COOMET regional comparison of national measurement standards of air kerma for ^{137}Cs γ radiation at protection level

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Abstract:

Results are presented of the COOMET supplementary comparison of the national measurement standards for air kerma in ^{137}Cs γ radiation at protection level (~10 mGy/h). Ten National Metrology Institutes from the COOMET organization and the International Atomic Energy Agency participated in this COOMET project no. 445. The PTB acted as pilot laboratory. Two of the participants, the SMU (Slovakia) and the NSC-"IM" (Ukraine) participated in the measurements but did not submit a valid report of results. The comparison reference value (CRV) was obtained as the mean result of the PTB and the VNIIM, both of which had previously taken part in the key comparison BIPM-RI(I)-K5. The degree of equivalence with the CRV was evaluated. The results were consistent within the relative standard uncertainties of the comparison ranging from 0.28% – 1.3% and deviated from the CRV by less than 1%.

1. Introduction

This report describes the COOMET regional comparison of national measurement standards for air kerma in ^{137}Cs γ radiation at protection level according to the CIPM Mutual Recognition Arrangement [1]. The comparison was proposed in 2008 as COOMET project no. 445. The measurements by the participants were made in the period from May 2011 until February 2013. The Draft A report was agreed upon by the participants in August 2013. The Draft B report was finally accepted in March 2014. This report will be available in Appendix B of the BIPM key comparison database (KCDB) under the identifier COOMET.RI(I)-S1. This is the first comparison of this kind within the COOMET region. Ten National Metrology Institutes (NMIs) and the International Atomic Energy Agency (IAEA), listed in Table 1, took part in the comparison.

Cs-137 gamma radiation is usually the reference radiation quality for the calibration of radiation protection dosimeters. National primary air kerma standards for Cs-137 gamma radiation are mostly based on the same cavity ionization chambers as used in Co-60 gamma radiation at therapy level air kerma rates (several Gy/h). Key comparisons are conducted bilaterally between the standards of the BIPM and the National Metrology Institutes (NMIs) within the ongoing comparison labeled BIPM.RI(I)-K5. However, many NMIs maintain radiation qualities with Cs-137 sources of much lower activities in order to calibrate dosimeters at protection level dose rates of the order of µGy/h and mGy/h. Primary cavity chambers are designed with small sensitive volumes and cannot be used in such low-dose-rate radiation fields because the current induced by ionization is too small. Larger volume ionization chambers are in use as secondary standards to calibrate dosimeters in such fields. The goal of this supplementary comparison was to confirm the calibration and measurement capabilities of the participating NMIs for air kerma calibrations at protection level Cs-137 gamma radiation. For this purpose the calibration coefficients and the corresponding uncertainties of three circulating ionization chambers with sensitive volumes of about 1000 cm^3 were compared at air kerma rates of about 10 mGy/h. This type of comparison differs significantly from the established key comparison BIPM.RI(I)-K5 due to the lower dose rates and larger ionization chambers and the expected larger uncertainties. Therefore it was decided by COOMET-TC1.9 and confirmed by the key comparison working group (KCWG) to regard this comparison as a supplementary one with the identifier COOMET.RI(I)-S1. The PTB [2] and the VNIIM [3] had previously participated in the key comparison BIPM.RI(I)-K5 [4]. Therefore it was decided that their mean result shall be taken as the comparison reference value (CRV). Each participant determined the calibration coefficients of the three transfer ionization chambers under reference conditions. The degrees of equivalence with the CRV were evaluated based on these results.

The procedure for the comparison is described in the next section. The results are presented in section 3. The evaluation of the results leading to the values of the degrees of equivalence with respect to the CRV is given in section 4.

Table 1. Participants of the comparison COOMET.RI(I)-S1

NMI	Country	Contact person	E-mail of contact person
VNIIM	Russia	Alexandr V. Oborin	oav@vniim.ru
BelGIM	Belarus	Valery S. Milevsky	milevsky@belgim.by
CPHR	Cuba	Gonzalo Walwyn Salas	gonzalo@cphr.edu.cu
GEOSTM	Georgia	Simon Sukhishvili	s.sukhishvili@gmail.com
INSM	Moldova	Ion Ginga	ginga-ioniz@mail.ru
NSC-“IM”	Ukraine	Andrii N. Orobinskyi	orobin@mail.ru
SMU	Slovakia	Norman Durný	durny@smu.gov.sk
PTB	Germany	Ludwig Büermann	ludwig.bueermann@ptb.de
BIM	Bulgaria	Rosen Ivanov	r.ivanov@bim.government.bg
VMT/FTMC	Lithuania	Arunas Gudelis	gudelis@ktl.mii.lt
IAEA	International	Igor Gomola	i.gomola@iaea.org

2. Procedure

2.1 Aim of comparison

The aim of the comparison was to establish the degrees of equivalence between the participants for the determination of air kerma in Cs-137 radiation protection beam, by means of the calibration of three ionization chambers of the same type under reference conditions, as defined in 2.3

2.2 Transfer chambers

Three ionization chambers of type TM32002 with a nominal volume of 1000 cm³ were provided by the PTB. The chambers were manufactured by PTW in Freiburg, Germany. The reference point for each chamber was taken to be the centre of the spherical volume. The chambers were aligned in the beam with the mark on the stem facing the radiation source. The chambers had a PTW-M type connector. The main technical data are shown in Table 2.

Table 2: Main technical data for the transfer chambers

Type	TM32002, serial numbers 416, 417, 418
Sensitive volume	1000 cm^3
Outside diameter	140 mm
Diameter of inner electrode	50 mm
Polarizing voltage	− 400 V [(a)]
Saturation loss	< 1% up to 0.42 Gy/h
Nominal response	about 40 μC/Gy
Minimum air kerma rate	1 mGy/h (yields about 11 pA)

[(a)]Potential of the chamber wall with respect to the guard (approximately that of the central electrode).

2.3 Reference conditions, measurement procedure and report of results

The recommended source-chamber distance (reference point of the chamber from the focus point of the Cs-137 source) was 200 cm. The air kerma rate of the collimated Cs-137 radiation beam was not less than 1 mGy/h. If possible, about 10 mGy/h was used for the comparison. The beam cross section in the reference plane fully covered the spherical volume of the chamber.

The transfer chambers were placed in the laboratory at least 12 hours before measurements started in order to let them adjust to the climatic conditions. Measurements were started not before 1 hour after connection of the high voltage. The transfer chamber currents at the reference position were measured with and without the Cs-137 radiation beam. The signal-to-background ratios of the currents were not less than 1000. The background current was subtracted from the signal current. A complete measurement consisted of at least 10 repeated single measurements and the mean value was taken as the result. The relative standard deviation of the 10 repeated measurements did not exceed 0.1%. The calibration coefficients of the transfer chambers were measured at one polarity (see table 2) and given in terms of air kerma per unit charge in units of Gy/C referring to standard conditions of air temperature, pressure and relative humidity of T = 293.15 K, P = 101.325 kPa and h = 50%. The relative air humidity was normally between 20% and 80% during the calibrations; otherwise a correction to h = 50% was applied. Participants did not apply any corrections for the incomplete charge collection.

The report of the results contained at least the following information:

- Description of the measurement system (electrometer type, connector types used, traceability of the electrometer calibration)
- Climatic conditions prevailing in the calibration laboratory during the calibration (temperature, pressure, humidity)
- Description of the radiation field (type of source, field size, air kerma rate)
- Uncertainty of the air kerma rate determined with the national air kerma standard
- Uncertainty of the calibration coefficient
- Calibration coefficients of the three transfer chambers
- Appendix: Copy of the original measurement results as obtained from the measurement system

A form “Report of Results” was distributed together with the technical protocol and was used for this purpose. The uncertainties were given in accordance with the ISO Guide to the expression of uncertainties in measurements (GUM) [5].

2.4 Course of comparison

The three transfer chambers were circulated in a star-shaped arrangement between the PTB and the participants. After calibration by each participant, the PTB performed chamber constancy checks. With a few exceptions, the chambers remained at the participant’s site for no longer than 2 weeks. The results were reported to the coordinator within about 2 weeks after each calibration.

2.5 Time schedule

The comparison started in May 2011 with the PTB measurements and was completed in February 2013 with the last stability measurements at the PTB. The time schedule is shown in Table 3.

Table 3. Time schedule of the comparison

Participant	Date of calibration at the participants site	Constancy measurements at the PTB
PTB, Germany	May-2011	
BelGIM, Belarus	Aug-2011	Sep-2011
GEOSTM, Georgia	Oct-2011	Nov-2011
INSM, Moldova	Dec-2011	Dec-2011
CPHR, Cuba	Mar-2012	Apr-2012
NSC-“IM”, Ukraine	Jun-2012	Jul-2012
SMU, Slovakia	Aug-2012	Aug-2012
VNIIM, Russia	Sep-2012	Oct-2012
BIM, Bulgaria	Nov 2012	Nov-2012
VMT/FTMC, Lithuania	Dec-2012	Dec-2012
IAEA, Vienna	Jan-2013	Feb-2013

2.6 Procedure for handling the results of the pilot laboratory

The pilot laboratory participated in the comparison. It determined its values of the calibration coefficients in May 2011. The report on these measurements was sent to the COOMET TC-IR Chairman before the first participant had submitted his report to the pilot laboratory. For the purpose of constancy checks, the pilot laboratory repeated its determination of the calibration coefficients after measurement by each participant.

3. Results

3.1 Constancy of the transfer chambers

The constancy of the three transfer chambers was measured by repeated calibrations in the Cs-137 and Co-60 beams at the PTB, applying both polarities. Measurements started in May 2011 and were repeated each time the chambers were returned to the PTB. The last stability check measurements were done in February 2013. Mean values of all the calibration coefficients of each transfer chamber were calculated and then used to normalize the individual values. The mean values and standard deviations of the normalized values are summarized in Table 4. Results of the individual values are shown in Figures 1 and 2 for Cs-137 and Co-60, respectively. None of the individual values deviates by more than 0.2% from the mean value. For all three chambers and for both Cs-137 and Co-60 a standard deviation of the mean normalized value close to 0.0010 was obtained. From these values a relative uncertainty of 0.1% was included, as u_{stab} in equation (2), to account for the long-term stability of the transfer chambers (see 3.4).

Table 4. Mean values and standard deviations of the normalized calibration factors

	Cs-137		Co-60	
Chamber S/N	Mean	Sdev	Mean	Sdev
416	0.9999	0.0011	1.0000	0.0010
417	0.9998	0.0009	1.0000	0.0010
418	0.9999	0.0009	0.9996	0.0009

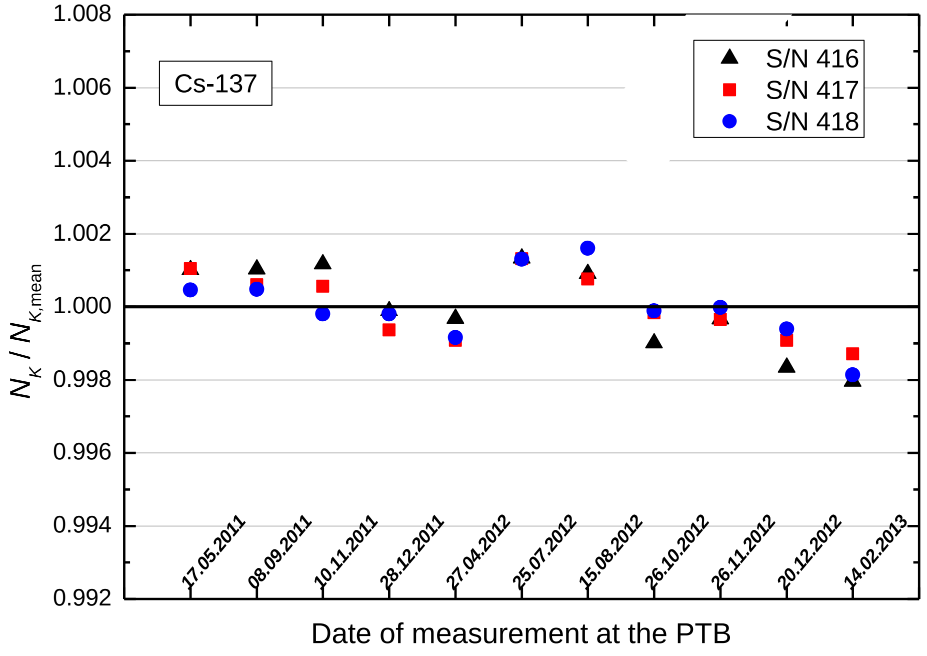

Figure 1. Calibration coefficients determined in Cs-137 for the three transfer chambers, normalized to their mean values as obtained from the constancy check measurements at the PTB during the comparison.

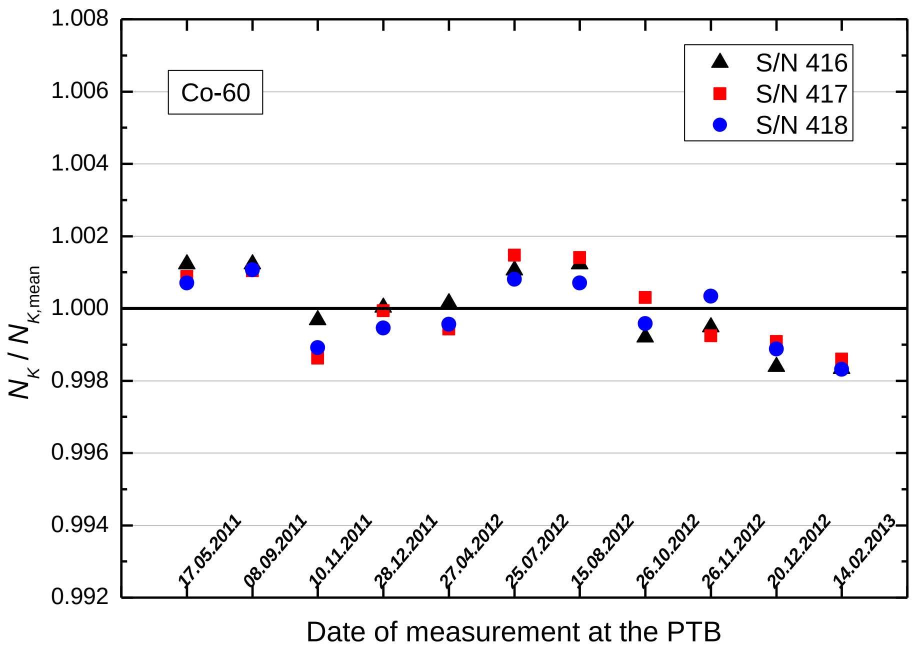

Figure 2. Calibration coefficients determined in Co-60 for the three transfer chambers, normalized to their mean values as obtained from the constancy check measurements at the PTB during the comparison.

3.2 Summary of the reported results

Tables 5 to 7 summarize the reported irradiation conditions, calibration coefficients and uncertainties. No data were received from SMU. The NSC-IM provided its measured calibration coefficients and uncertainties but no report of results was received. Therefore there are no results listed for these two participants. The distance between source and reference point was 200 cm except for two participants who used 150 cm. The air kerma rates ranged from 1.4 mGy/h to 12 mGy/h. The relative uncertainties of the calibration coefficients ranged from 0.26% to 1.27%. The comparatively high relative standard uncertainties of about 1% reported by three participants were due to the uncertainties in the air kerma rate determinations using their national standards (see Table 7).

Table 5. Irradiation conditions at the participating laboratories

	PTB	VNIIM	BelGIM	GEOSTM	INSM	CPHR	BIM	VMT/ FTMC	IAEA
Standard	HRK3	C30	32002	32002	LS01	NE2575	32002	32003	LS01
Volume/cm^3	6.138	30.024	1000	1000	1000	600	1000	10000	1000
Traceablity	primary	primary	VNIIM	IAEA	IAEA-BIPM	IAEA-BIPM	PTB	SMU	BIPM
Source									
Distance / cm	200	150	200	200	200	200	150	200	200
Diameter / cm	34	40	28	54	60	50	31	50	48
Rate / mGy/h	11.5	3.3	10.4	11.3	12.0	7.4	2.0	1.4	8.9

Table 6. Calibration coefficients (/10^4 Gy/C) and their relative standard uncertainties

Chamber	PTB	VNIIM	BelGIM	GEOSTM	INSM	CPHR	BIM	VMT/ FTMC	IAEA
S/N 416	2.500	2.499	2.481	2.505	2.508	2.488	2.508	2.492	2.502
S/N 417	2.503	2.505	2.484	2.506	2.520	2.494	2.521	2.488	2.505
S/N 418	2.516	2.520	2.498	2.520	2.560	2.506	2.563	2.510	2.518
u / %	0.47	0.26	1.12	0.57	0.51	0.96	0.75	1.28	0.36

Table 7. Reported relative standard uncertainties given in %.

	PTB	VNIIM	BelGIM	GEOSTM	INSM	CPHR	BIM	VMT/ FTMC	IAEA
$u(\dot{K}_a)$	0.30	0.22	1.02	0.49	0.39	0.94	0.68	1.04	0.33
u_{other}	0.36	0.13	0.47	0.30	0.33	0.19	0.32	0.73	0.15
u_{total}	0.47	0.26	1.12	0.57	0.51	0.96	0.75	1.28	0.36

The NSC-"IM" (Ukraine) sent the following calibration coefficients to the pilot laboratory: $N_K = 2.474 \times 10^4$ Gy/C (S/N 416), 2.478×10^4 Gy/C (S/N 417) and 2.491×10^4 Gy/C (S/N 418). The relative standard uncertainty was estimated to be 1.04%. According to the contact person, Andrii N. Orobinskyi, the air kerma rate was determined using a newly developed primary standard cavity chamber. Unfortunately, there was no written report of this primary standard available. Further, no report of results was submitted to the pilot laboratory. Therefore it was not possible to include these results in the official results of this comparison although the calibration coefficients were sent in time.

3.3 Comparison reference value

The PTB and the VNIIM participated previously in the key comparison BIPM.RI(I)-K5 with the following results for the ratio $R_{\mathrm{NMI}} = N_{K,\mathrm{NMI}} / N_{K,\mathrm{BIPM}}$: $R_{\mathrm{PTB}} = 1.0034(28)$ [2,4] and $R_{\mathrm{VNIIM}} = 1.0013(27)$ [3,4]. From these data the indirect ratio of the calibration coefficients of the PTB and the VNIIM was evaluated as 1.0021 which differs by 0.29% from the comparison ratio $N_{K,\mathrm{PTB}} / N_{K,\mathrm{VNIIM}} = 0.9992$ obtained in this work. This difference is still within the estimated uncertainties of the two different comparison procedures and gives acceptable confidence to the measurements of both laboratories.

The comparison reference value (CRV) was calculated as the mean of the PTB and the VNIIM calibration coefficients. The following results were obtained:

$N_{K,\mathrm{CRV}} = 2.500 \times 10^4$ Gy/C (S/N 416),
$N_{K,\mathrm{CRV}} = 2.504 \times 10^4$ Gy/C (S/N 417)
$N_{K,\mathrm{CRV}} = 2.518 \times 10^4$ Gy/C (S/N 418).

The relative standard uncertainty of $N_{K,\mathrm{CRV}}$ was estimated to be 0.25 %.

3.4 Comparison results

The ratios, $R_{K,i}$, of the calibration factor of the participants, $N_{K,i}$ and the CRV, $N_{K,\mathrm{CRV}}$, were calculated according to

$$R_{K,i} = \frac{N_{K,i}}{N_{K,\mathrm{CRV}}} \tag{1}$$

The uncertainties, $u_{R,i}$ of $R_{K,\mathrm{i}}$ were calculated according to the following equation:

$$u_{R,i}^2 = u_i^2 + u_{\mathrm{CRV}}^2 + u_{\mathrm{stab}}^2 - \sum_k (f_k u_i(k))^2 - \sum_k (f_k u_{\mathrm{CRV}}(k))^2 \tag{2}$$

where u_i is the relative standard uncertainty of the transfer chamber calibration coefficient reported by laboratory *i*, $u_i(k)$, a particular (correlated) uncertainty component *k*, u_{CRV} is the relative uncertainty associated with the CRV, $u_{\mathrm{CRV}}(k)$ the uncertainty for the same component *k*, u_{stab} is the relative uncertainty due to the long-term stability of the transfer chambers. The last two terms account for any correlated uncertainties between the NMI and the CRV, where the factor f_k is the correlation coefficient. u_{stab} was estimated to be 0.1% from the relative standard deviation of the calibration coefficients obtained from the repeated measurements at the PTB as described in 3.1. Results of $R_{K,i}$ obtained for each of the three transfer chambers are listed in

Table 8 and shown in Figure 3. The mean values, $R_{K,i,\text{mean}}$ of the individual $R_{K,i}$ values and the corresponding relative uncertainties are also included in Table 8 and shown in Figure 4.

Table 8. Ratios $R_{K,i}$ for the three transfer chambers and the mean values, $R_{K,i,\text{mean}}$

Chamber	PTB	VNIIM	BelGIM	LEPL	INSM	CPHR	BIM	VMT/ FTMC	IAEA
$R_{K,i}$ S/N 416	1.0001	0.9999	0.9925	1.0021	1.0032	0.9953	1.0034	0.9969	1.0009
$R_{K,i}$ S/N 417	0.9996	1.0004	0.9920	1.0008	1.0065	0.9960	1.0068	0.9936	1.0004
$R_{K,i}$ S/N 418	0.9991	1.0009	0.9920	1.0007	1.0166	0.9952	1.0178	0.9968	0.9999
$R_{K,i,\text{mean}}$	0.9996	1.0004	0.9922	1.0012	1.0088	0.9955	1.0093	0.9958	1.0004
$u_{R,i}$ / %	0.28	0.28	1.08	0.62	0.56	0.99	0.74	1.30	0.41

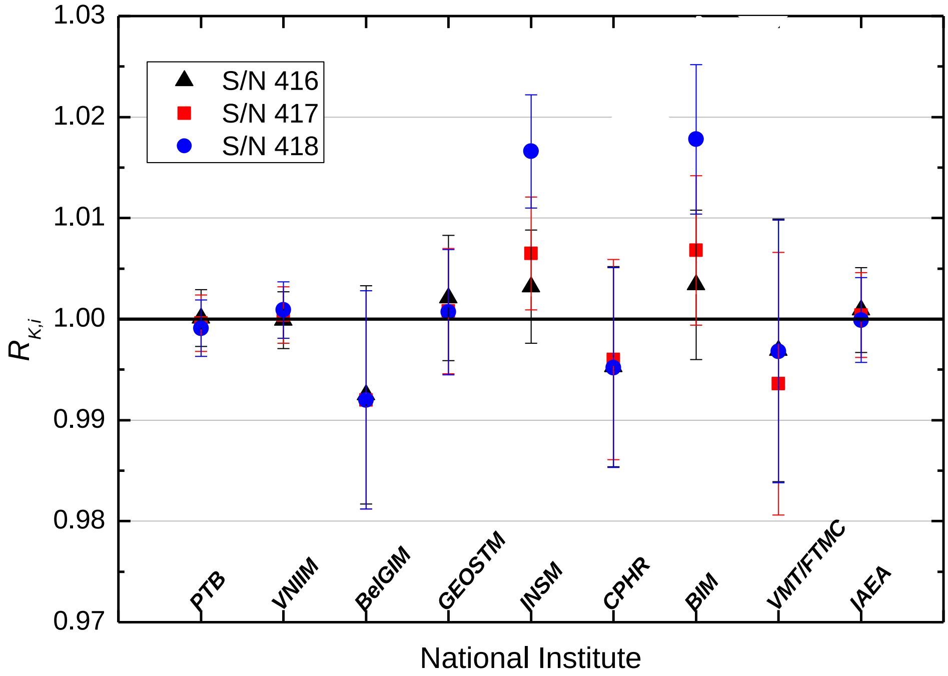

Figure 3. Ratios $R_{K,i}$ for the three transfer chambers as obtained by the participants and the corresponding standard uncertainties, $u_{R,i}$.

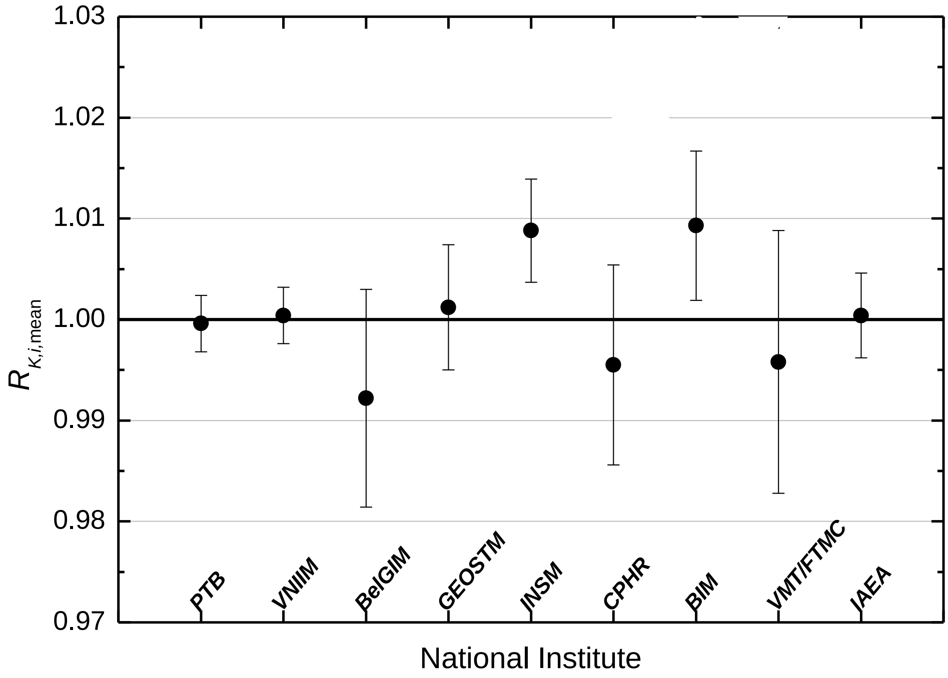

Figure 4. Mean values $R_{K,i,\mathrm{mean}}$ and the corresponding standard uncertainties, $u_{R,i}$.

From Figure 3 it can be concluded that except for two individual results all other values deviate from unity by less than 1%. Two results, namely those of the INSM and the BIM obtained for the chamber S/N 418, deviate by more than 1% and also by more than the standard uncertainty. This is not the case for the other two transfer chambers. All other participants obtained consistent results for the three transfer chambers.

From Figure 4 it is concluded that none of the mean ratios $R_{K,i,\mathrm{mean}}$ deviates by more than 1% from the CRV and all values are consistent with the CRV within their standard uncertainties except for those of the INSM and the BIM which reflect slightly larger deviations, mainly due to the large deviation of the results obtained with the S/N 418 chamber.

4. Evaluation of the degree of equivalence with the CRV

Usually, a result is considered acceptable if the deviation from the CRV is less than the expanded uncertainty of the comparison result. From Figure 5 it is concluded that the results of all participants meet this requirement.

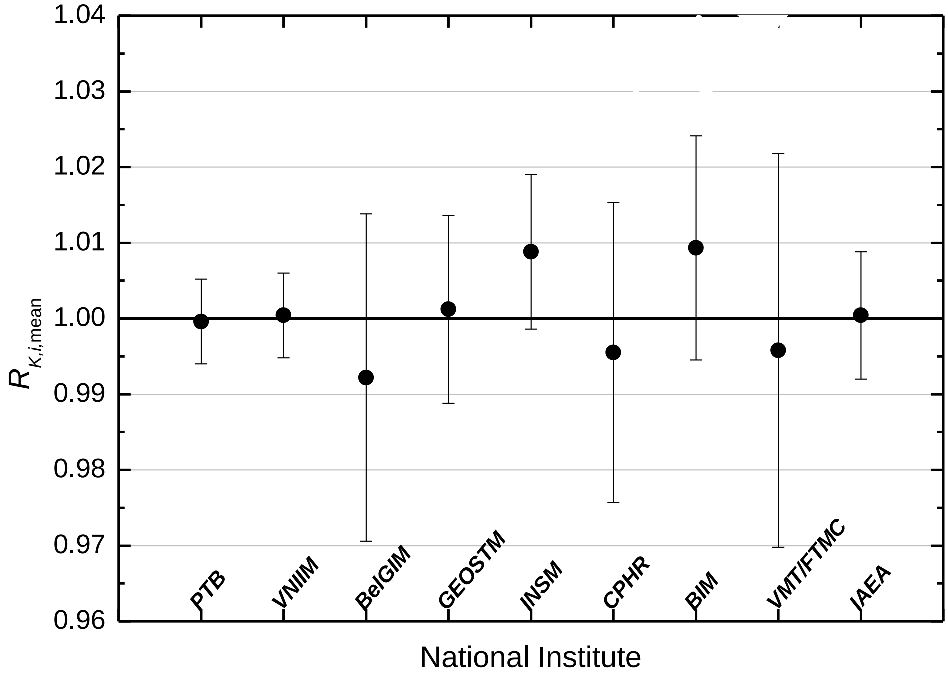

Figure 5. Mean values $R_{K,i,\text{mean}}$ and the corresponding expanded uncertainties, $U_i = 2u_{R,i}$.

The degree of equivalence of the laboratory i with respect to the CRV is effectively given by the difference $D_i = R_{K,i,\text{mean}} - 1$ and its expanded ($k = 2$) uncertainty U_i. The values obtained in this way using the data of Table 8 are listed in Table 9 together with their expanded uncertainties, U_i. Note that no values are listed in Table 9 for the PTB and the VNIIM because their results were mainly used to define the CRV (see section 3.3). The degree of equivalence between these two primary standard laboratories is still given by the result obtained in the key comparison BIPM.RI(I)-K5 [4]. However, it is important to note that the results obtained by the PTB and the VNIIM in this supplementary COOMET comparison were consistent with those of the corresponding key comparison (see section 3.3) which gives more confidence in the CRV.

Table 9. Degrees of equivalence of each NMI measurement standard with respect to the CRV

	D_i	U_i
	mGy/Gy	
BelGIM	-7.8	21.6
GEOSTM	1.2	12.4
INSM	8.8	11.2
CPHR	-4.5	19.8
BIM	9.3	14.8
VMT/FTMC	-4.2	26.0
IAEA	0.4	8.2

5. References

[1] MRA: *Mutual Recognition Arrangement of national measurement standards and of calibration and measurement certificates issued by national metrology institutes,* International Committee for Weights and Measures, 1999.

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