Comparison of the air kerma and exposure standards of the OMH and BIPM for X Rays (10 to 50 kV)

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Abstract

A comparison between the air kerma and exposure standards of the Országos Mérésügyi Hivatal and the Bureau International des Poids et Mesures has been performed in the low-energy X-ray range. The ratio of the air kerma rates determined by each standard varies with the radiation quality from 0.997 to 1.002.

1. Introduction

The low-energy X-ray air kerma and exposure standards of the Országos Mérésügyi Hivatal (OMH), Budapest, and of the Bureau International des Poids et Mesures (BIPM) have been compared at the reference radiation qualities defined by the Comité Consultatif pour les Etalons de Mesure des Rayonnements Ionisants (CCEMRI) [1].

The measurements were performed in October and November 1988. These standards had already been compared in 1979 [2], but a change has been made to the OMH standard since this time: a new diaphragm was constructed since the results of the 1979 comparison had shown that the previous one was not suitable. Thus, the air attenuation path length in the chamber has been slightly modified.

2. Conditions of measurement

The main characteristics of the standards are given in Table 1 and the conditions of measurement at BIPM in Table 2.

The exposure rate and air kerma rate are determined for one standard by

$$\dot{X} = \left(\frac{I}{m}\right) (\Pi\, k_i) , \qquad (1)$$

$$\dot{K} = \left(\frac{I}{m}\right) (\Pi\, k_i) \frac{W}{e} \frac{1}{(1-g)} , \qquad (2)$$

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where

(I/m) is the mass ionization current measured by the standard,
(Πk_i) is the product of the correction factors to be applied to the standard,
W is the average energy spent by an electron of charge e, to produce an ion pair in dry air,
g is the fraction of energy lost by bremsstrahlung.

The physical constants entering in eqs (1) and (2) are given in Table 3, and the correction factors k_i in Table 4.

Tables 5 and 6 give the uncertainties associated with the measurements of $\dot{X}$ and $\dot{K}$, for both the BIPM and OMH standards. In these tables the relative uncertainties estimated by statistical methods (type A) are designated by s_i and they correspond to one standard deviation; the relative uncertainties estimated by other means (type B), designated by u_j, also correspond to one standard deviation.

3. Results

The results of the comparison are given in Table 7. Some of the uncertainties in $\dot{X}$ and $\dot{K}$ (such as air density, W/e, k_h, g) cancel for the uncertainty in the ratio R, where R is given by

$$R = \dot{K}_{OMH}/\dot{K}_{BIPM} = \dot{X}_{OMH}/\dot{X}_{BIPM} . \quad (3)$$

In Figure 1 curve (a) shows the present results. The ratio R varies from 0.997 at 10 kV to 1.002 at 50 kV for the more strongly filtered of the two reference radiations. Curve (b) shows the results of the 1979 comparison.

The diaphragms of the OMH and of the BIPM have been compared: they were placed in the BIPM standard and the ionization currents per unit area were compared. The difference is of the order of 0.2 % and varies slightly (0.16 %) with the radiation quality, as can be seen in Table 8.

4. Conclusion

The improvements applied to the OMH diaphragm since 1979 have led to a good agreement between the two standards. A part of the variation of the ratio R, defined in eq. (3), with the radiation quality can be explained by the observed difference in the diaphragms.

Table 1

Main characteristics of the OMH and BIPM standards

		OMH standard	BIPM standard
Plate separation	(mm)	60	70
Collecting plate height	(mm)	60.4	71
Collecting plate width	(mm)	40.99	15.466
Diaphragm diameter	(mm)	5.004	4.9992
Measurement volume	(cm^3)	0.8061	0.30358
Air attenuation path length	(cm)	6.37	10.000
Voltage applied to the standard	(V)	± 1600	± 1500

Table 2

Conditions of measurement at BIPM

Distance between beryllium window of X-ray tube and the reference plane: 50 cm
Beam diameter in the reference plane: 4 cm

X-ray tube voltage	(kV)	10	25	50(a)	50(b)
Current	(mA)	5	5	5	5
Filtration					
Be	(mm)	≈ 2.9	≈ 2,9	≈ 2.9	≈ 2.9
Al .	(mm)	0	0.373	3.989	1.007
air	(mg/cm^2)	59.4	59.4	59.4	59.4
Half-value thickness					
Al	(mm)	≈ 0.036	0.250	2.257	1.021
Air attenuation coefficient, μ/ρ	(cm^2/g)	15.1	2.57	0.39	0.79

Table 3

Physical constants entering in the determination of $\dot{X}_{BIPM}$ and $\dot{K}_{BIPM}$

Dry air density (273.15 K, 101 325 Pa)	1.293 03 kg/m^3
W/e [3]	33.97 J/C
Fraction $\bar{g}$ of energy lost by bremsstrahlung: (X rays from 10 to 50 kV) [3]	$\leqslant 1 \cdot 10^{-4}$

Table 4

Correction factors applied to the OMH and BIPM air kerma and exposure standards

X-ray tube voltage (kV)		10		25		50(a)		50(b)	
		OMH	BIPM	OMH	BIPM	OMH	BIPM	OMH	BIPM
scattered radiation,	k_{sc}	0.9949	0.9944	0.9960	0.9957	0.9982	0.9971	0.9979	0.9965
electron loss,	k_e	1.000	1.0000	1.000	1.0000	1.000	1.0000	1.000	1.0000
recombination losses,	k_s	1.0011	1.0010	1.0011	1.0006	1.0011	1.0006	1.0011	1.0009
air attenuation,	k_a *	1.1199	1.1930	1.0196	1.0309	1.0029	1.0046	1.0058	1.0091
field distorsion,	k_d	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
transmission through edges of diaphragm,	k_l	1.000	1.0000	1.000	1.0000	1.000	1.0002	1.000	1.0000
transmission through walls of standard,	k_p	1.000	1.0000	1.000	1.0000	1.000	1.0000	1.000	1.0000
humidity,	k_h	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998

* The values of k_a are given for the following conditions: air pressure = 10^5 Pa and air temperature = 20 °C.

Table 5

Estimated relative uncertainties in BIPM exposure rate and air kerma rate
(standard deviation, in %)

X-ray tube voltage (kV)	10		25		50(a)		50(b)	
	s_i	u_j	s_i	u_j	s_i	u_j	s_i	u_j
<u>Physical constants</u>								
dry air density		≤ 0.01		≤ 0.01		≤ 0.01		≤ 0.01
(273.15 K, 101 325 Pa)								
W/e } for air kerma		0.15		0.15		0.15		0.15
g } for air kerma		-		-		-		-
<u>Correction factors applied to the standard</u>								
scattered radiation, k_{sc}		0.07		0.07		0.07		0.07
electron loss, k_e		≤ 0.01		≤ 0.01		0.03		≤ 0.01
recombination losses, k_s	0.013	≤ 0.01	0.02	≤ 0.01	0.007	≤ 0.01	0.007	≤ 0.01
air attenuation, k_a	0.013	≤ 0.01	0.02	≤ 0.01	0.02	≤ 0.01	0.03	≤ 0.01
field distorsion, k_d		0.07		0.07		0.07		0.07
transmission through edges of diaphragm, k_l		≤ 0.01		≤ 0.01		≤ 0.01		≤ 0.01
transmission through walls of standard, k_p	≤ 0.01		≤ 0.01		≤ 0.01		≤ 0.01	
humidity, k_h		0.03		0.03		0.03		0.03
<u>Measurement of $I/v\rho$</u>								
measurement volume, v	0.015	0.007	0.015	0.007	0.015	0.007	0.015	0.007
ionization current, I } corrections concerning ρ (temperature, pressure)	0.02	0.01	0.02	0.01	0.03	0.01	0.02	0.01
<u>Uncertainty on $\dot{X}_{BIPM}$</u>								
quadratic sum	0.03	0.10	0.04	0.10	0.04	0.11	0.04	0.10
combined uncertainty	0.11		0.11		0.12		0.11	
<u>Uncertainty on $\dot{K}_{BIPM}$</u>								
quadratic sum	0.03	0.18	0.04	0.18	0.04	0.19	0.04	0.18
combined uncertainty	0.18		0.19		0.19		0.19	

Table 6

Estimated relative uncertainties in OMH exposure rate and air kerma rate measured at BIPM (standard deviation, in %)

X-ray tube voltage (kV)	10		25		50(a)		50(b)	
	s_i	u_j	s_i	u_j	s_i	u_j	s_i	u_j
Physical constants								
dry air density (273.15 K, 101 325 Pa)		⩽ 0.01		⩽ 0.01		⩽ 0.01		⩽ 0.01
$\overline{W/e}$ for air kerma; $\bar{g}$ for air kerma		0.15; -		0.15; -		0.15; -		0.15; -
Correction factors applied to the standard								
scattered radiation, k_{sc}		0.15		0.15		0.15		0.15
electron loss, k_e		0.1		0.1		0.1		0.1
recombination losses, k_s	0.04	0.05	0.04	0.05	0.04	0.05	0.04	0.05
air attenuation, k_a	0.013	⩽ 0.01	0.02	⩽ 0.01	0.02	⩽ 0.01	0.03	⩽ 0.01
field distorsion, k_d		0.05		0.05		0.05		0.05
transmission through edges of diaphragm, k_l		0.01		0.01		0.01		0.01
transmission through walls of standard, k_p	0.01		0.01		0.01		0.01	
humidity, k_h		0.03		0.03		0.03		0.03
Measurement of $I/v\rho$								
measurement volume, v		0.05		0.05		0.05		0.05
ionization current, I; corrections concerning ρ (temperature, pressure)	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02
Uncertainty on $\dot{X}_{OMH}$								
quadratic sum	0.05	0.20	0.05	0.20	0.05	0.20	0.05	0.20
combined uncertainty	0.21		0.21		0.21		0.21	
Uncertainty on $\dot{K}_{OMH}$								
quadratic sum	0.05	0.25	0.05	0.25	0.05	0.25	0.05	0.25
combined uncertainty	0.26		0.26		0.26		0.26	

Table 7

Results of the OMH-BIPM comparison

$$R = \dot{X}_{OMH}/\dot{X}_{BIPM} = \dot{K}_{OMH}/\dot{K}_{BIPM}$$

X-ray tube voltage (kV)	Date	$\dot{X}_{OMH}$ * (μA/kg)	$\dot{X}_{OMH}$ * (mR/s)	$\dot{K}_{OMH}$ * (μGy/s)	Polarity effect $(I_+/I_-)_{OMH}$	$\dot{X}_{BIPM}$ * (μA/kg)	$\dot{X}_{BIPM}$ * (mR/s)	$\dot{K}_{BIPM}$ * (μGy/s)	Polarity effect $(I_+/I_-)_{BIPM}$	R **
10	1988-11-08	16.470	63.836	559.47	1.0005	16.515	64.014	561.04	0.9999	0.9973 ± 0.0023
	"	16.479	63.874	559.80	1.0006	16.524	64.048	561.33	0.9995	
25	1988-11-04	33.212	128.73	1128.2	1.0001	33.230	128.80	1128.8	0.9985	0.9994 ± 0.0023
	1988-11-09	33.213	128.73	1128.3	1.0003	33.237	128.83	1129.1	0.9978	
50(a)	1988-11-03	10.028	38.869	340.65	1.0001	10.008	38.790	339.97	0.9988	1.0020 ± 0.0024
50(b)	1988-10-28	46.232	179.19	1570.5	1.0005	46.185	179.01	1568.9	0.9989	1.0010 ± 0.0023

The correction for the leakage current of each standard chamber was less than 0.01 %.

* Each value given in this column is an average value based on 40 to 50 measurements.
** The quoted uncertainties represent 1 standard deviation.

Table 8

Comparison of the OMH and BIPM diaphragms

X-ray tube voltage (kV)	Date	$(I/A)_{OMH}/(I/A)_{BIPM}$ *
10	1988-11-08	0.9971 ± 0.0005
25	1988-11-04	0.9977 ± 0.0005
50(a)	1988-11-03	0.9987 ± 0.0005
50(b)	1988-10-28	0.9986 ± 0.0005

* I is the ionization current measured by the BIPM chamber for a diaphragm of geometrical area equal to A.

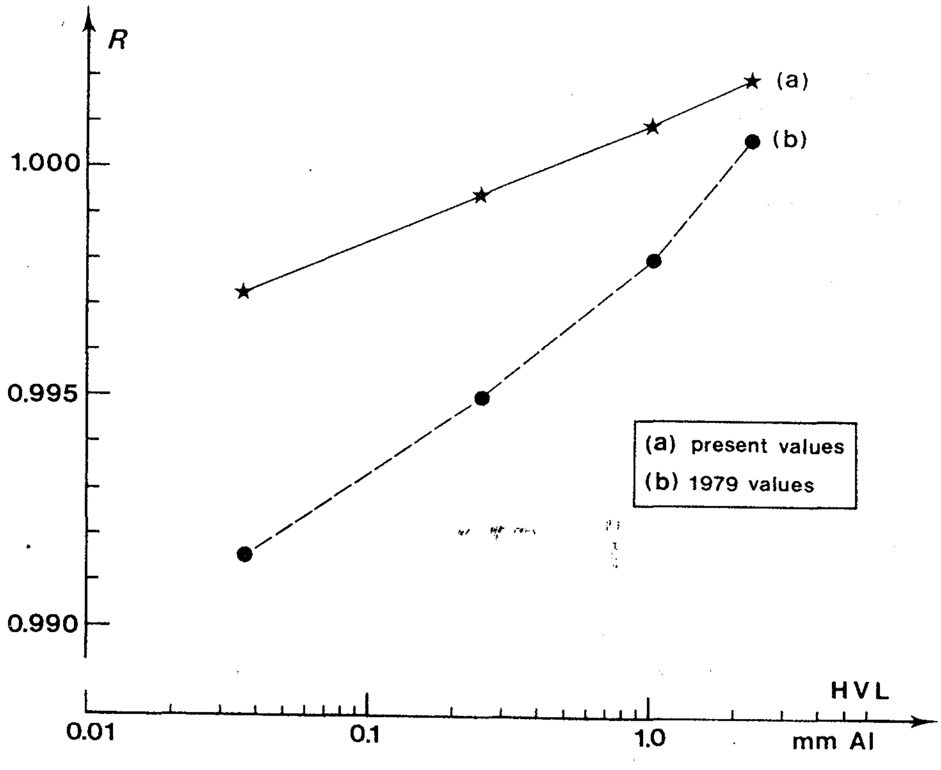

Fig. 1 - Comparison of the air kerma and exposure standards of OMH and BIPM. $R = \dot{K}_{OMH}/\dot{K}_{BIPM} = \dot{X}_{OMH}/\dot{X}_{BIPM}$.

References

[1] BIPM, Qualités de rayonnement, BIPM Com. Cons. Etalons Mes. Ray. Ionisants (Section I) 2, 1972, p. R 15 (Offilib, F-75240 Paris Cedex 05).

[2] Boutillon M., Rayons X, BIPM Proc.-Verb. Com. Int. Poids et Mesures 47, 1979, p. 46 (Offilib, F-75240 Paris Cedex 05).

[3] BIPM, Constantes physiques pour les étalons de mesure de rayonnement, BIPM Com. Cons. Etalons Mes. Ray. Ionisants 11, 1985, p. R 45 (Offilib, F-75240 Paris Cedex 05).

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