Final Report of the SIM ^{60}Co Air-Kerma Comparison

(KCDB Entry SIM.RI(I)-K1)

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Abstract

Transfer chambers were used to compare the standards for ^{60}Co air kerma maintained by seven laboratories. Six of the laboratories are members of the Sistema Interamericano de Metrología (SIM) regional metrology organization while the seventh is the International Atomic Energy Agency (IAEA) laboratory in Vienna. The National Research Council (NRC) acted as the pilot laboratory for the comparison. Because of the participation of laboratories holding primary standards, the comparison results could be linked to the key comparison reference value maintained by the Bureau International des Poids et Mesures (BIPM). The results for all laboratories were within the expanded uncertainty (two standard deviations) of the reference value. The estimated relative standard uncertainty of the comparison between any pair of laboratories ranged from 0.5 % to 1.0 %. The largest discrepancy between any two laboratories was 1.0 %.

1 Introduction

A comparison of standards for ^{60}Co air kerma was carried out between seven laboratories. Six of the laboratories were national metrology institutes (NMIs) and members of the Sistema Interamericano de Metrología (SIM) regional metrology organization. The seventh was the International Atomic Energy Agency (IAEA) laboratory in Vienna. The National Research Council (NRC, Ottawa) was the pilot laboratory for the comparison that took place between 2000 and 2002. The comparison was carried out using three transfer ionization chambers that were circulated among the laboratories. Two of the laboratories (the National Institute of Standards and Technology (NIST) and the NRC) maintain primary standards for air kerma and their participation in the comparison allows the results to be linked to the key comparison data base (KCDB) [1] of the Mutual Recognition Arrangement of the International Committee for Weights and Measures (CIPM MRA) [2].

This report describes the protocol used for the comparison and presents the results in tabular and graphical form. It describes how previous comparisons between the NRC and the BIPM and between the NIST and the BIPM can be used to link the data of this comparison to the key comparison reference value. The degree of equivalence is calculated for each laboratory with respect to the reference value, as well as the degrees of equivalence between any pair of laboratories.

2 Participating Laboratories

The participating laboratories are listed in Table 1.

Table 1. Listing of the laboratories that participated in the ^{60}Co air-kerma comparison. The NIST and the NRC are primary standards laboratories, while the others operate as secondary standards laboratories.

Laboratory		Country
CNEA	Comisión Nacional de Energía Atómica	Argentina
IAEA	International Atomic Energy Agency	-
ININ	Instituto Nacional de Investigaciones Nucleares	Mexico
IRD[1]	Instituto de Radioproteçao e Dosimetria	Brazil
LSCD[2]	Laboratorio Secundario de Calibración Dosimetrica	Venezuela
NIST	National Institute of Standards and Technology	United States
NRC	National Research Council	Canada

[1]The designated institute for the CIPM MRA is known as the Laboratório Nacional de Metrologia das Radiações Ionizantes (LNMRI).

[2]Note that Venezuela has not yet signed the CIPM MRA.

3 Transfer Chambers

Three Exradin A12 ionization chambers with serial numbers 101, 149 and 150 were used in the comparison. These are cylindrical chambers constructed from C552 plastic. The main characteristics of the A12 ionization chamber are summarized in Table 2. No electrometer was provided with the chambers so each laboratory was responsible for their own measurement of the electrical current or charge arising from the ion pairs produced in the air cavity.

Table 2. Characteristics of the cylindrical A12 ionziation chamber.

Characteristic		Nominal value
Dimensions	Inner diameter	6.1 mm
	Wall thickness	0.5 mm
	Cavity length	24.7 mm
	Tip to center of collecting volume	12.9 mm
Electrode	Diameter	1.0 mm
	Height	21.6 mm
Volume	Air cavity	0.65 cm^3
Wall	Material	C552 plastic
	Density	1.76 g cm^{-3}
Buildup cap	Material	C552 plastic
	Thickness	2.7 mm
Applied voltage		300 V
Sign of collected charge		Positive

4 Calibration Coefficients

The comparison of the air-kerma standards was made indirectly by comparing the calibration coefficients, N_K, determined by the individual laboratories for the three transfer chambers. The calibration coefficient is given by

$$N_K = \dot{K}_a / \dot{Q}, \qquad (1)$$

where $\dot{Q}$ is the charge per unit time or current, I, due to positive ions produced in the cavity gas when the air-kerma rate is $\dot{K}_a$. All laboratories were asked to report values of N_K that would apply if positive charge were collected. Each chamber was positioned so that the center of its sensitive volume was at the reference point and $\dot{K}_a$ is the air-kerma rate that would be present at the reference point in the absence of the chamber.

In order to determine the current, I, from the measured current, I_m, a number of corrections must be considered. These include:

Leakage current: This is the current measured when the primary radiation field is blocked. For all the chambers at all the laboratories, the leakage current was less than 0.01 % of the current measured when the chamber was exposed to the ^{60}Co beam. In practice, the measured leakage current includes contributions from background radiation.

Recombination: No correction for recombination was applied. The volume recombination is negligible for air-kerma rates less than 15 mGy s^{-1} for this chamber type and polarizing voltage and the initial recombination will be the same for all the laboratories.

Temperature and pressure normalization: For all the laboratories, the measured ionization current of the transfer chambers was normalized to a temperature of 295.15 K and a pressure of 101.325 kPa. (This is consistent with normal practice at the NIST and the NRC but several of the other laboratories would normally use a reference temperature of 293.15 K.)

Humidity: None of the laboratories applied a correction to their measured current (or charge) for humidity. As long as the relative humidity is within the range from 10 to 80 % for all the laboratories, the effect on the chamber calibration coefficient of variations in the humidity is less than 0.1 %.

Radial non-uniformity: It was assumed than any correction for radial non-uniformity would be similar for all the ^{60}Co beams and thus need not be applied when comparing calibration coefficients.

5 Air-Kerma Standards

The air-kerma standards of the secondary laboratories are all traceable to the air-kerma standard maintained by the BIPM. Three of the laboratories (the CNEA, the IAEA and the IRD) have their secondary standards calibrated directly by the BIPM. The other two (the ININ and the LSCD) have their chambers calibrated at the IAEA, which in turn is traceable to the BIPM.

The BIPM, the NIST and the NRC maintain primary standards for air kerma that are based on graphite-walled ionization chambers. Work carried out at several national laboratories has led to improved values for the correction factors associated with cavity chambers. All three laboratories have declared new values for their ^{60}Co air-kerma standards since the measurements associated with this comparison were completed. We have chosen to express the results of the comparison in terms of the new standards, so that they would reflect what would be expected if the comparison were repeated today. The changes applied to the original data are described below.

The BIPM primary standard is based on a graphite-walled chamber that is in the shape of a flat cylindrical box [3]. The correction factors have recently been re-evaluated [4,5], leading to an increase of 0.54 % in the measured air-kerma rate in a given field. We have adjusted the results of the secondary laboratories as if they were based on this value for the BIPM standard. This was achieved by increasing the original values of N_K by 0.54 %.

Previously, the NIST standard for ^{60}Co air kerma was based on the weighted average of results obtained with six spherical graphite-walled ionization chambers [6]. Several of the correction factors associated with these chambers have been re-evaluated [7] and the new air-kerma standard is based on the mean of results obtained with just two of the original chambers. The estimated relative standard uncertainty of the air-kerma rate at the reference point is 0.31 %. The NIST has reported that calibration coefficients based on the new standard are about 1.1 % larger than those obtained using the old standard [8], in close agreement with the increase of 1.05 % predicted by the re-evaluation of the correction factors [7]. The results reported here are based on the re-evaluated standard and they were obtained by increasing the original values of N_K by 1.05 %.

The NRC standard for ^{60}Co air kerma is based on a cylindrical graphite-walled ionization chamber [9]. The estimated relative standard uncertainty of the air-kerma rate at the reference point is 0.32 %. Several of the correction factors have been re-evaluated since this comparison was completed [10], and the results reported here are based on the re-evaluated standard. They were obtained by increasing the original values of N_K by 0.59 %.

6 Chamber Calibrations

The chambers were circulated among the laboratories as follows: the NRC to the IAEA; the IAEA to the NRC; the NRC to the CNEA; the CNEA to the IRD; the IRD to the NRC; the NRC to the LSCD; the LSCD to the ININ; the ININ to the NRC; the NRC to the NIST; the NIST to the IAEA; the IAEA to the NRC. By having the chambers return several times to the NRC, their stability could be verified.

The conditions under which the chambers were calibrated were similar at all of the laboratories. Each chamber was fitted with its build-up cap and mounted in the reference plane at approximately 1 m from the source in a 10 cm by 10 cm field. The polarizing voltage was set to 300 V and laboratories were asked to report values of N_K that would apply if positive charge were collected. None of the laboratories used a shutter or source transfer system to define the irradiation time. Instead, each chamber was irradiated continuously during the measurement session and the charge accumulated by the electrometer was measured at well-defined times.

7 Results

The calibration coefficients, N_K , obtained by the different laboratories for each of the three transfer chambers are given in Table 3. The chambers were calibrated on two separate occasions at the IAEA and on five separate occasions at the NRC. The values reported in Table 3 for these laboratories are the averages of the repeated calibrations. The ratios of the calibration coefficients for each laboratory to that of the NRC are given in columns 3, 5 and 7. The mean values of the ratios for the three chambers and for each of the laboratories are given in the final column. The spread of these mean values is about 1 %.

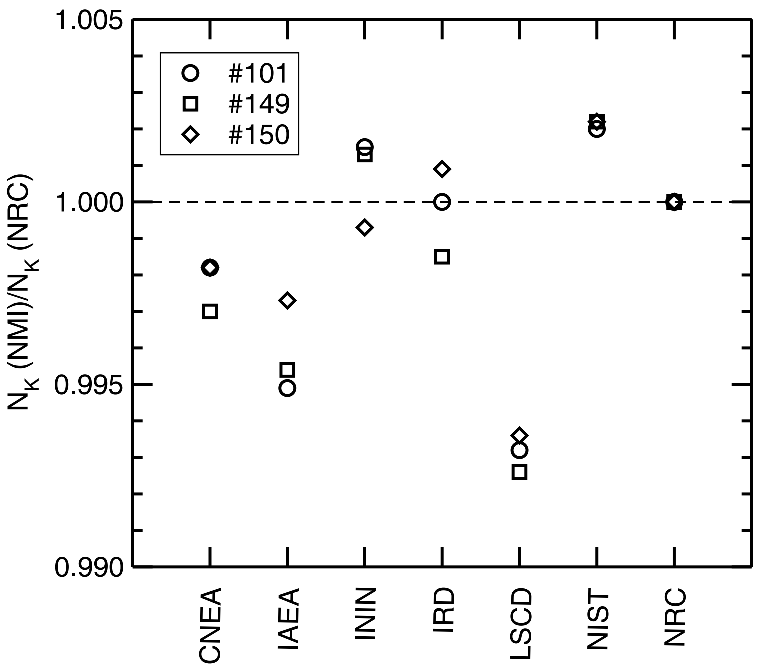
Table 3. The air-kerma calibration coefficients, expressed as mGy/nC, obtained by each laboratory for each ionization chamber are given in columns 2, 4 and 6. Columns 3, 5 and 7 report the ratio of the calibration coefficient for a given NMI to that of NRC while column 8 gives the mean value of the ratio for all three chambers. Note that the calibration coefficients have been corrected for recent changes to the primary standards of the BIPM, the NIST and the NRC.

Laboratory	#101		#149		#150		Mean
CNEA	45.20	0.9982	45.84	0.9970	45.06	0.9982	0.9978
IAEA	45.05	0.9949	45.77	0.9954	45.02	0.9973	0.9959
ININ	45.35	1.0015	46.04	1.0013	45.11	0.9993	1.0007
IRD	45.28	1.0000	45.91	0.9985	45.18	1.0009	0.9998
LSCD	44.97	0.9932	45.64	0.9926	44.85	0.9936	0.9931
NIST	45.37	1.0020	46.08	1.0022	45.24	1.0022	1.0021
NRC	45.28	1.0000	45.98	1.0000	45.14	1.0000	1.0000

The ratios of the calibration coefficients obtained by each laboratory for each chamber to that obtained by the NRC are shown graphically in Figure 1. Ideally, all three calibration-coefficient ratios for each laboratory should be approximately the same. Instead, differences of up to 0.2 % are apparent. Calibrations were repeated at the NRC five times during the course of the comparison, and these results are shown in Figure 2. The calibration coefficients for each one of the three chambers were always consistent to better than 0.05 %. Thus, the differences apparent in Figure 1 are probably not due to changes in chamber response due to transport.

Although Figure 2 shows that the three chambers behave in the same way on repeated calibrations, there are differences between the mean values of each set of three that are substantially greater that the variation within the set. This suggests that some common parameter was not measured with adequate accuracy during repeated calibrations at the NRC. A discrepancy of about 0.3 °C in the measurement of air temperature would lead to an apparent change in the calibration coefficient of about 0.1 %, and we speculate that this is the most likely cause of the differences between the repeated calibrations. The NRC calibration coefficient for each chamber is based on the mean of all the repeated values for that chamber.

Figure 1. Graphical summary of the ratio of the air-kerma calibration coefficients reported by each laboratory to that of the NRC for each of the ionization chambers.



8 Uncertainties

Each laboratory reported the key components contributing to their uncertainty budget, and the results are summarized in Table 4. The uncertainty of the primary standards as reported by the NIST and the NRC are listed in the row labeled "N_K of reference chamber". Components 2, 3, 5 and 6 in this section of the table have already been incorporated into their overall uncertainty. However, there will be an additional component due to source decay because both the NIST and the NRC use the ^{60}Co half-life to track the air-kerma rate as a function of time.

The ionization-chamber current is obtained by all of the laboratories by measuring the charge collected in a known time interval. Most of the laboratories assume the uncertainty of the measured time interval is negligible and that the uncertainty of the current is dominated by the uncertainty of the charge. If the laboratory reported separate uncertainties for the charge and time, they have been combined in quadrature to obtain the uncertainty of the current.

Figure 2. Summary of the results obtained for repeated chamber calibrations at the NRC. The calibration coefficient for each chamber's repeat measurement is shown with respect to the average of all five calibration coefficients.

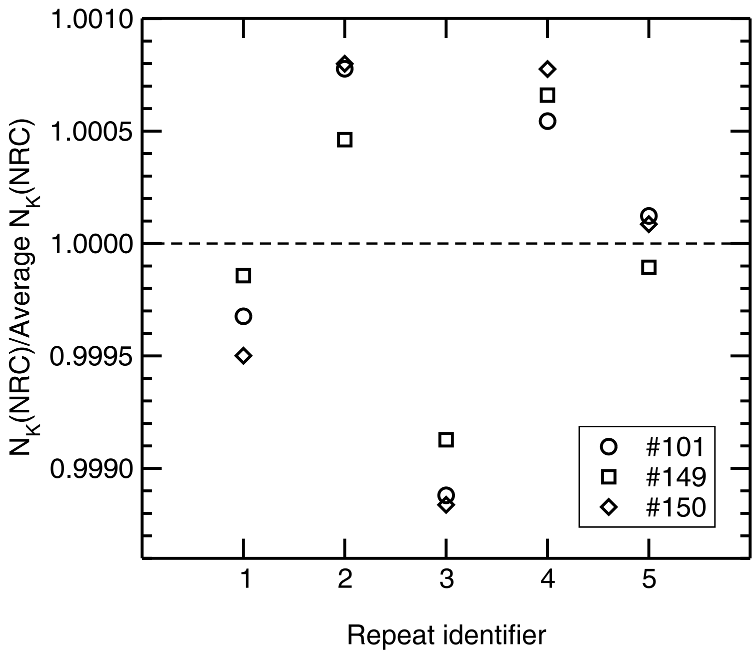


Table 4. Summary of the standard uncertainty estimates reported by the laboratories participating in the comparison.

		Relative standard uncertainty (%)													
	Source of uncertainty	CNEA		IAEA		ININ		IRD		LSCD		NIST		NRC	
		A	B	A	B	A	B	A	B	A	B	A	B	A	B
	Related to air kerma rate														
1	N_K of ref. chamber	-	0.36	-	0.2	-	0.69	-	0.18	-	0.4	0.11	0.29	0.07	0.31
2	Long-term stability of ref. chamber	-	0.07	-	0.2	0.34	-		0.2	-	0.1	-	-	-	-
3	Positioning of ref. chamber	-	-	-	0.01	-	-	0.01	0.1	-	0.02	-	-	-	-
4	Source decay	-	-	-	-	-	0.01	-	-	-	-	-	0.01	-	0.02
5	Temperature and pressure		0.04	0.03	0.1	-	0.02		0.39	0.03	0.1	-	-	-	-
6	Current	0.02	0.3	0.05	0.1	0.03	-	0.01	0.11	0.05	0.1	-	-	-	-
	Related to the transfer instrument														
7	Chamber positioning	-	0.03	-	-	-	0.06	0.01	0.03	-	0.02	-	0.02	0.01	-
8	Temperature, pressure, humidity	-	0.04	0.03	0.1	-	0.02	-	0.39	0.03	0.1	-	0.07	0.04	0.06
9	Current	0.02	0.3	0.05	0.1	0.04	0.30	0.04	0.29	0.05	0.1	0.10	0.11	0.06	0.06
	Quadratic summation	0.03	0.56	0.08	0.35	0.34	0.76	0.04	0.70	0.08	0.46	0.15	0.32	0.10	0.32
	Combined standard uncertainty	**0.57**		**0.36**		**0.83**		**0.70**		**0.47**		**0.35**		**0.34**	

9 Degrees of Equivalence

Two of the laboratories participating in the present comparison (the NRC and the NIST) maintain primary standards for air kerma and have participated in previous comparisons with the BIPM. Thus, we can link the results of this comparison to the air-kerma standard maintained by the BIPM. For the NIST, using the comparison results reported in [11] and adjusting for the recent changes in standards gives 1.0031(40) for $K_{\mathrm{a,NIST}} / K_{\mathrm{a,BIPM}}$, while the corresponding result for the NRC [12] is 1.0025(31). Note that $K_{\mathrm{a,NIST}}$, $K_{\mathrm{a,BIPM}}$ and, more generally, $K_{\mathrm{a,NMI}}$, are the values of the air kerma that would be reported by each national standard for identical irradiation conditions. The numbers in parentheses represent the standard uncertainties in the last two digits of the ratios. Although both the NIST and the NRC could be used as the link, in what follows, we have used the NRC result which is more robust as they measured the chambers five times. This also enables the NIST to update their 1996 comparison value in the KCDB.

In this comparison, each NMI reported calibration coefficients. However, the calibration coefficients are proportional to the air kerma as determined by the national standard of the NMI, so ratios of calibration coefficients will be equal to air-kerma ratios. In the following, any air-kerma ratio can be replaced by the numerical value of the equivalent ratio of calibration coefficients.

The CCRI meeting in 1999 agreed that, in an air-kerma key comparison, the BIPM value of the air kerma would be taken as the key comparison reference value (KCRV). Furthermore, the Key Comparison Working Group of the CCRI(I) confirmed at its meeting in April 2008 that, for these dosimetry comparisons, the degree of equivalence, D_i, is defined as the difference between the air kerma measured by a participating NMI and the KCRV, divided by the KCRV, and the expanded uncertainty of this difference. That is,

$$D_i = (K_{a,i} - K_{a,BIPM}) / K_{a,BIPM} = K_{a,i} / K_{a,BIPM} - 1 = R_i - 1, \quad (2)$$

where the index, *i*, is used to identify the NMI and

$$R_i = K_{a,i} / K_{a,BIPM}. \quad (3)$$

R_i for each NMI can be found by multiplying $N_{K,NMI} / N_{K,NRC}$ as reported in Table 3 by $K_{a,NRC} / K_{a,BIPM}$, as given above.

The uncertainty, $u_{R,i}$, of R_i is obtained by combining the uncertainty of the calibration coefficients reported by the NMI, the air-kerma uncertainty of the BIPM standard and the uncertainty of the link through the ratio $K_{a,NRC} / K_{a,BIPM}$, including the effects of correlations between the laboratories. We denote by u_i the overall relative uncertainty reported by a particular NMI for its calibration coefficient and by $u_i(k)$ a particular component, *k*, of the uncertainty. We use u_r to denote the relative uncertainty of the link through $K_{a,NRC} / K_{a,BIPM}$ and u_{stab} to denote the uncertainty due to the long term stability of the transfer chambers. Then

$$u_{R,i}^2 = u_i^2 + u_{BIPM}^2 + u_r^2 + u_{stab}^2 - \sum_k (f_k u_i(k))^2 - \sum_k (f_k u_{BIPM}(k))^2, \quad (4)$$

where the last two terms account for any correlated quantities between the NMI and the BIPM. The factor, f_k, which can range from zero to unity, accounts for the possibility that the quantities are not fully correlated.

In this comparison, there are several correlated quantities. All of the secondary standards laboratories participating in this comparison are traceable to the BIPM and thus the uncertainty associated with the BIPM air-kerma standard must be subtracted (0.17 %). Correlated quantities associated with the air-kerma standards of the primary laboratories [13] include the air density (ρ_{air}), the correction for humidity (k_h), the mass energy absorption coefficient $(\bar{\mu}_{en} / \rho)$, the radiative correction (g) and the product of the energy to create an ion pair and the graphite-to-air stopping power ratio $(W/e \cdot \bar{s}_{\mathrm{c,a}})$. The wall correction factor (k_{wall}), which is obtained by all laboratories using Monte Carlo techniques, may also be considered to be correlated, but with a value of f_k less than unity [13]. The uncertainties assigned to several of these quantities are quite small so they need not be considered. The quantities for which the effects of correlations have been calculated are $W/e \cdot \bar{s}_{\mathrm{c,a}}$, $\bar{\mu}_{\mathrm{en}}/\rho$ and k_{h}.

At first sight, one might set u_{r} to 0.31 %, which is the uncertainty given earlier for $K_{\mathrm{a,NRC}}/K_{\mathrm{a,BIPM}}$. However, the uncertainty of the link through the NRC to the BIPM standard as the link depends on the stability of the results obtained using transfer chambers and not on the value of air kerma determined by either laboratory. According to [12] a reasonable estimate for u_{r} is 0.10 %.

The value for u_{stab} was obtained as recommended by Burns and Allisy-Roberts [14] by calculating the standard deviation of the repeated measurements at the NRC for each of the chambers. The data are shown graphically in Figure 2 and give values of the relative standard deviation for each of the chambers of 0.08 %, 0.06 % and 0.08 %. The mean value of 0.07 % was used for u_{stab}. As discussed in Section 7 it is likely that some of this uncertainty is due to a problem recalibrating the chambers at the NRC. It also may be that some of the uncertainty attributed to u_{stab} is already included in the uncertainties quoted by the NMIs. We have not tried to quantity these effects.

The standard uncertainty of D_i is approximately equal to the relative uncertainty of R_i because R_i is close to unity. By convention, the uncertainty, U_i, associated with D_i is given as twice the standard uncertainty. Values for D_i and U_i are given in the shaded columns of Table 5 and are shown in graphical form in Figure 3.

The degree of equivalence, D_{ij}, between any pair of NMIs, *i* and *j*, is given by

$$D_{ij} = D_i - D_j = R_i - R_j, \quad (5)$$

with expanded uncertainty U_{ij} .The standard uncertainty of D_{ij} is given by

$$u_{ij}^2 = u_i^2 + u_j^2 + 2 \cdot u_{\text{stab}}^2 - \sum_k (f_k u_i(k))^2 - \sum_k (f_k u_j(k))^2, \quad (6)$$

where the notation is similar to that used with equation (4). The form of equation (6) may seem surprising because it involves only the relative uncertainties, u_i and u_j, of the NMI air-kerma determinations and there is no term related to the uncertainty of $K_{\text{a,BIPM}}$. This follows by making the reasonable assumption that, for purposes of estimating the uncertainties, all of the air-kerma determinations can be considered equal. Note that u_{stab} enters twice in equation (6) (once for each laboratory) but only once in equation (4). The correlations that must be considered have been described earlier.

Values for D_{ij} and its associated expanded uncertainty are given in Table 5 for each pair of laboratories participating in the comparison. The largest discrepancy between any pair of laboratories is just under 1 %. In no case is the difference between any pair of laboratories larger than its expanded uncertainty.

10 Conclusions

A comparison of air-kerma standards has been carried out between seven laboratories. The participating laboratories included the IAEA and six NMIs that are members of the SIM regional metrology organization. Three ionization chambers were circulated among the seven laboratories and each laboratory was asked to provide calibration coefficients and associated uncertainties. The ionization chambers were returned several times to NRC during the comparison and they showed satisfactory stability.

Because two laboratories maintaining primary standards for air kerma participated in the comparison, and because these laboratories have participated in earlier comparisons with the BIPM, the results of all the laboratories participating in this comparison could be compared to the key comparison reference value maintained by the BIPM. The IRD subsequently conducted a comparison at the BIPM and so the later result supersedes the result in this report. For results to be included in the KCDB, the participant must be a signatory to the CIPM MRA and, unfortunately, this is not yet the case of Venezuela.

The difference of each result with respect to the KCRV, expressed as a fraction, was calculated for each laboratory and in each case it was smaller than the corresponding expanded uncertainty, indicating that each laboratory has a satisfactory realization of the gray for ^{60}Co air kerma.

The largest discrepancy between any pair of laboratories is just under 1 %, very close to the expanded uncertainty. This suggests that there is still room for improvement in establishing the ^{60}Co air kerma, as the uncertainties associated with the transfer system are almost negligible.

Table 5. The degree of equivalence of each laboratory with respect to the reference value is given in the shaded columns. The degree of equivalence is the difference between the value obtained by a particular NMI and that obtained by the BIPM, divided by the BIPM value, along with the expanded uncertainty on this fractional difference. The degrees of equivalence between any pair of laboratories are given in the rest of the table.

Lab *j* ⇒

Lab *i* ⇓

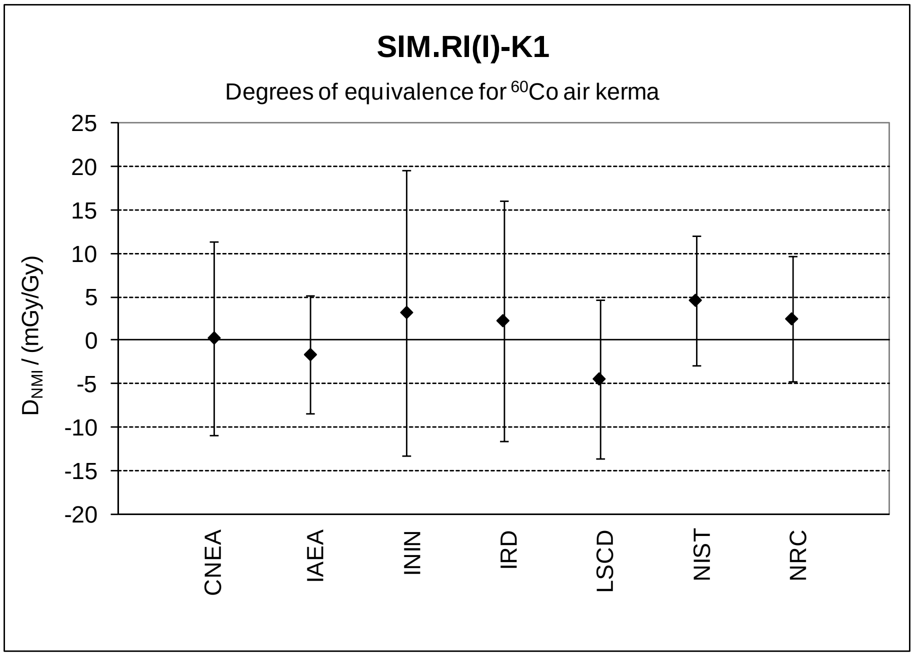
			CNEA		IAEA		ININ		IRD		LSCD	
	D_i /(mGy/Gy)	U_i	D_{ij} /(mGy/Gy)	U_{ij}	D_{ij} /(mGy/Gy)	U_{ij}	D_{ij} /(mGy/Gy)	U_{ij}	D_{ij} /(mGy/Gy)	U_{ij}	D_{ij} /(mGy/Gy)	U_{ij}
CNEA	**0.3**	11.2			**1.9**	12.8	**-2.9**	19.7	**-2.0**	17.5	**4.7**	14.1
IAEA	**-1.6**	6.8	**-1.9**	12.8			**-4.8**	17.6	**-3.9**	15.1	**2.8**	11.0
ININ	**3.2**	16.4	**2.9**	19.7	**4.8**	17.6			**0.9**	21.3	**7.6**	18.6
IRD	**2.3**	13.8	**2.0**	17.5	**3.9**	15.1	**-0.9**	21.3			**6.7**	16.3
LSCD	**-4.4**	9.1	**-4.7**	14.1	**-2.8**	11.0	**-7.6**	18.6	**-6.7**	16.3		
NIST	**4.6**	7.4	**4.3**	13.1	**6.2**	9.6	**1.4**	17.8	**2.3**	15.4	**9.0**	11.4
NRC	**2.5**	7.2	**2.2**	13.0	**4.1**	9.5	**-0.7**	17.7	**0.2**	15.3	**6.9**	11.3

Lab *j* ⇒

Lab *i* ⇓

			NIST		NRC	
	D_i /(mGy/Gy)	U_i	D_{ij} /(mGy/Gy)	U_{ij}	D_{ij} /(mGy/Gy)	U_{ij}
CNEA	**0.3**	11.2	**-4.3**	13.1	**-2.2**	13.0
IAEA	**-1.6**	6.8	**-6.2**	9.6	**-4.1**	9.5
ININ	**3.2**	16.4	**-1.4**	17.8	**0.7**	17.7
IRD	**2.3**	13.8	**-2.3**	15.4	**-0.2**	15.3
LSCD	**-4.4**	9.1	**-9.0**	11.4	**-6.9**	11.3
NIST	**4.6**	7.4			**2.1**	9.4
NRC	**2.5**	7.2	**-2.1**	9.4		

Figure 3. Graphical representation of the degrees of equivalence for the various laboratories participating in the comparison. The degree of equivalence is the difference between the value obtained by a particular NMI and that obtained by the BIPM, divided by the BIPM value, along with the expanded uncertainty on this fractional difference. The expanded uncertainty corresponds to twice the standard uncertainty.



11 Acknowledgements

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