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Comparison of the standards for air kerma of the VSL and the BIPM for ^{60}Co gamma radiation

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Abstract

An indirect comparison of the standards for air kerma of the Dutch Metrology Institute (VSL), The Netherlands, and of the Bureau International des Poids et Mesures (BIPM) was carried out in the ^{60}Co radiation beam of the BIPM in September 2005. The comparison result, based on the calibration coefficients for three transfer standards and expressed as a ratio of the VSL and the BIPM standards for air kerma, is 0.9985 with a combined standard uncertainty of 2.2×10^{-3}. The latest result agrees with the result of the previous comparison in ^{60}Co γ rays, made in 1996 and updated for recent changes made to the standards to give a value of 0.9982 (37).
The degrees of equivalence between the VSL and the other participants in the key comparison BIPM.RI(I)-K1 have been calculated and the results are presented in the form of a matrix. A graphical presentation is also given.

1. Introduction

The previous comparison of the air kerma standards of the Dutch Metrology Institute (VSL) of The Netherlands and the Bureau International des Poids et Mesures (BIPM) for ^{60}Co gamma radiation was made in 1996 [1]. An indirect comparison between both laboratories was carried out in September 2005.

The air kerma standard of the VSL for ^{60}Co is a graphite-walled spherical cavity ionization chamber of volume 4.85 cm^3 as described in [2]. The BIPM standard is a parallel-plate graphite cavity ionization chamber with a volume of about 6.8 cm^3 as described in [3]. The changes made recently to both standards are described in [4] and [5] for the BIPM and the VSL, respectively.

The comparison was undertaken using three ionization chambers of the VSL as transfer standards. The result of the comparison is given in terms of the mean ratio of the calibration coefficients of the transfer chambers determined at the two laboratories under the same reference conditions. The ionization chambers NE2611, serial numbers 118, 119 and 120 were used for the present comparison.

The comparison result has been approved by the Consultative Committee for Ionizing Radiation (CCRI) and the degrees of equivalence between the VSL and the other participants in this ongoing comparison for air kerma have been evaluated and are presented in the form of a matrix in Section 5. A graphical presentation is also given.

2. Determination of the air kerma

The air kerma rate is determined by

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

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 by bremsstrahlung production in air,
$(\mu_{\text{en}}/\rho)_{\text{a,c}}$	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.

Reference conditions

The reference conditions for the air kerma determination at the BIPM are given in Table 7 of [6]:

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

The reference conditions at the VSL are identical to those at the BIPM.

Physical data and correction factors

The data concerning the various factors entering in the determination of air kerma in the ^{60}Co beam using the primary standards of the VSL and of the BIPM are shown in Table 1. They include the physical constants [7], 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 [6]. The data for the VSL standard are taken from [2, 5].

Reference values

The BIPM reference air kerma rate value $\dot{K}_{\mathrm{BIPM}}$ is taken from the mean of the four measurements made around the period of the comparison. The $\dot{K}_{\mathrm{BIPM}}$ values refer to an evacuated path length between source and standard and are given at the reference date of 2005-01-01, 0 h UTC. The half-life of ^{60}Co was taken as 1925.5 days (u = 0.3 days) [8]. The same half-life is used at the VSL. The $\dot{K}_{\mathrm{VSL}}$ used to calibrate the transfer chambers is a running average over the last 5 years referred to local time as are the calibration coefficients of the transfer chambers.

Table 1. Physical constants and correction factors entering in the determination of air kerma and their estimated relative uncertainties in the BIPM ^{60}Co beam

	BIPM			VSL		
	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
$(\mu_{\mathrm{en}}/\rho)_{\mathrm{a,c}}$	0.9989	0.01	0.05	0.999	–	0.05
$\bar{s}_{\mathrm{c,a}}$	1.0010	–	0.11 (3)	1.0006	–	0.11 (3)
W/e (J/C)	33.97	–		33.97	–	
$\bar{g}$ bremsstrahlung loss	0.0031	–	0.02	0.0032	–	0.03
Correction factors :						
k_{g} re-absorption	0.9996	–	0.01			
k_{h} humidity	0.9970	–	0.03	0.9970	–	0.03
k_{s} recombination losses	1.0022	0.01	0.02	1.0038		0.03
k_{st} stem scattering	1.0000	0.01	–	0.999		0.05
k_{wall} wall attenuation and scattering	1.0011	–	– (5)	1.0214		0.08
k_{an} axial non-uniformity	1.0020	–	– (5)	1.000	–	0.09
k_{rn} radial non-uniformity	1.0015	–	0.02	1.000		0.02
V chamber volume /cm^3	6.7967 (4)	–	0.08 (5)	4.845	–	0.10
I ionization current /pA		0.01	0.02		0.02	0.02
Relative standard uncertainty						
quadratic summation		0.02	0.15		0.02	0.21
combined uncertainty		**0.15**			**0.21**	
Relative standard uncertainty neglecting contributions from physical constants and k_{h}						
quadratic summation	0.03			0.19		
combined uncertainty	**0.19**					

(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 $\bar{s}_{\mathrm{c,a}}$ and W/e

(4) For standard CH5-1, the measured volume 6.8028 cm^3 reduced by the factor 1.0009 [4]

(5) The uncertainties for k_{wall} and k_{an} are included in the determination of the effective volume [4]

The characteristics of the BIPM and VSL beams are given in Table 2.

Table 2. **Parameters of the ^{60}Co beams at the VSL and the BIPM**

^{60}Co beam	Nominal $\dot{K}$ (2005-01-01)	Source dimensions /mm		Scatter contribution/ energy fluence	Field size at 1 m
		diameter	length		
VSL source	9.3 mGy s^{-1}	21	25$^{(*)}$	~ 21 %	10 cm × 10 cm
BIPM source	1.6 mGy s^{-1}	20	5.6	14 %	10 cm × 10 cm

$^{(*)}$ nominal height of the ^{60}Co volume inside the source container

3. The transfer chambers and their calibration

The comparison of the VSL and BIPM standards was made indirectly using the calibration coefficients N_K for the three transfer chambers given by

$$N_{K,\mathrm{lab}} = \dot{K}_{\mathrm{lab}} / I_{\mathrm{lab}} \,, \qquad (2)$$

where $\dot{K}_{\mathrm{lab}}$ is the air kerma rate at each lab and I_{lab} is the ionization current of a transfer chamber measured at the VSL or the BIPM. The current is corrected for the effects and influences described in this section.

The ionization chambers NE2611 serial numbers 118, 119 and 120, belonging to the VSL, were the transfer chambers used for this comparison. Their main characteristics are listed in Table 3.

Table 3. **Characteristics of the VSL transfer chambers**

Characteristic/Nominal values		NE2611
Dimensions	Inner diameter	7.5 mm
	Wall thickness	0.5 mm
	Cavity length	9.22 mm
	Tip to reference point	5 mm
Electrode	Length	6.4 mm
	Diameter	1.7 mm (hollow)
Volume	Air cavity	0.3 cm^3
Wall	Material	graphite
	Density	1.7 g cm^{-3}
Voltage applied to outer electrode	Positive polarity	200 V

The experimental method for calibrations at the VSL is described in this report and that for the BIPM in [6] and the essential details are reproduced here.

Positioning

At each laboratory the chambers were positioned with the stem perpendicular to the beam direction and with the appropriate marking on the stem (engraved text) facing the source.

Applied voltage and polarity

A collecting voltage of 200 V (positive polarity) was applied to the outer electrode of each chamber at least 30 min before any measurements were made. No corrections were applied at either laboratory for polarity.

Volume recombination

Volume recombination is negligible at a dose rate of less than 15 mGy s^{-1} for these chambers at these polarizing voltages, and the initial recombination loss will be the same in the two laboratories. Consequently, no correction for recombination was applied.

Charge and leakage measurements

The charge Q collected by each transfer chamber was measured using a Keithley electrometer, model 642 at the BIPM. The source is operational during the entire exposure series and the charge is collected for the appropriate, electronically controlled, time interval. At the VSL, the charge was measured, using a Keithley electrometer model 6517A, and the chambers were pre-irradiated for at least 15 min (≈ 7 Gy). At the BIPM, pre-irradiation was for at least 30 min (≈ 2 Gy) before any measurements were made.

The ionization current measured from each transfer standard was corrected for the leakage current at each laboratory. This correction was less than 2×10^{-4} and less than 3×10^{-4} in relative value, at the BIPM and the VSL, respectively.

Ambient conditions

During a series of measurements, the air temperature is measured for each current measurement and it was stable to better than 0.01 °C at the BIPM and 0.05 °C at the VSL. The measurements are normalized to 293.15 K and 101.325 kPa at both the BIPM and the VSL. Relative humidity is controlled at (50 ± 5) % at the BIPM and the VSL. Consequently, no correction for humidity is applied to the ionization current measured.

Radial non-uniformity correction

At the BIPM, the corrections applied to the ionization current for the radial non-uniformity would only be 1.0002 for the transfer chambers with an uncertainty of 2×10^{-4}. No non-uniformity correction is made. At the VSL, no correction is applied to the ionization current for the radial non-uniformity of the beam.

Energy spectrum influence

The difference in the scatter contributions of the two ^{60}Co beams (14 % and 21 % given in Table 2) can result in a difference to the response of a given transfer chamber type of up to 1 part in 10^3. However, measurements made at the BIPM for NE2611 chambers in beams with scatter contributions of 14 % and 21 % show no significant difference at a few parts in 10^4 in their calibration coefficient.

Uncertainties

Contributions to the relative standard uncertainty of $N_{K,\mathrm{lab}}$ are listed in Table 4. Some of the uncertainties in $\dot{K}$ that appear in both the BIPM and the VSL determinations (namely air density, W/e, μ_{en}/ρ, $\bar{g}$, $\bar{s}_{\mathrm{c,a}}$ and k_{h}) cancel when evaluating the uncertainty of the comparison result R_K, as given in Table 4.

Table 4. Estimated relative standard uncertainties of the calibration coefficient, $N_{K,\mathrm{lab}}$, of the transfer chambers and of the comparison result, R_K

Relative standard uncertainty	**BIPM** 100 s_i	 100 u_i	**VSL** 100 s_i	 100 u_i
Air kerma	0.02	0.15	0.02	0.21
Ionization current of the transfer chambers	0.01	0.02	0.02	0.02
Distance and orientation	0.01	–	–	0.02
Correction factors (P,T)	–	–	–	0.04
Time	–	–	–	0.01
Humidity	–	–	–	0.10
Relative standard uncertainty of $N_{K,\mathrm{lab}}$				
quadratic summation	0.02	0.15	0.03	0.24
combined uncertainty	0.15		0.24	
Relative standard uncertainties of R_K	100 s_i		100 u_i	
quadratic summation[1]	0.04		0.22	
combined uncertainty	**0.22**			

[1] taking correlation into account as explained above.

The relative standard uncertainty of the mean ionization current measured with each transfer chamber over the short period of calibration was estimated to be 10^{-4} (two calibrations with repositioning, in series of 30 measurements for each chamber) at the BIPM. The relative standard uncertainty of the mean normalized ionization current measured at the VSL with a given transfer chamber over several months is typically better than 2×10^{-3}. The calibrations were repeated at the VSL after the comparison at the BIPM and the results are consistent as shown in Table 5.

4. Results of the comparison

The result of the comparison, R_K, is expressed in the form

$$R_K = N_{K,\mathrm{VSL}} \big/ N_{K,\mathrm{BIPM}} \quad , \qquad (3)$$

in which the average value of measurements made at the VSL prior to those made at the BIPM (pre-BIPM) and those made afterwards (post-BIPM) for each chamber is compared with the mean of the measurements made at the BIPM. Table 5 lists the relevant values of N_K for each chamber at the stated reference conditions.

The comparison result is taken as the unweighted mean value for the three transfer chambers, R_K = 0.9985 with a combined standard uncertainty for the comparison of 0.0022.

Table 5. Results of the comparison

Transfer chamber NE2611	$N_{K,\mathrm{VSL}}$ / Gy µC^{-1} pre-BIPM	$N_{K,\mathrm{BIPM}}$ / Gy µC^{-1}	$N_{K,\mathrm{VSL}}$ / Gy µC^{-1} post-BIPM	$N_{K,\mathrm{VSL}}$ / Gy µC^{-1} overall mean	R_K	u_c
118	94.077	94.228	94.097	94.087	0.9985	0.0022
119	94.054	94.222	94.099	94.077	0.9985	0.0022
120	94.773	94.923	94.794	94.784	0.9985	0.0022
				Mean values	**0.9985**	**0.0022**

The VSL has now made four air kerma comparisons with the BIPM for ^{60}Co radiation beams using transfer standards. The first comparison dates from 1975 and the results of all three comparisons are compared in Table 6, taking the earlier data from [1]. The consistency of the results is noteworthy, bearing in mind the changes to the primary standards over the years.

Table 6. Long-term stability of the comparison results between the VSL and the BIPM

Year	Standards	R_K	R_K revised (1)	u_c
1972 [2]	Direct comparison	1.0015	0.9966	0.0070
1991 [9]	NE 2561 sn 246	1.0022	0.9973	0.0046
1996	NE 2561 sn 246	1.0031	0.9982	0.0037
2005	NE2611 sn 118, 119, 120	–	0.9985	0.0022

(1) results revised taking changes in both standards into account

5. Degrees of equivalence

Comparison of a given NMI with the key comparison reference value

Following a decision of the CCRI, the BIPM determination of the dosimetric quantity for each of the CCRI radiation qualities is taken as the key comparison reference value [10]. It follows that for each NMI i having a BIPM comparison result $R_{K,i}$ (denoted x_i in the KCDB) with combined standard uncertainty, u_i, the degree of equivalence with respect to the reference value for the NMI comparison, here $K_{\mathrm{R},i}$, is given by a pair of terms:

the relative difference $$D_i = (K_i - K_{\mathrm{R},i}\,)/\,K_{\mathrm{R},i}\,)) = R_{Ki} - 1 \qquad (4)$$

and the expanded uncertainty (k = 2) of this difference,

$$U_i = 2\,u_i. \qquad (5)$$

The results for D_i and U_i are expressed in mGy/Gy [10]. Table 7 gives the values for D_i and U_i for each NMI i taken from [11] and this report, using (4) and (5), and forms the basis of the entries in the KCDB of the CIPM MRA. These data are presented graphically in Figure 1 where the black squares indicate results that date prior to 1999 although the VNIIM has made a comparison more recently and a comparison is scheduled with the ARPANSA. The results of recently published SIM and COOMET comparisons [12, 13] and for the comparisons with the ITN (Portugal) [14], NIM (China) [15], NPL (UK) [16], NRC (Canada) [17] and the BEV (Austria) [18] are also presented.

Comparison of any two NMIs with each other

The degree of equivalence between any pair of national measurement standards is expressed in terms of the difference between the two comparison results and the expanded uncertainty of this difference; consequently, it is independent of the choice of key comparison reference value.

The degree of equivalence, D_{ij}, between any pair of NMIs, i and j, is thus expressed as the difference

$$D_{ij} = D_i - D_j = R_i - R_j \tag{6}$$

and the expanded uncertainty ($k = 2$) of this difference, $U_{ij} = 2\, u_{ij}$, where

$$u_{ij}{}^2 = u_{c,i}{}^2 + u_{c,j}{}^2 - \sum_k \left(f_k u_{k,\mathrm{corr}}\right)_i^2 - \sum_k \left(f_k u_{k,\mathrm{corr}}\right)_j^2 \tag{7}$$

and the final two terms are used to take into account correlation between the primary standards, notably that arising from the physical constants and correction factors for similar types of standard.

The results for D_i and U_i and those for D_{ij} and U_{ij} are given in Table 7 in the format in which they appear in the key comparison database. Note that the data presented in the table, while correct at the time of preparation of the present report, become out-of-date as NMIs make new comparisons. The formal results under the CIPM MRA [19] are those available in the key comparison database.

6. Conclusion

The VSL standard for air kerma in ^{60}Co gamma radiation compared with the present BIPM air kerma standard gives a comparison result of 0.9985 (0.0022). This compares favourably with the other primary standards and is consistent within the uncertainties with the results of previous comparisons between the VSL and the BIPM dating back to 1972.

Table 7. Degrees of equivalence with the BIPM.RI(I)-K1 and RMO.RI(I)-K1 comparisons for the VSL participation

- **Key comparison BIPM.RI(I)-K1**

MEASURAND : Air kerma

The key comparison reference value is the BIPM evaluation of air kerma.

The degree of equivalence of each laboratory *i* with respect to the reference value is given by a pair of terms both expressed in mGy/Gy:

$\boldsymbol{D_i}$ and $\boldsymbol{U_i}$, its expanded uncertainty (k = 2), with $\boldsymbol{U_i} = \boldsymbol{2u_i}$.

(See Final Report for the computation of $\boldsymbol{D_i}$)

The degree of equivalence between two laboratories is given by a pair of terms both expressed in mGy/Gy:

$\boldsymbol{D_{ij} = D_i - D_j}$ and $\boldsymbol{U_{ij}}$, its expanded uncertainty (k = 2).

The approximation for $\boldsymbol{U_{ij}}$ is explained in this Final Report.

- **Linking RMO.RI(I)-K1 to BIPM.RI(I)-K1**

MEASURAND : Air kerma

The value $\boldsymbol{x_i}$ is the comparison result for laboratory *i* participant in RMO.RI(I)-K1 having been normalized to the value of the NRC as the linking laboratory (see RMO.RI(I)-K1 Final Reports).

The degree of equivalence of each laboratory *i* participant in RMO.RI(I)-K1 with respect to the reference value is given by a pair of terms both expressed in mGy/Gy:

$\boldsymbol{D_i}$ and $\boldsymbol{U_i}$, its expanded uncertainty (k = 2).

See RMO.RI(I)-K1 Final Report for the computation of $\boldsymbol{D_i}$ and the approximation used for $\boldsymbol{U_i}$ in the Matrix of equivalence.

The degree of equivalence between two laboratories *i* and *j*, one participant in BIPM.RI(I)-K1 and one in RMO.RI(I)-K1, or both participant in RMO.RI(I)-K1, is given by a pair of terms both expressed in mGy/Gy:

$\boldsymbol{D_{ij} = D_i - D_j}$ and $\boldsymbol{U_{ij}}$, its expanded uncertainty (k = 2).

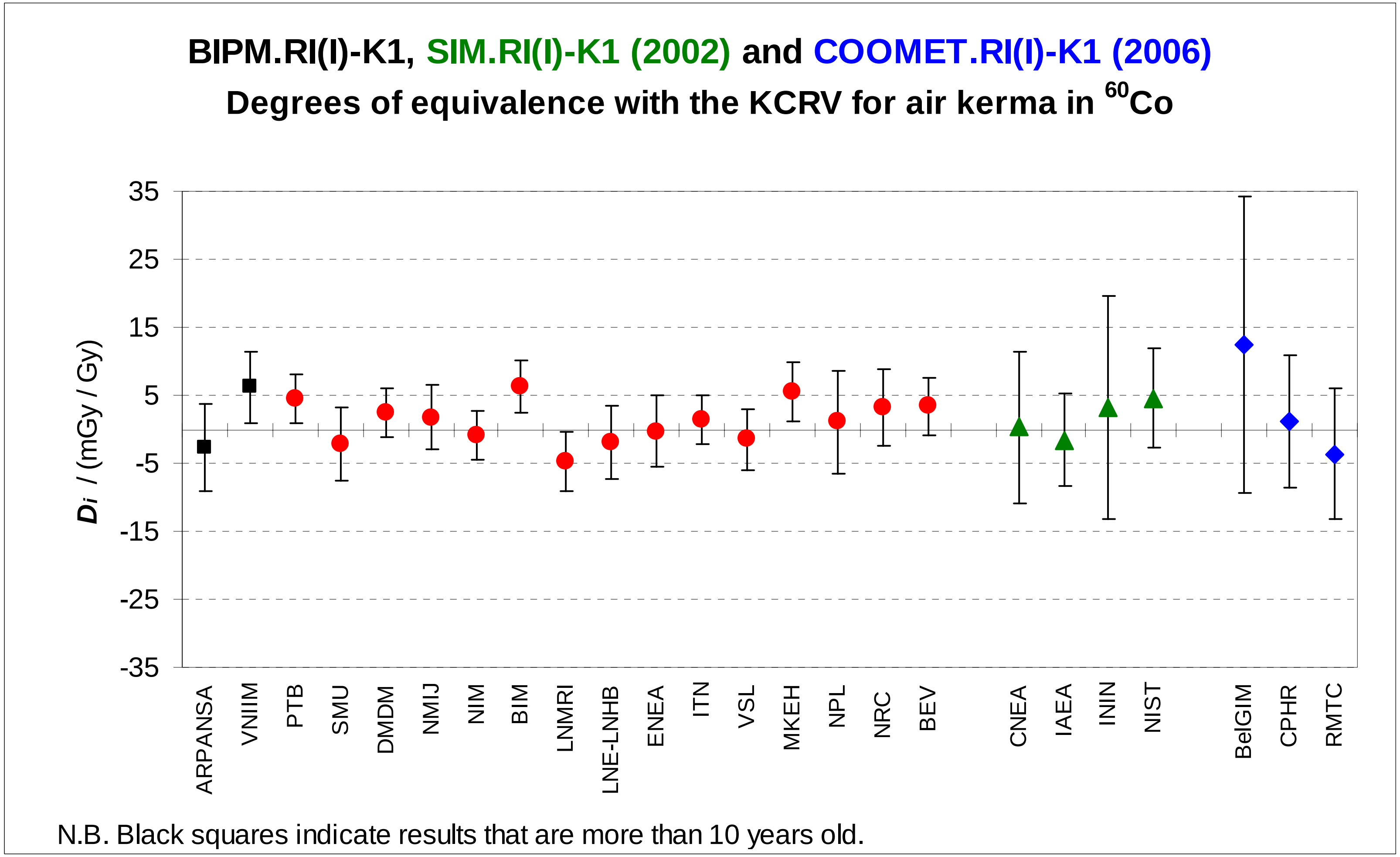
The approximation for $\boldsymbol{U_{ij}}$ is given in RMO.RI(I)-K1 Final Reports [12, 13].

Table 7. continued Degrees of equivalence with the BIPM.RI(I)-K1 and RMO.RI(I)-K1 comparisons for the VSL participation

Lab i ⇩			Lab *j* VSL	
	D_i	U_i	D_{ij}	U_{ij}
	/ (mGy/Gy)		/ (mGy/Gy)	
ARPANSA	**-2.6**	6.4	**-1.1**	7.1
VNIIM	**6.2**	5.2	**7.7**	5.8
PTB	**4.5**	3.6	**6.0**	4.4
SMU	**-2.1**	5.4	**-0.6**	5.8
DMDM	**2.5**	3.6	**4.0**	4.3
NMIJ	**1.8**	4.8	**3.3**	5.3
NIM	**-0.8**	3.6	**0.7**	4.7
BIM	**6.3**	3.8	**7.8**	4.5
LNMRI	**-4.7**	4.4	**-3.2**	5.3
LNE-LNHB	**-1.9**	5.4	**-0.4**	5.0
ENEA	**-0.3**	5.2	**1.2**	5.7
ITN	**1.5**	3.6	**3.0**	4.2
VSL	**-1.5**	4.4		
MKEH	**5.5**	4.4	**7.0**	5.1
NPL	**1.1**	7.6	**2.6**	8.0
NRC	**3.2**	5.6	**4.7**	6.2
BEV	**3.4**	4.2	**4.9**	4.9
CNEA	**0.3**	11.2	**1.8**	11.6
IAEA	**-1.6**	6.8	**-0.1**	7.5
ININ	**3.2**	16.4	**4.7**	16.7
NIST	**4.6**	7.4	**6.1**	7.5
BelGIM	**12.5**	21.8	**14.0**	22.1
CPHR	**1.1**	9.7	**2.6**	10.2
RMTC	**-3.6**	9.7	**-2.1**	10.2

See [11] to [18] for the acronyms.

Figure 1. **Graph of degrees of equivalence with the KCRV**



BIPM.RI(I)-K1 – red circles

SIM.RI(I)-K1 – green triangles COOMET.RI(I)-K1 – blue diamonds

References

[1] Allisy-Roberts P.J.,Boutillon, M., Comparisons of the standards of air kerma of the NMi and the BIPM for ^{60}Co gamma rays, *Rapport BIPM-97/04*, 11 pp.

[2] Hofmeester G.H. and Somerwil A., 1976, Absolute exposure measurements in the Netherlands in the 10 – 250 kV x-ray region and for ^{60}Co gamma rays, *Annalen van de Belgische Vereniging voor Stralingsbescherming*, Vol **1**, N° 4, 317-326.

[3] Boutillon M. and Niatel M.-TA., 1973, Study of a graphite cavity chamber for absolute measurements of ^{60}Co gamma rays, *Metrologia*, **9**, 139-146.

[4] Burns D.T., Allisy P.J., Kessler C., 2007, Re-evaluation of the BIPM international standard for air kerma in ^{60}Co gamma radiation, *Metrologia*, 2007, **44**, L53-L56.

[5] Van Dijk E., 2006, Wall correction factors for cavity chambers and ^{60}Co radiation using Monte-Carlo methods, *NMi report* nr: VSL-ESL-IO-2006/1.

[6] Allisy-Roberts P.J., Burns D.T. and Kessler C., 2009, Measuring conditions used for the calibration of national ionometric standards at the BIPM, 2009, *Rapport BIPM-09/04*, 20 pp.

[7] *Comité Consultatif pour les Étalons de Mesures des Rayonnements Ionisants*, Constantes physiques pour les étalons de mesure de rayonnement, 1985, *CCEMRI Section (I)*, **11**, R45.

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

[9] Van Dijk E., Grimbergen T.W.M., Report of the indirect comparison of kerma standards of BIPM and NMi, December 1991, *NMi report,* 1993, Bilthoven, 10 pp.

[10] Allisy P.J., Burns D.R., Andreo P., 2009, International framework of traceability for radiation dosimetry quantities, *Metrologia*, 2009, **46(2)**, S1-S8.

[11] Allisy-Roberts P.J., Burns D.T., Kessler C., 2007, Summary of the BIPM.RI(I)-K1 comparison for air kerma in ^{60}Co gamma radiation, *Metrologia*, 2007, **44**, *Tech. Suppl.*, 06006.

[12] Ross C.K., Shortt K., Saravi M., Meghzifene A., Tovar V.M., Barbosa R.A., da Silva C.N., Carrizales L., Seltzer S.M., 2008, Final Report of the SIM ^{60}Co Air-Kerma Comparison (KCDB Entry SIM.RI(I)-K1), *Metrologia*, 2008, **45**, *Tech. Suppl.*, 06010.

[13] Büermann L., Oborin A.V., Dobrovosky J.S,, Milevsky V.S., Walwyn Salas G., Lapenas A., 2009, COOMET.RI(I))-K1 comparison of national measurement standards of air kerma for ^{60}Co γ-radiation, *Metrologia*, 2009, 46, *Tech. Suppl.*, 06015.

[14] Allisy-Roberts P.J., Burns D.T., Kessler C., Cardoso J., 2009, Comparison of the standards for air kerma of the ITN (Portugal) and the BIPM for ^{60}Co γ-rays, *Metrologia*, 2009, **46**, *Tech. Suppl.*, 06007.

[15] Allisy-Roberts P.J., Kessler C., Burns D.T., Zhongqing T., Jiacheng H., Xiaoyuan Y., Kun W., 2009, Comparison of the standards for air kerma of the NIM and the BIPM for ^{60}Co gamma radiation, *Metrologia*, 2009, **46**, *Tech. Suppl.*, 06013.

[16] Kessler C., Allisy P.J., Burns D.T., Duane S., Manning J., Nutbrown R., 2010, Comparison of the standards for air kerma of the NPL and the BIPM for ^{60}Co γ rays *Metrologia* ***47*** 06004

[17] Kessler C., Allisy P.J., Burns D.T., McCaffrey J.C., Ross C.K., 2010, Comparison of the standards for air kerma of the NRC and the BIPM for ^{60}Co γ rays *Metrologia* ***47*** 06005

[18] Kessler C., Allisy-Roberts P.J., Steurer A., Tiefenboeck W., Gabris F. 2010, Comparison of the standards for air kerma of the BEV and the BIPM for ^{60}Co gamma radiation, *Metrologia* ***47*** 06006

[19] CIPM MRA: *Mutual recognition of national measurement standards and of calibration and measurement certificates issued by national metrology institutes*, International Committee for Weights and Measures, 1999, 45 pp. http://www.bipm.org/pdf/mra.pdf.