMH and the BIPM for ^{60}Co gamma radiation

C. Kessler, P. Roger, D.T. Burns, P.J. Allisy
BIPM

G. Machula, I. Csete
OMH

H. Rabus
PTB

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Pavillon de Breteuil, F-92312 SEVRES cedex

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C. Kessler, P. Roger, D.T. Burns, P.J. Allisy
Bureau International des Poids et Mesures, F-92312 Sèvres Cedex

G. Machula, I. Csete
Országos Mérésügyi Hivatal, Budapest, Hungary

H. Rabus
Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Abstract

A direct comparison between the standards for air kerma of the Országos Mérésügyi Hivatal (OMH) and of the Bureau International des Poids et Mesures (BIPM) has been carried out in the ^{60}Co radiation beams of the BIPM. The result, expressed as a ratio of the OMH and the BIPM standards for air kerma, indicates a relative difference of 10.9×10^{-3} with a combined standard uncertainty of 2.2×10^{-3}. This new result agrees at the level of 0.4×10^{-3} with the earlier direct comparisons performed in 1986 and 1994, as modified in 2001 by the application of wall and axial non-uniformity correction factors, calculated for the OMH standards using the Monte Carlo method.

1. Introduction

A third direct comparison of the standards for air kerma of the Országos Mérésügyi Hivatal (OMH), Budapest, Hungary, and of the Bureau International des Poids et Mesures (BIPM), has been carried out in the ^{60}Co radiation beams at the BIPM.

The standard for air kerma of the OMH is a set of three nominally identical cavity ionization chambers constructed at that laboratory (type ND 1005, serial numbers 7707, 7708 and 7714) in 1977. Their main characteristics are given in Table 1, the small differences in volume coming from their assembly. The standard of the BIPM is a parallel-plate graphite-walled cavity ionization chamber described in [1].

The comparison took place at the BIPM in January 2006. The standards for air kerma had been compared previously at the BIPM in 1986, using only the OMH chamber with serial number 7707, and in 1994, using only serial number 7714 [2]. The present comparison is the first time that the complete set of three chambers has been measured at the BIPM.

Table 1. The main dimensions and characteristics of the OMH cavity standards

Type and serial number	**ND1005-7707**	**ND1005-7708**	**ND1005-7714**
Chamber Dimensions* / mm			
outer height	19	19	19
outer diameter	19	19	19
inner height	11	11	11
inner diameter	11	11	11
wall thickness	4	4	4
Electrode Dimensions / mm			
Diameter	2	2	2
Height	8.97	8.97	8.97
Volume of air cavity / cm^3	1.0182	1.0227	1.0219
Wall material	Ultra-pure graphite EK51 Ringsdorf (impurities less than 1.5×10^{-4})		
Wall density / g cm^{-3}	1.75	1.75	1.75
Insulators	PTFE (Teflon)	PTFE (Teflon)	PTFE (Teflon)
Applied voltage (both polarities)	250 V	250 V	250 V

* major dimensions machined with a tolerance of 3 µm.

2. Determination of air kerma

The air kerma rate is determined by

$$\dot{K} = \frac{I}{m}\frac{W}{e}\frac{1}{1-\bar{g}}\left(\frac{\mu_{\text{en}}}{\rho}\right)_{a,c}\bar{s}_{c,a}\Pi k_i \quad , \tag{1}$$

where

I is the ionization current measured for the mass m of air in the cavity,

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 in bremsstrahlung production in air,

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

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

$\prod k_i$ is the product of the correction factors to be applied to the standard
$= k_{\text{s}}\, k_{\text{h}}\, k_{\text{st}}\, k_{\text{sc}}\, k_{\text{at}}\, k_{\text{CEP}}\, k_{\text{an}}\, k_{\text{m}}$ for the BIPM standard
$= k_{\text{s}}\, k_{\text{h}}\, k_{\text{st}}\, k_{\text{wall}}\, k_{\text{an}}\, k_{\text{rn}}$ for the OMH standard

The values for the physical data used in (1) are consistent with the CCEMRI(I) 1985 recommendations [3] and the correction factors needed for ^{60}Co radiation are given in Tables 2 and 3 for the OMH and BIPM standards, respectively, together with their associated uncertainties.

Table 2. Physical constants and correction factors with their estimated relative uncertainties of the OMH standards for the two ^{60}Co gamma radiation beams at the BIPM

OMH standards		^{60}Co (Picker beam)			^{60}Co (CISBio beam)		
		values	uncertainty[1]		values	uncertainty[1]	
			100 s_i	100 u_i		100 s_i	100 u_i
Physical Constants							
ρ_0	dry air density[2] / kg m^{-3}	1.2930		0.01	1.2930		0.01
$(\mu_{en}/\rho)_{a,c}$		0.9985		0.05	0.9985		0.05
$\bar{s}_{c,a}$		1.0007		0.11[3]	1.0007		0.11[3]
W/e	J/C	33.97			33.97		
$\bar{g}$	bremsstrahlung loss	0.0032		0.02	0.0032		0.02
Correction factors:							
k_s	recombination losses[4]	1.0020	0.01	0.01	1.0022	0.01	0.01
k_h	humidity	0.9970		0.03	0.9970		0.03
k_{st}	stem scattering	0.9998	0.05		0.9998	0.05	
k_{wall}	wall effects	1.0216	0.01	0.07	1.0216	0.01	0.07
k_{an}	axial non-uniformity	0.9998	0.04	0.08	0.9998	0.04	0.08
k_{rn}	radial beam non-uniformity[5]	1.0003		0.01	1.0002		0.01
V	chamber volume / cm^3	[6]	0.10	0.05	[6]	0.10	0.05
I	ionization current / pA		0.01	0.05		0.01	0.05
Relative standard uncertainty							
quadratic summation			0.12	0.18		0.12	0.18
combined uncertainty			**0.22**			**0.22**	
Relative standard uncertainty neglecting contributions from physical constants and k_h							
quadratic summation			0.12	0.13		0.12	0.13
combined uncertainty			**0.18**			**0.18**	

(1) Expressed as one standard deviation
s_i represents the relative standard uncertainty estimated by statistical methods, Type A
u_i represents the relative standard uncertainty estimated by other means, Type B.

(2) At 101 325 Pa and 273.15 K.

(3) Combined uncertainty for the product of $\bar{s}_{c,a}$ and W/e.

(4) Measured at the BIPM; at the OMH, the value 1.0020 (6) is used, see Table 5 for details of the source.

(5) Evaluated for the BIPM beams; at the OMH, a value of 1.0002 (5) is used.

(6) See Table 1 for the volume of each standard.

Table 3. Physical constants and correction factors with their estimated relative uncertainties of the BIPM standard for the two ^{60}Co gamma radiation beams at the BIPM

BIPM standard		^{60}Co (Picker beam)			^{60}Co (CISBio beam)		
		values	uncertainty(1)		values	uncertainty(1)	
			$100\ s_i$	$100\ u_i$		$100\ s_i$	$100\ u_i$
Physical Constants							
ρ_0	dry air density(2) / kg m^{-3}	1.2930		0.01	1.2930		0.01
$(\mu_{en}/\rho)_{a,c}$		0.9985		0.05	0.9985		0.05
$\bar{s}_{c,a}$		1.0010		0.11(3)	1.0010		0.11(3)
W/e	J/C	33.97			33.97		
$\bar{g}$	bremsstrahlung loss	0.0032		0.02	0.0032		0.02
Correction factors:							
k_s	recombination losses	1.0015	0.01	0.01	1.0018	0.01	0.01
k_h	humidity	0.9970		0.03	0.9970		0.03
k_{st}	stem scattering	1.0000	0.01		1.0000	0.01	
k_{at}	wall attenuation	1.0398	0.01	0.04	1.0398	0.01	0.04
k_{sc}	wall scattering	0.9720	0.01	0.07	0.9720	0.01	0.07
k_{cep}	mean origin of electrons	0.9922		0.01	0.9922		0.01
k_{an}	axial non-uniformity	0.9964		0.07	0.9964		0.07
k_{rn}	radial non-uniformity	1.0016	0.01	0.02	1.0015	0.01	0.02
V	CH5-1 chamber volume / cm^3	6.8028	0.01	0.03	6.8028	0.01	0.03
I	ionization current / pA		0.01	0.02		0.01	0.02
Relative standard uncertainty							
quadratic summation			0.02	0.17		0.02	0.17
combined uncertainty			**0.17**			**0.17**	
Relative standard uncertainty neglecting contributions from physical constants and k_h							
quadratic summation			0.02	0.12		0.02	0.12
combined uncertainty			**0.12**			**0.12**	

(1) Expressed as one standard deviation
s_i represents the relative standard uncertainty estimated by statistical methods, Type A
u_i represents the relative standard uncertainty estimated by other means, Type B

(2) At 101 325 Pa and 273.15 K

(3) Combined uncertainty for the product of $\bar{s}_{c,a}$ and W/e

3. The OMH air kerma standards

The OMH produced its set of three primary ionization chamber standards in 1977. Their history has indicated a consistent and stable set of standards not just by comparison at the BIPM in 1986 and 1994 [2], but also in recent bilateral comparisons of primary standards with the SZMDM (Serbia and Montenegro) in 1999 and the PTB (Germany) in 2000 [4, 5].

In 2001, the OMH re-evaluated the corrections applied to their standards, particularly with respect to the effects concerning the graphite walls [6]. Monte Carlo (MC) calculations made by the PTB were adopted by the OMH in preference to their previous use of the extrapolation method using graphite caps added to the standard. These new results were presented to the CCRI in 2001 and accepted as the revised evaluation for air kerma in ^{60}Co gamma radiation for the OMH [7]. However, the data in Table 2 for the wall and axial non-uniformity corrections are those calculated more recently taking into account the new source dimension and collimator geometry. These calculations are described in the next section. The new data agree within the statistical uncertainties with those calculated by the BIPM for this type of chamber using the MC code PENELOPE [8].

4. Calculations of wall and axial non-uniformity correction factors for the OMH standards

The correction factors for wall effects, k_{wall} and for axial non-uniformity, k_{an}, have been derived from Monte Carlo calculations carried out with the *cavrznrc* [9] package of the *EGSnrc* code system [10]. Each calculation comprised 10^9 primary photons so as to achieve a target numerical statistical uncertainty of 0.03 % for the calculated dose deposited in the cavity. Particle histories were followed down to 10 keV kinetic energy for electrons and to 1 keV for photons. Simulations have been carried out for three different source geometries, i.e. a parallel beam, a point source, and an isotropically radiating circular disc of the same diameter as the OMH source active volume.

In order to study the dependence of the two correction factors on the fraction of scattered radiation, calculations have been performed for three spectra differing in their scatter contribution to the total energy fluence, as well as for sources emitting only the two main ^{60}Co gamma lines or mono-energetic photons of 1.25 keV, respectively. One of the spectra is part of the *EGSnrc* distribution with 21 % of the energy fluence due to scattered radiation. The other two spectra come from *BEAM* [11] simulations of ^{60}Co irradiation facilities operated at the Physikalisch-Technische Bundesanstalt (PTB), one of which has a close similarity to the OMH source. The spectrum of this latter source has a scatter contribution of 25 % as compared to 18 % for the other spectrum.

The values for k_{wall} for each spectrum and source are obtained directly from the output files generated by the simulation program, which has the determination of this correction factor as a built-in option. The resulting values of k_{wall} for the three spectra depart from those found for the line sources by 0.2 % on average, and a similar departure is encountered between the values of k_{wall} for the parallel beam, on the one hand, and those for the point and extended circular sources, on the other. The correction factor k_{wall} appropriate to the measurement setups used in this comparison is taken as the average of the simulation results for the extended circular source, namely $k_{\mathrm{wall}} = 1.0216$. The statistical uncertainty for k_{wall} given in the output files is used as the Type A uncertainty contribution, which amounts to 0.01 %. The standard deviation of the calculated correction factors for the three different realistic spectra, 0.07 %, is used as the estimate for the contribution to the Type B uncertainty of k_{wall} due to the influence of the fraction of scattered radiation. The Type B uncertainty contributions inherited from the material data entering the simulations are derived from additional Monte Carlo calculations. To this end, a set of modified material data was generated with the *EGSnrc* pre-processor *PEGS4* [10] using a different value for the average ionization potential of graphite. The departure from the recommended value of 78 eV was equal to the uncertainty of 7 eV specified in the ICRU recommendations. The Monte Carlo calculations based on these modified input data changed the value of k_{wall} by about 0.02 %, so that an overall Ttype B uncertainty of 0.07 % is obtained.

The correction factor k_{an} for axial non-uniformity of the beam is derived as the ratio of the calculated doses, corrected for wall effects, as calculated for the parallel beam and the circular source, respectively. The latter kind of source geometry can be expected to be a more realistic approximation of the true source than a point source, which was previously used to determine k_{an} for the OMH standards [5]. It should be noted, however, that using the results from the present Monte Carlo calculations for the point source rather than the circular disc changed the value of k_{an} by less than 0.01 % on average.

Unlike the correction for wall effects, k_{an} does not show a systematic dependence on the spectrum. The mean value over all spectra of 0.9998 is used as the estimate for k_{an}, which agrees within 0.01 % with the value used for this correction in 2000 [5]. The Type A uncertainty contribution for k_{an} of about 0.04 % is calculated by error propagation from the numerical uncertainty estimates for the two doses, as taken from the simulation output files. As in the case of k_{wall}, two major contributions to the Type B uncertainty of k_{an} are taken into account. The standard deviation for the values derived for different spectra, which amounts to 0.07 %, is used as estimate of the contribution due to the fraction of scattered radiation. Using the material data based on the modified average ionization energy of graphite, yielded a change in the value of k_{an} by 0.04 %. The total Type B uncertainty is obtained by sum in quadrature of the two components and amounts to 0.08 %.

5. Comparison of the air kerma standards for ^{60}Co radiation

Air kerma at the BIPM is determined under the conditions given in Tables 7 and 8 of [12]:
- the distance from source to reference plane is 1 m,
- the field size in air at the reference plane is 10 cm × 10 cm.

A comparison of the ^{60}Co beams at the OMH and the BIPM is given in Table 4.

Table 4. Parameters of the ^{60}Co beams at the OMH and the BIPM

^{60}Co beam	Nominal source activity at 01/01/06	Source diameter and length	Scatter contribution/ energy fluence	Field size	Approximate air kerma rate mGy s^{-1}
OMH source	95 TBq	20 mm × 20 mm	25 %	11.3 cm diameter#	8.9
BIPM Picker	20 TBq	20 mm × 5.6 mm	14 %	10 cm × 10 cm*	1.4
BIPM CISBio	130 TBq	20 mm × 14 mm	21 %	10 cm × 10 cm*	10.8

at 0.9 m

* at 1 m

At the OMH, the standards are set up with the signal connector pointing towards the source, which is the reference orientation of the ND 1005 type chamber. It was not possible to set the standards in this position at the reference distance in the BIPM Picker beam. Consequently, at another distance, a set of relative measurements was made with the standard 7708 first with the signal connector pointing towards the source and then with the base plate and serial number facing the source. The difference between the two sets of measurements was of the order of the statistical uncertainty (in relative terms 3×10^{-5}). A similar set of measurements with standard 7707 indicated that there is a slight orientation effect of 3.7×10^{-4}, but for the standard 7714 this effect was at the level of 1.0×10^{-3}. This last value could be related to a repair of this chamber in 1995 during which the central electrode may have been displaced slightly. All subsequent measurements with all three standards in both BIPM beams were made with the serial numbers facing the source. Appropriate correction factors have been applied to correct the responses to those for the reference orientation

The collecting voltage applied to the OMH standard was 250 V using both polarities. The chambers were left for 30 min after each voltage change to allow them to stabilize before each measurement. The polarity effect, determined for each standard as the ratio of positive and negative currents, was measured to be 1.0015, 1.0009 and 1.0006 for the three standards 7707, 7708 and 7714, respectively. The value for standard 7707 agrees with the value 1.0013 measured at the BIPM in 1986. In 1994, only the positive polarity was used at the BIPM for the standard 7714 and a correction factor of 0.9988 supplied by the OMH was applied to correct for the polarity effect. This implies a ratio of positive to negative currents of 1.0024, which is significantly greater than the value of 1.0006 measured at the BIPM during the present comparison. The OMH remeasured the positive and negative current ratios for this chamber in 2006. When in the same orientation as at the BIPM, the value was measured at the OMH as 1.0009, which is in agreement with the value measured at the BIPM, while in the reference orientation the value was 1.0019, which is in reasonable agreement with the OMH 1994 value. No corrections are made in the present comparison as the mean of both polarities is used on each occasion.

With the exception of k_{rn} and k_s, the correction factors for the OMH standard were determined at the OMH. The correction factors k_{rn}, for the radial non-uniformity of the BIPM beams over the section of the OMH standards, have been estimated from measurements carried out at the BIPM [13]. The values are included in Table 2.

The air kerma rate at the OMH is around 9 mGy s^{-1} at their reference distance of 0.900 m. As the air kerma rates of the two BIPM ^{60}Co beams are significantly different, of the order of 1.4 mGy s^{-1} and 11 mGy s^{-1}, the corrections for losses due to recombination, k_s, were also measured at the BIPM. The results are presented in Figure 1 and the corrections are consistent with the value of 1.0020 (6) measured at the OMH.

The recombination measurements were made with the OMH standard 7708 only. The ratio of the ionization currents with applied voltages of 250 V and 80 V (using both polarities) was measured for three different air kerma rates (using both ^{60}Co beams and a brass filter, as recombination is insensitive to the spectrum). Applying the method of Niatel and the notation in [14],

$$I_V / I_{V/n} = 1 + (n-1)\, A/V + (n^2 - 1) m^2 (g/V^2) I_V \tag{3}$$

Figure 1 illustrates the measurements made for $n = 250/80 = 3.125$.

The recombination correction k_s can be expressed as

$$k_s = 1 + k_{init} + k_{vol} I_V \quad (4)$$

and Table 5 gives the values and uncertainties for k_{init} and k_{vol}. The current, I_V, is the current as measured by the chamber, not corrected for decay and not normalized for temperature and pressure. Consequently, a correction factor of 1.0020 (1) for ion recombination at 250 V was applied to the OMH standards in the BIPM Picker beam. The appropriate value in the CISBio beam is 1.0022 (1). These values are given in Table 2.

Figure 1. Recombination measurements made at the BIPM for the OMH standard ND1005-7708

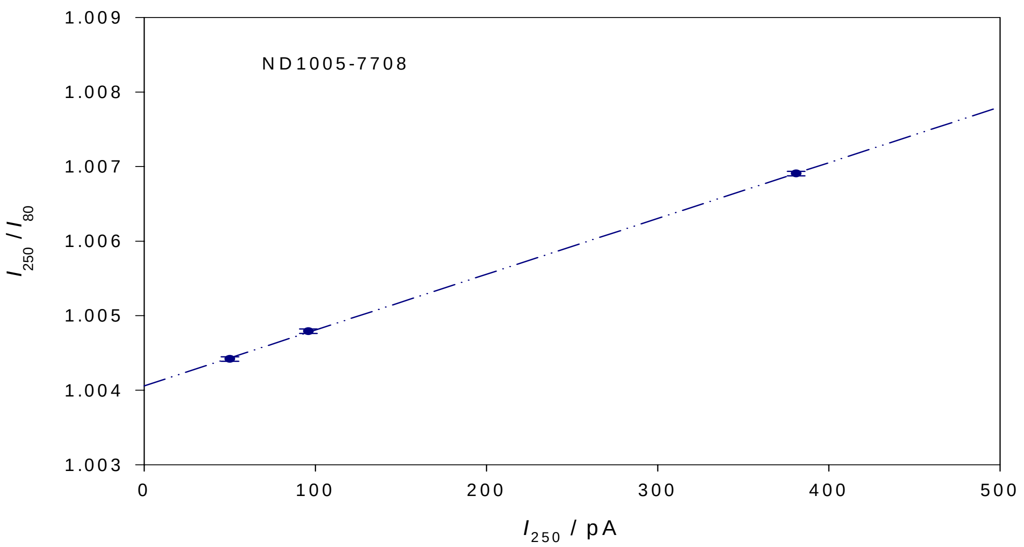

Table 5. Results of ion recombination measurements made at the BIPM for the OMH standard

OMH Standard ND1005-7714	**Correction**	**Standard uncertainty**
Initial recombination and diffusion, k_{init}	19.1×10^{-4}	5×10^{-5}
Volume recombination coefficient, k_{vol}, / pA^{-1}	8.5×10^{-7}	5×10^{-8}
k_s in the BIPM Picker beam, BIPM values	1.0020	1×10^{-4}
k_s in the BIPM CISBio beam, BIPM values	1.0022	1×10^{-4}

The values for the ionization current measured by each standard and used to determine the air kerma in the BIPM beams are given in Table 6. These values are for both polarities, corrected for leakage and for decay from the measurement date to the reference date of 2006-01-01, 0 h UTC. The half-life of ^{60}Co is taken as 1925.5 days (u = 0.5 days) [15]. The currents are also normalized to the reference conditions of air temperature 273.15 K and pressure of 101.325 kPa. Two independent measurements were made with each standard in each beam.

Table 6. Ionization currents measured with the OMH standards at the BIPM
(Corrected for orientation and normalized to 101 325 Pa and 273.15 K)

OMH ND1005 standards; current / pA **BIPM Picker beam**			**Mean values**	**100 s**[*]
7707	54.167	54.167	54.167	< 0.01
7708	54.407	54.417	54.412	< 0.01
7714[#]	54.444	54.444	54.444	< 0.01
BIPM CISBio beam**				
7707	413.27	413.22	413.24	< 0.01
7708	415.06	415.08	415.07	< 0.01
7714	415.22	415.24	415.23	< 0.01

[*] relative statistical standard uncertainty of the measurements
[#] this chamber is not part of the comparison result
** the results in this beam are not part of the comparison

The volume of each standard was determined mechanically at the OMH. As the correction factors are identical for each of the standards, the ratio of the ionization currents measured in each beam should equal the ratio of the chamber volumes. These ratios are presented in Table 7. For the OMH standards 7707 and 7708, the current ratios determined at the OMH and at the BIPM are in agreement when the chambers are used in the same orientation. The difference of (1.4 to 1.8) $\times 10^{-3}$ between the volume ratio and the current ratio for standard 7714 is consistent with the difference of 2×10^{-3} between the comparison results of 1994 and 1986, made with this chamber and the standard 7707, respectively. Considering the discrepancy of the current per volume ratio of the chamber 7714 and the unexpected orientation effect (1.0003 and 1.0013 for positive and negative polarity, respectively) measured at the OMH after the comparison at BIPM, this chamber has been withdrawn by the OMH from the set of primary standards and is not part of the comparison result.

Table 7. Comparison of volume and current ratios for the OMH standards[#]

Standard ND1005	**Volume / cm^3**	**Volume ratio with 7708**	**Current ratio at the OMH**[##]	**Current ratio at the BIPM**
7707	1.0182	0.9956	0.9955	0.9955
7708	1.0227	1	1	1
7714	1.0219	0.9992	1.0010	1.0006

[#] measured in the Picker beam
[##] mean of measurements before and after the comparison at the BIPM

6. Comparison result and discussion

The comparison result is given by,

$$R_{\dot{K}} = \dot{K}_{\mathrm{OMH}} / \dot{K}_{\mathrm{BIPM}}, \tag{5}$$

where $\dot{K}$ is the value of the air kerma rate at the BIPM as measured by the OMH and BIPM standards, respectively. The results are given in Table 9 together with their uncertainties. As some constants (such as air density, W/e, $\overline{\mu}_{\mathrm{en}}/\rho$, $\overline{g}$, $\overline{s}_{c,a}$ and k_h) are derived from the same basic data in both laboratories, the uncertainty in R_K is due only to the uncertainties in the correction factors, the volumes of the standards, the measured ionization currents and the positioning at the reference distance, the values of which are given in the final rows of Tables 2 and 3. The relative standard uncertainty arising from the positioning of each chamber at the BIPM is less than 10^{-4}.

Each air kerma value for the OMH standards in Table 8 is derived from the mean of each measurement series in Table 6 using the volumes in Table 1 and the physical constants and correction factors given in Table 2.

The $\dot{K}_{\mathrm{BIPM}}$ values are taken as the mean of the four measurements for each beam made around the period of the comparison. Both air kerma rates were verified immediately before the comparison measurements. The $\dot{K}_{\mathrm{BIPM}}$ values refer to an evacuated path length between source and standard and are given at the reference date of 2006-01-01, 0 h UTC.

As indicated in [9], the reference beam for air kerma comparisons at the BIPM is the Picker ^{60}Co beam. The CISBio ^{60}Co beam characterization has not yet been published nor adopted as the reference, so these results are for information at this time and will serve in the future.

In 2001, the OMH applied a correction of 1.0084 to their air kerma rate to take into account the changes in correction factors derived from the Monte Carlo calculations [7]. This changed the 1994 comparison result to 1.0109 (20). However, with the introduction of further changes to these corrections as described in section 4, the 1994 result becomes 1.0105 (20) which value agrees with the present results for the standards 7707 and 7708 in the BIPM reference beam.

A comparison between the new primary standard chambers of the PTB and the OMH chamber 7708 was made in 2000 [5]. The average result ($K_{\mathrm{PTB}}/K_{\mathrm{OMH}}$) was 1.0009, which would be 1.0005 taking into account the recent small changes of k_{wall} k_{s} and k_{an} corrections for the OMH standard. The result of the 2003 comparison of the PTB standard at the BIPM ($K_{\mathrm{PTB}}/K_{\mathrm{BIPM}}$) was 1.0099 [16]. The ratio of the direct and indirect (via the PTB) OMH comparisons with the BIPM standard is 1.0015, which is in agreement within the uncertainties associated with positioning and spectra in the different radiation beams in the three laboratories.

Table 8. Results of the comparisons of standards for air kerma

^{60}Co Beam	OMH chamber	$\dot{K}_{\mathrm{OMH}}$ /mGy s^{-1}	$\dot{K}_{\mathrm{BIPM}}$ /mGy s^{-1}	R_K	100 u_c
Picker	7707	1.4297	1.4144	1.0108	0.22
	7708	1.4230	1.4144	1.0111	0.22
Mean values		**1.4298**	**1.4144**	**1.0109**	**0.22**

^{60}Co Beam	OMH chamber	$\dot{K}_{\mathrm{OMH}}$ /mGy s^{-1}	$\dot{K}_{\mathrm{BIPM}}$ /mGy s^{-1}	R_K	100 u_c
CISBio	7707	10.908	10.804	1.0097	0.22
	7708	10.908	10.804	1.0097	0.22
Mean values		10.908	10.804	1.0097	0.22

Taking the mean of the results for the two OMH standards, the present direct comparison has a result of 1.0109 (22) as shown in Table 8 and confirms that the OMH and the BIPM standards for air kerma in the ^{60}Co beam differ by about 5 times the standard uncertainty.

Over the last two years, the BIPM has also made Monte Carlo calculations of the wall corrections and other factors for its ^{60}Co standard to verify its determination of air kerma [17]. The effect that this would have on the present comparison result is shown in Table 9. However, further work is in progress and any new result needs to be approved and implemented at a date to be confirmed by the CCRI, probably in 2007.

Table 9. Possible changes to the results if the Monte Carlo calculated correction factors are used for the BIPM standard

Correction factor	**^{60}Co**		
	present	new [17]	ratio
k_{wall}	1.0028 (8)	1.0012 (2)	0.9984
k_{an}	0.9964 (7)	1.0027 (3)	1.0063
total difference*			**1.0046**
R_K (new)	**1.0063 (21)**		

*including other small changes [17]

For the ^{60}Co beam, the change due to the re-evaluation of k_{an} is more significant than the changes due to the calculated k_{wall} correction factor. However, there remains a systematic difference between the OMH and BIPM air kerma standards of about 0.6 %. A similar difference of about 0.5 % was identified in the comparison with the PTB [16] and also found in the analyses made by Rogers et al [18] for many other national standards. No satisfactory explanation has been identified yet for such a difference, and the BIPM is currently investigating possible causes, including a new determination of the volume of the BIPM standard. Initial results for this determination indicate a volume decrease of around 0.2 %.

7. Analysis of the BIPM ongoing ^{60}Co air kerma comparisons

The results of air kerma comparisons in ^{60}Co at the BIPM are currently being re-evaluated, taking into account the effect of changes being made in many national standards following the recommendation of the Consultative Committee for Ionizing Radiation (CCRI) [19]. The NRC (Canada), PTB (Germany) and the BEV (Austria) have already declared new values for their air kerma standards [20, 21, 22]. The SZMDM (Serbia and Montenegro), the NCM (Bulgaria), ENEA (Italy) and the ITN (Portugal), all of which have made comparisons recently with the BIPM [23, 24, 25, 26], have also changed their previous method of k_{wall} determination, now using Monte Carlo calculations. The NMi (Netherlands) has re-evaluated their corrections [27] and is in the process of declaring their new standard value. The LNMRI/IRD (Brazil) has recently confirmed their earlier comparison result [28] but is in the process of recalculating wall effects for their primary standard, which has a similar shape and size to the OMH standard.

In the meantime, the other comparisons that have been made are being reviewed, such as for the NIST (USA) [29], the LNE-LNHB (France) [30] and the ARPANSA (Australia). Once the evaluations have been completed and the results approved by the CCRI(I), they will be published in the BIPM key comparison database (KCDB) that was set up under the CIPM Mutual Recognition Arrangement (CIPM MRA) [31]. The key comparison identifier for ^{60}Co air kerma comparisons is BIPM.RI(I)-K1.

8. Conclusion

The OMH standard for air kerma in ^{60}Co gamma radiation compared with the present BIPM air kerma standard gives a comparison result of 1.0109 (21). Although this is significantly different from the earlier comparisons with the BIPM, due to changes in correction factors, it compares favourably with other primary standards for which the wall and axial non-uniformity correction factors have also been calculated using Monte Carlo methods. For example, the mean comparison value for the six similar types of national standard is now 1.0086 (0.0013).

All the comparison results of the national metrology institutes (NMIs) and designated laboratories will be used as the basis of the entries in Appendix B of the KCDB set up under the CIPM MRA. The NMIs that have previously used experimental extrapolation methods to determine wall correction factors are currently checking their factors, using various Monte Carlo codes or other methods. It is expected that all the NMIs will be ready for their results to be entered into the KCDB for the ongoing BIPM.RI(I)-K1 comparison by the end of 2006. In the meantime, the BIPM has also reviewed and published its experimental and calculated results for the wall and other correction factors for its primary standard. Formal adoption by the CCRI will be proposed in May 2007.

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