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Abstract

A third comparison of the standards for air kerma of Laboratório Nacional de Metrologia das Radiações Ionizantes/Instituto de Radioproteção e Dosimetria (LNMRI/IRD), Rio de Janeiro, Brazil and of the Bureau International des Poids et Mesures (BIPM) has been carried out in ^{60}Co radiation. The comparison result is 1.0007 and demonstrates that the LNMRI/IRD and BIPM standards agree closely, as was the case for the previous comparisons in 1986 and 1996.

1. Introduction

A comparison of the standards for air kerma of the Laboratório Nacional de Metrologia das Radiações Ionizantes/Instituto de Radioproteção e Dosimetria, Rio de Janeiro, Brazil, and of the Bureau International des Poids et Mesures, has been carried out in ^{60}Co radiation. The LNMRI/IRD standard for air kerma is a graphite cylindrical cavity ionization chamber, constructed at the Österreichisches Forschungszentrum (ÖFS), Austria (type CC01, serial number 110), details of which are given in section 2 of this report. The BIPM standard is described in [1]. The standards of the LNMRI/IRD and the BIPM were last compared in 1995 [2] and the present comparison took place at the BIPM in January 2003.

2. The LNMRI/IRD standard

The main characteristics of the LNMRI/IRD primary standard are listed in Table 1. The volume was determined by the ÖFS with an uncertainty of 0.1 %.

Table 1. Characteristics of the LNMRI/IRD standard for the measurement of air kerma.

LNMRI/IRD standard		CCO1-110
		Nominal values
Chamber	Outer height / mm	19
	Outer diameter / mm	19
	Inner height / mm	11
	Inner diameter / mm	11
	Wall thickness / mm	4
Electrode	Diameter / mm	2
	Height / mm	10
Volume	Air cavity / cm^3	1.0176
Wall	Materials	ultrapure graphite EK51 Ringsdorff
	Density / $g \cdot cm^{-3}$	1.71
	Impurity	$< 1.5 \times 10^{-4}$
Insulator		polyethylene
Applied voltage (both polarities)	Voltage / V	250

3. Conditions of measurement

The air kerma is determined at the BIPM under the following conditions [3]:

- the distance from source to reference plane is 1 m,
- the field size in air at the reference plane is 10 cm × 10 cm, 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.

4. Determination of the air kerma rate

The air kerma rate is determined using the relation

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

where

I/m is the ionization current per unit mass of air measured by the standard,

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 to bremsstrahlung,

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

$\bar{s}_{\mathrm{c,a}}$ 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.

5. Experimental results

Data concerning the various factors entering in the determination of air kerma in the ^{60}Co beam using the two standards are shown in Table 2. They include the physical constants [4], the correction factors entering in (1), the volume of each chamber cavity and the associated uncertainties. For the BIPM standard, these data are taken from [3]. Also shown in Table 2 are the relative uncertainties in the ratio $R_K = \dot{K}_{\mathrm{LNMRI/IRD}} \big/ \dot{K}_{\mathrm{BIPM}}$

Table 2. Physical constants and correction factors entering in the determination of air kerma rate and their estimated relative standard uncertainties in the BIPM ^{60}Co beam.

	BIPM values	100 × relative uncertainty (a)		LNMRI/ IRD values	100 × relative uncertainty (a)		100 × relative (a) uncertainty of $R_{\dot{K}}$	
		100 s_i	100 u_i		100 s_i	100 u_i	100 s_i	100 u_i
Physical constants								
dry air density / kg·m^{-3} (b)	1.2930	-	0.01	1.2930	-	0.01	-	-
$(\mu_{\mathrm{en}}/\rho)_{\mathrm{a,c}}$	0.9985	-	0.05	0.9985	-	0.05	-	-
$\bar{s}_{\mathrm{c,a}}$	1.0010	-	0.11	1.0011	-	0.30	-	0.01
W/e / (J·C^{-1})	33.97	-		33.97	-	0.15	-	-
$\bar{g}$ fraction of energy lost to bremsstrahlung	0.0032	-	0.02	0.0032	-	0.02	-	-
Correction factors								
k_{s} recombination losses	1.0015	0.01	0.01	1.0022	0.01	0.01	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	0.01	0.01
k_{at} wall attenuation	1.0398	0.01	0.04	1.0155	0.01	0.08 (c)	0.02	0.11
k_{sc} wall scattering	0.9720	0.01	0.07					
k_{CEP} mean origin of electrons	0.9922	-	0.01	0.997	-	0.10	-	0.10
k_{an} axial non-uniformity	0.9964	-	0.07	1.000	-	0.07	-	0.10
k_{rn} radial non-uniformity	1.0016	0.01	0.02	1.0002	-	0.02	0.01	0.03
V volume / cm^3	6.8028	0.01	0.03	1.0176	-	0.10	0.01	0.10
I ionization current / pA (b)		0.01	0.02	80.122	0.01	0.05	0.01	0.05
I_+ / I_- polarity correction factor		-	-		0.02	-	0.02	-
Uncertainty								
quadratic summation		0.03	0.17		0.03	0.39	0.04	0.22
combined uncertainty		0.17			0.39		0.22	

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

(b) At 101.325 kPa and 273.15 K.

(c) Values obtained by De Almeida *et al* [5].

The correction for scattering from the stem was measured during the previous comparison in 1995 [2]. The effect of attenuation and scatter in the graphite wall of the LNMRI/IRD standard has been determined experimentally in 1986 by adding graphite caps to the chamber wall and extrapolating to zero thickness [6]. The correction for the centre for electron production was derived in 1995 assuming that the mean centre is at 0.78 mm from the inner cavity wall of CC01 type chambers [7].

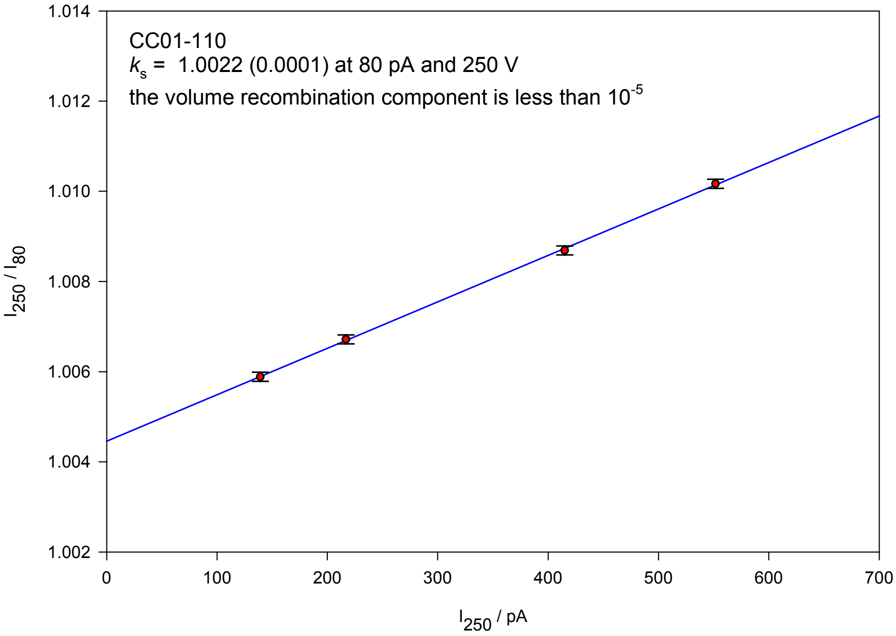
The correction factor for losses due to ion recombination was determined at the BIPM during the present comparison using the method of Niatel as described in [8]. The ratio of the ionization currents with applied voltages of 250 V and 80 V (using both polarities) was measured for four different air kerma rates in the ^{60}Co γ-ray beam. A correction factor k_s of 1.0022 (0.0001) for ion recombination at 250 V and 80 pA was applied to the LNMRI/IRD standard in the BIPM beam. Figure 1 shows the experimental results where, applying the method of Niatel,

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

and $n = 250/80 = 3.125$.

The correction factor for the radial non-uniformity of the BIPM beam over the section of the LNMRI/IRD standard has been estimated from [9]; its numerical value is 1.0002 (0.0001)

Figure 1 LNMRI/IRD primary standard for ^{60}Co air kerma recombination effect



6. Results of the comparison

The value of the air kerma rate obtained by the LNMRI/IRD standard in the BIPM beam using the data in Table 2 refers by convention to an evacuated path length between the source and the standard. The value used for the linear attenuation coefficient of air was 7.8×10^{-3} m^{-1}. The result is given at the reference date of 2003-01-01, 0 h UTC where the half-life of ^{60}Co is taken as 1925.5 d. (u = 0.5 days) [10].

The $\dot{K}_{\text{BIPM}}$ value is derived from a linear fit to all the decay-corrected air kerma rate determinations between 1991 and 2002.

The result of the comparison $R_{\dot{K}} = \dot{K}_{\mathrm{LNMRI/IRD}}/\dot{K}_{\mathrm{BIPM}}$ is given in Table 3. Some of the uncertainties in $\dot{K}$ which appear in both the BIPM and LNMRI/IRD determinations (such as air density, W/e, μ_{en}/ρ, $\bar{g}$, $\bar{s}_{c,a}$ and k_{h}) cancel when evaluating the uncertainty of $R_{\dot{K}}$ (see Table 2). The ratio of the air kerma rates determined by the LNMRI/IRD and the BIPM standards is 1.0007 with a combined standard uncertainty u_{c} of 0.0022. The present result for $R_{\dot{K}}$ agrees with the value obtained previously, well within the statistical uncertainties (see Table 4).

Table 3. Results of the LNMRI/IRD-BIPM comparison of primary standards for air kerma

$\dot{K}_{\mathrm{LNMRI}}$ / mGy·s^{-1}	$\dot{K}_{\mathrm{BIPM}}$ / mGy·s^{-1}	$R_{\dot{K}} = \dot{K}_{\mathrm{LNMRI}}/\dot{K}_{\mathrm{BIPM}}$	u_{c}
2.0990	2.0975	1.0007	0.0022

Table 4. Previous comparison results with the LNMRI/IRD CC01-110 chamber

Year of comparison	$\dot{K}_{\mathrm{LNMRI/IRD}}$ / mGy·s^{-1}	$\dot{K}_{\mathrm{BIPM}}$ / mGy·s^{-1}	$R_{\dot{K}} = \dot{K}_{\mathrm{LNMRI/IRD}}/\dot{K}_{\mathrm{BIPM}}$	u_{c}
1986	0.1209	0.1208	1.0006	0.0026
1995	6.0102	6.0077	1.0004	0.0023
2003	2.0990	2.0975	1.0007	0.0022

7. Discussion

The comparison result for the LNMRI/IRD uses an experimental determination for the wall effect. It is known that this is not a reliable method to determine this correction for a chamber of cylindrical shape such as the LNMRI/IRD standard. Consequently, in accordance with the recommendation of the CCRI [11] in 2003, the LNMRI/IRD is currently using Monte Carlo methods to produce a new factor. When this evaluation is published, it will be taken into account to modify the comparison value.

The BIPM is also in the process of determining wall corrections using Monte Carlo methods [12] and will publish the new values in a summary report that includes all present comparison values. This will occur once the CCRI has approved the results.

8. Conclusion

The result of the present comparison shows close agreement between the LNMRI/IRD and the BIPM standards for ^{60}Co air kerma within the estimated uncertainties. This result confirms the good agreement observed in the previous comparisons and the stability of the LNMRI/IRD standard.

Future determinations of the wall effect by the LNMRI/IRD and the BIPM may change this comparison result.

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