Comparison of the standards of air kerma of the OMH and the BIPM for ^{137}Cs and ^{60}Co γ rays

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Abstract
Comparisons between the standards of air kerma of the Országos Mérésügyi Hivatal and of the Bureau International des Poids et Mesures have been carried out in the ^{137}Cs and ^{60}Co radiation beams. They show an agreement of 0,46 % and 0,3 % for ^{137}Cs and ^{60}Co, respectively.

1. Introduction

Comparisons of the standards of air kerma of the Országos Mérésügyi Hivatal (OMH), Budapest, Hungary, and of the Bureau International des Poids et Mesures (BIPM), have been carried out in ^{137}Cs and ^{60}Co radiation beams.

The standard of air kerma of the OMH is a cavity ionization chamber constructed at the OMH (type ND 1005, serial number 7714). Its main characteristics are given in Table 1. The standards of the BIPM are flat cylindrical cavity chambers which are described in [1].

An indirect comparison by means of a transfer chamber of the OMH has also been carried out in the ^{60}Co radiation beam, the transfer chamber, in this case, being calibrated in terms of absorbed dose to water.

The comparison took place at the BIPM in October 1994. An earlier comparison of air kerma standards took place in the ^{60}Co radiation beam in 1986. At that time, the OMH standard was a different cavity ionization chamber of the same type.

2. Conditions of measurement

Air kerma is determined under the conditions given in Table 6 of [2]:
- the distance from source to reference plane is 1 m,
- the field size in air at the reference plane is 10 cm x 10 cm for the ^{60}Co beam and 10 cm in diameter for the ^{137}Cs beam.

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The air kerma rate is determined by

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

where

I/m	is the mass ionization current measured by the standard,
W	is the average energy spent by an electron to produce an ion pair in dry air,
e	is the electron charge,
$\bar{g}$	is the fraction of energy lost by bremsstrahlung,
$(\mu_{en}/\rho)_{a,c}$	is the ratio of the mean mass-energy absorption coefficients of air and graphite,
$\bar{s}_{c,a}$	is the ratio of the mean stopping powers of graphite and air,
Πk_i	is the product of the correction factors to be applied to the standard.

Table 1. Characteristics of the OMH standard of air kerma

Dimensions (nominal values) (mm)			
	Chamber	Outer height and outer diameter	19
		Inner height and inner diameter	11
		Wall thickness	4
	Electrode	Diameter	2,00
		Height	8,97
Volume of the air cavity (cm^3)			1,021 9
Materials			
	Wall	Ultrapure graphite EK51 Ringsdorf, of density 1,75 $g\cdot cm^{-3}$ and with impurities less than 1,5 x 10^{-4}	
	Insulator	PTFE (Teflon)	

3. Comparison of the air kerma standards for ^{137}Cs radiation

The volume of the OMH standard was determined mechanically at the OMH. The collecting voltage applied to this standard is ± 250 V. The polarity effect I_+/I_- is 1,002 3.

The correction factors for the OMH standard were determined at the OMH. As a check, some of them were measured again in the BIPM beam. These concern corrections due to the wall (k_{at} , k_{sc}) and to recombination losses (k_s). The results agree with the OMH determination well within the uncertainties. The correction factor k_{rn} , for the radial non-uniformity of the BIPM beam over the section of the OMH standard, has been estimated from measurements carried out at the BIPM and is 1,000 4.

The physical constants and the correction factors entering in (1) and the uncertainties associated with the measurement of $\dot{K}$ are given in Table 2 for both the BIPM and OMH standards.

Table 2. Physical constants and correction factors entering in the determination of the air kerma rates, $\dot{K}_{BIPM}$ and $\dot{K}_{OMH}$, for the BIPM ^{137}Cs beam, and estimated relative uncertainties in the ratio $\dot{K}_{OMH} / \dot{K}_{BIPM}$.

The estimated relative uncertainties* are given as standard deviations, (in %).

			$\dot{K}_{BIPM}$			$\dot{K}_{OMH}$			$\dot{K}_{OMH} / \dot{K}_{BIPM}$	
			value	uncertainty		value	uncertainty		uncertainty	
				s	*u*		*s*	*u*	*s*	*u*
Physical constants										
dry air density (273,15 K, 101 325 Pa)		($kg \cdot m^{-3}$)	1,293 0		< 0,01	1,293 0		< 0,01		-
$(\mu_{en}/\rho)_{a,c}$			0,999 0		0,02	0,999 0		0,10		-
$\bar{s}_{c,a}$			1,010 4		0,11	1,010 1		0,30		0,03
W/e		($J \cdot C^{-1}$)	33,97		0,15	33,97		0,15		-
$\bar{g}$	fraction of energy lost by bremsstrahlung		0,001 2		< 0,01	0,001 2		< 0,01		-
Correction factors										
k_s	recombination losses		1,001 4		0,01	1,002 3	0,04	0,05	0,04	0,05
k_h	humidity		0,997 0		0,03	0,997 0		0,03		-
k_{st}	stem scattering		0,999 8		0,01	0,999 5		0,05		0,05
k_{at}	wall attenuation		1,054 0		0,05	}			}	
k_{sc}	wall scattering		0,953 5		0,18	1,018 6	0,05	0,05	0,05	0,19
k_{CEP}	mean origin of electrons		0,997 2		0,02	0,998 0		0,10		0,10
k_{an}	axial non-uniformity		0,998 1		0,02	0,999 8		0,10		0,10
k_{rn}	radial non-uniformity		1,007 0		0,02	1,000 4		0,02		0,02
Measurement of $I/V\rho$										
V	volume	(cm^3)	6,834 4		0,10	1,021 9		0,10		0,14
I	ionization current			0,03	0,02		0,03	0,05	0,04	-
Uncertainty in $\dot{K}_{BIPM}$ and $\dot{K}_{OMH}$										
by quadratic summation				0,03	0,29		0,07	0,40		
combined uncertainty				0,30			0,41			
Uncertainty in $\dot{K}_{OMH} / \dot{K}_{BIPM}$										
by quadratic summation									0,08	0,29
combined uncertainty									0,30	

* *s* = uncertainty estimated by statistical methods, type A,
u = uncertainty estimated by other means, type B.

The result of the comparison $R_K = \dot{K}_{OMH} / \dot{K}_{BIPM}$ is given in Table 3. The $\dot{K}$ values refer to an evacuated path length between source and standard. They are given at the reference date of 1994-01-01, 0h UT (the half life of ^{137}Cs is taken as (11 050 ± 40) days [3]). The $\dot{K}_{BIPM}$ value is the mean of measurements which were performed over a period of one month before and after the comparison at the BIPM. The ratio of the air kerma rates determined by the OMH and the BIPM standards is 0,995 4.

Some of the uncertainties which appear in the BIPM and OMH determinations of the air kerma rate (such as air density, W/e, μ_{en}/ρ, $\bar{g}$, $\bar{s}_{c,a}$, k_h, ...) cancel when evaluating the ratio R_K. The resulting uncertainty of R_K is estimated to be 0,30 % (see Table 2). It can be concluded that the standards of air kerma of the OMH and the BIPM agree well within their uncertainties.

Table 3. Result of the OMH-BIPM comparison of standards of air kerma (^{137}Cs beam)

$\dot{K}_{OMH}$* (Gy·µC^{-1})	$\dot{K}_{BIPM}$ (Gy·µC^{-1})	$\dot{K}_{OMH} / \dot{K}_{BIPM}$
21,570	21,670	0,995 4 ± 0,003 0

* Mean value of 60 measurements.

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

The collecting voltage applied to the OMH standard was + 250 V. A correction factor of 0,998 8 has been applied to the ionization current for the polarity effect. The correction factors for the OMH standard were determined at the OMH. The correction factor k_{rn}, for the radial non-uniformity of the BIPM beam over the section of the OMH standard, has been estimated from measurements carried out at the BIPM [4].

The physical constants and the correction factors in (1) and the uncertainties associated with the measurement of $\dot{K}$ are given in Table 7 of [2] for the BIPM standard and in Table 4 of the present report for the OMH standard.

The result of the comparison $R_K = \dot{K}_{OMH} / \dot{K}_{BIPM}$ is given in Table 5. As for the comparison in the ^{137}Cs radiation, the $\dot{K}$ values refer to an evacuated path length between source and standard and are given at the reference date of 1994-01-01, 0h UT (the half life of ^{60}Co is taken as (1 925,5 ± 0,5) days [3]). The $\dot{K}_{BIPM}$ value is the mean of measurements which were carried out over a period of one month before and after the comparison at the BIPM.
The ratio of the air kerma rates determined by the OMH and the BIPM standards is 1,002 8.

Some of the uncertainties which appear in the BIPM and OMH determinations of the air kerma rate (such as air density, W/e, μ_{en}/ρ, $\bar{g}$, $\bar{s}_{c,a}$, k_h, ...) cancel when evaluating the ratio R_K. A detailed analysis of the uncertainty of R_K, which is estimated to be 0,24 %, is given in Table 4.

The result of the present comparison is nearly 0,2 % higher than the value obtained during the 1986 comparison.A difference of the same order with the BIPM standard has already been observed for another air kerma standard of the same type as the OMH standard [5].

Table 4. Physical constants and correction factors entering in the determination of the air kerma rate, $\dot{K}_{OMH}$, in the BIPM ^{60}Co beam.

The estimated relative uncertainties are given as standard deviations (in %).

	value	$\dot{K}_{OMH}$ uncertainty		$\dot{K}_{OMH}$ / $\dot{K}_{BIPM}$ uncertainty	
		s	u	s	u
Physical constants					
dry air density (273,15 K, 101 325 Pa) (kg·m^{-3})	1,293 0		< 0,01		-
$(\mu_{en}/\rho)_{a,c}$	0,998 5		0,05		-
$\bar{s}_{c,a}$	1,000 7 }				0,03
W/e (J·C^{-1})	33,97 }		0,11*		-
$\bar{g}$ fraction of energy lost by bremsstrahlung [10]	0,003 2		0,02		-
Correction factors					
k_s recombination losses	1,002 7	0,04	0,05	0,04	0,05
k_h humidity	0,997 0		0,03		-
k_{st} stem scattering	0,999 8		0,05		0,05
k_{at} wall attenuation	{			{	
k_{sc} wall scattering	1,015 7	0,05	0,05	0,05	0,10
k_{CEP} mean origin of electrons	0,997 0		0,10		0,10
k_{an} axial non-uniformity	0,999 8		0,10		0,12
k_{rn} radial non-uniformity	1,000 2		0,01		0,01
Measurement of $I/V\rho$					
V volume (cm^3)	1,021 9		0,10	0,01	0,11
I ionization current		0,01	0,02	0,01	0,02
Uncertainty in $\dot{K}_{OMH}$					
by quadratic summation		0,06	0,23		
combined uncertainty		0,24			
Uncertainty in $\dot{K}_{OMH}$ / $\dot{K}_{BIPM}$					
by quadratic summation				0,07	0,23
combined uncertainty				0,24	

* Uncertainty in the product $W \bar{s}_{c,a}$.

Table 5. Result of the OMH-BIPM comparison of standards of air kerma (^{60}Co beam)

$\dot{K}_{OMH}$* (Gy·µC^{-1})	$\dot{K}_{BIPM}$ (Gy·µC^{-1})	$\dot{K}_{OMH}$ / $\dot{K}_{BIPM}$
6,871 0	6,853 5	1,002 5 ± 0,002 4

* Mean value of 60 measurements.

In addition, an indirect comparison of the standards of air kerma was carried out by means of a transfer chamber, type NE-2561. The collecting voltage applied to the transfer chamber was + 200 V. At the BIPM, the calibration was carried out under the conditions of measurement described in [2]. The calibration factor was determined using the relations

$$(N_K)_{\mathrm{BIPM}} = \frac{\dot{K}_{\mathrm{BIPM}}}{I_{\mathrm{BIPM}}} , \qquad (N_K)_{\mathrm{OMH}} = \frac{\dot{K}_{\mathrm{OMH}}}{I_{\mathrm{OMH}}} , \qquad (2)$$

where
$\dot{K}$ is the air kerma rate determined at the BIPM and the OMH,
I is the ionization current, at 20 °C and 101 325 Pa, measured by the transfer chamber at the BIPM and the OMH. No correction has been applied to the ionization current I measured by the chamber for humidity, for incomplete ion collection or for the radial non-uniformity of the beam over the section of the transfer chamber.

The result of the indirect comparison $R_K = (N_K)_{\mathrm{OMH}} / (N_K)_{\mathrm{BIPM}}$ is given in Table 6 and the analysis of its uncertainty in Table 7. This result is in very good agreement, within the uncertainties, with that of the direct comparison.

Table 6. Result of the indirect OMH-BIPM comparison of standards of air kerma (^{60}Co beam)

$(N_K)_{\mathrm{OMH}}$* (Gy·µC^{-1})	$(N_K)_{\mathrm{BIPM}}$ (Gy·µC^{-1})	R_K
93,51	93,23	1,003 0 ± 0,002 5

* Mean value of 60 measurements.

Table 7. Estimated relative uncertainties in the ratio R_K (standard deviation, in %)

Uncertainty in the measurement of	s	u
Air kerma ratio $\dot{K}_{\mathrm{OMH}} / \dot{K}_{\mathrm{BIPM}}$	0,07	0,24
Ionization current of NE 2561 chamber		
at the BIPM	0,01	0,02
at the OMH	0,01	0,02
Distance		
at the BIPM	-	0,02
at the OMH	-	0,02
Uncertainty in R_K		
quadratic summation	0,07	0,24
combined uncertainty	0,25	

5. Calibration of transfer chamber in terms of absorbed dose to water (^{60}Co beam)

Transfer chamber NE 2561-084 was calibrated at the BIPM in terms of absorbed dose to water at the reference depth of 5 g/cm^2. Information on the conditions of measurement and the determination of the calibration factor N_W is given in [2].

For calibration, the axis of the transfer chamber was located in the reference plane. The chamber was inserted in a perspex envelope (1,1 mm thick) provided by the BIPM. A collecting voltage of +200 V was applied to the chamber. During calibration the relative humidity was in the range of 40 % to 45 % and the water temperature was stable to within 0,05 °C. The short-term relative standard deviation of the mean ionization current is estimated to be 0,01 % (60 measurements). The correction for the leakage current of the chamber is less than 0,01 %.

Table 8 gives the result of the calibration as well as the ratio N_W / N_K. The value obtained for N_W holds for 20 °C and 101 325 Pa. No correction has been applied to the ionization current measured by the chamber for humidity, for incomplete ion collection or for the radial non-uniformity of the beam over the section of the transfer chamber. The uncertainties in N_W are given in Table 9.

The value of the ratio N_W / N_K is in agreement with those obtained for other NE 2561 chambers calibrated previously at the BIPM [6].

Table 8. Calibration factor, N_W, of the OMH transfer chamber NE 2561-084 in terms of absorbed dose to water (^{60}Co beam)

$(\dot{D}_W)_{BIPM}$ (mGy·s^{-1})	$(N_W)_{BIPM}$ (Gy·μC^{-1})	N_W / N_K
6,856	101,9 ± 0,5	1,093

Table 9. Estimated relative uncertainties in the calibration factor, N_W, of transfer chamber NE 2561-084 (standard deviations, in %)

Uncertainty in the measurement of	s	u
Absorbed dose rate $\dot{D}_W$ at 5 g/cm^2 in water [7]	0,20	0,38
Ionization current of NE 2561 chamber	0,01	0,02
Distance	-	0,04
Depth in water	-	0,10
Uncertainty in N_W		
quadratic summation	0,20	0,40
combined uncertainty	0,5	

6. Conclusion

The agreement between the standards of air kerma of the OMH and the BIPM for ^{137}Cs radiation is of order 0,4 % which is a satisfactory result taking into account the uncertainties involved.
In the ^{60}Co radiation beam, the agreement between the standards is better than 0,3 %. This result is 0,2 % higher than that found in the comparison of 1986 and is explained by changes relating to the OMH standard such as the determination of its volume.

References

[1] BOUTILLON M. and NIATEL M.-T., A study of a graphite cavity chamber for absolute measurements of ^{60}Co gamma rays, *Metrologia,* 1973, **9,** 139-146.

[2] PERROCHE A.-M. and BOUTILLON M., Measuring conditions used for the calibration of ionization chambers at the BIPM, *Rapport BIPM-91/5*, 1991, 11 pages.

[3] IAEA, X- and gamma-ray standards for detector calibration, *IAEA TECDOC-619,* 1991.

[4] BOUTILLON M. and PERROCHE A.-M., Radial non-uniformity of the BIPM ^{60}Co beam, *Rapport BIPM-89/2*, 1989, 9 pages.

[5] PERROCHE A.-M., BOUTILLON M. and LEITNER A., Comparison of the standards of air kerma and absorbed dose to water of the BEV and the BIPM for ^{60}Co γ rays, *Rapport BIPM-94/7*, 1994, 7 pages.

[6] BOUTILLON M. and PERROCHE A.-M., Comparisons and calibrations at the Bureau international des poids et mesures in the field of x and γ rays, *International Symposium on measurement assurance in dosimetry,* 1993, IAEA-SM-330/22.

[7] BOUTILLON M. and PERROCHE A.-M., Ionometric determination of absorbed dose to water for cobalt-60 gamma rays, *Phys. Med. Biol.*, 1993, **38**, 439-454.

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