BIPM comparison BIPM.RI(II)-K1.Ge-68 of activity measurements of the radionuclide ^{68}Ge for the LNMRI/IRD, NIST, NIM, IRA-METAS, LNE-LNHB and the TAEK, and the linked 2015 CCRI(II)-K2.Ge-68 comparison

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Abstract

This report summarises the results for the new BIPM.RI(II)-K1.Ge-68 comparison. Six metrology institutes have participated, enabling the first value of the key comparison reference value (KCRV) to be determined. The KCRV was calculated using the power-moderated weighted mean and the results. A link has been made to the CCRI(II)-K2.Ge-68 comparison held in 2015 through the NIST, NIM, IRA-METAS and the LNE-LNHB who participated in both comparisons. One NMI used the K2 comparison to update their degree of equivalence. The degrees of equivalence between each equivalent activity measured in the International Reference System (SIR) and the KCRV have been calculated and the results are given in the form of a table for the remaining five NMIs in the BIPM.RI(II)-K1.Ge-68 comparison and the 12 other participants in the CCRI(II)-K2.Ge-68 comparison. A graphical presentation is also given.

1. Introduction

The SIR for activity measurements of γ-ray-emitting radionuclides was established in 1976. Each national metrology institute (NMI) may request a standard ampoule from the BIPM that is then filled with 3.6 g of the radioactive solution. For radioactive gases, a different standard ampoule is used. Each NMI completes a form that details the standardization method used to determine the absolute activity of the radionuclide and the full uncertainty budget for the evaluation. The ampoules are sent to the BIPM where they are compared with standard sources of ^{226}Ra using pressurized ionization chambers. Details of the SIR method, experimental set-up and the determination of the equivalent activity, A_e, are all given in [1].

From its inception until 31 December 2019, the SIR has measured 1016 ampoules to give 771 independent results for 72 different radionuclides. The SIR makes it possible for national laboratories to check the reliability of their activity measurements at any time. This is achieved by the determination of the equivalent activity of the radionuclide and by comparison of the result with the key comparison reference value determined from the results of primary standardizations. These comparisons are described as BIPM ongoing comparisons and the results form the basis of the BIPM key comparison database (KCDB) of the CIPM Mutual Recognition Arrangement (CIPM MRA) [2]. The comparison described in this report is known as the BIPM.RI(II)-K1.Ge-68 key comparison.

In addition, an international comparison was held in 2015 for this radionuclide, CCRI(II)-K2.Ge-68 [3]. Seventeen laboratories took part in this comparison including the NIST, NIM, IRA-METAS and the LNE-LNHB who participated in the SIR at the same time, enabling to link the CCRI(II)-K2 comparison to the BIPM.RI(II)-K1 comparison. One NMI had previously submitted ampoules to the SIR and has updated their result through this CCRI(II) comparison.

2. Participants

Six NMIs submitted ampoules for inclusion in this new BIPM.RI(II)-K1 comparison. The details of the laboratories that have participated in the comparison are given in Table 1a. The date of measurement in the SIR is also included and is used in the KCDB and all references in this report.

The 13 additional NMIs that took part in the CCRI(II) international comparison CCRI(II)-K2.Ge-68 in 2015 and are also eligible for the KCDB are shown in Table 1b. This include the LNMRI/IRD, that used this comparison to update their result, and the TAEK, whose result is superseded by the later participation in the SIR.

Table 1a. Details of the participants in the BIPM.RI(II)-K1.Ge-68

NMI	**Original acronym**	**Full name**	**Country**	**Regional metrology organization**	**Date of measurement at the BIPM** YYYY-MM-DD
LNMRI/ IRD*	–	Laboratorio Nacional de Metrologia das Radiaçoes Ionizantes/ Instituto de Radioproteção e Dosimetria	Brazil	SIM	2013-01-17
NIST	–	National Institute of Standards and Technology	United States	SIM	2014-12-15
NIM	–	National Institute of Metrology	China	APMP	2015-03-23
IRA-METAS	–	Institut de radiophysique appliquée - Institut fédéral de métrologie	Switzerland	EURAMET	2015-04-22
LNE-LNHB	–	Laboratoire national de métrologie et d'essais – Laboratoire national Henri Becquerel	France	EURAMET	2015-05-28
TAEK	–	Turkish Atomic Energy Authority	Turkey	EURAMET	2018-01-04

*Participation superseded by the 2015 CCRI(II)-K2.Ge-68 comparison below

Table 1b. Details of the participants in the 2015 CCRI(II)-K2.Ge-68 to be linked to BIPM.RI(II)-K1.Ge-68 comparison

NMI	**Full name**	**Country**	**Regional metrology organization**
ANSTO	Australian Nuclear Science and Technology Organisation	Australia	APMP
BARC	Bhabha Atomic Research Centre	India	APMP
CIEMAT	Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas	Spain	EURAMET
IFIN-HH	Institutul National de Cercetare - Dezvoltare in Fizica si Inginerie Nucleara - “Horia Hulubei”	Romania	EURAMET, COOMET
INER	Institute of Nuclear Energy Research	Taiwan	APMP
KRISS	Korea Research Institute of Standards and Science	Korea	APMP
LNMRI/IRD	Laboratório Nacional de Metrologia das Radiações Ionizantes, Instituto de Radioproteção e Dosimetria	Brazil	SIM
NMIJ	National Metrology Institute of Japan	Japan	APMP
NPL	National Physical Laboratory	United Kingdom	EURAMET
POLATOM	National Centre for Nuclear Research, Radioisotope Centre POLATOM	Poland	EURAMET
PTB	Physikalisch-Technische Bundesanstalt	Germany	EURAMET, COOMET
SMU	Slovenský Metrologický Ústav	Slovakia	EURAMET, COOMET
TAEK*	Turkish Atomic Energy Authority	Turkey	EURAMET, COOMET

*Participation superseded by the submission of an ampoule to the SIR in 2018

3. NMI standardization methods

Each NMI that submits ampoules to the SIR has measured the activity either by a primary standardization method or by using a secondary method, for example a calibrated ionization chamber. In the latter case, the traceability of the calibration needs to be clearly identified to ensure that any correlations are taken into account.

A brief description of the standardization methods, the activities submitted, the relative combined standard uncertainties and the half-life used by the participants in the SIR are given in Table 2. Most participants performed primary standardizations of ^{68}Ga from which the activity of ^{68}Ge was inferred. The uncertainty budgets for the SIR submissions from LNMRI/IRD and TAEK are given in Appendix 1. The uncertainty budgets for the other SIR participants and all the participants in the CCRI(II)-K2.Ge-68 comparison were published as Appendix B of the final report [3]. The acronyms used for the measurement methods are given in Appendix 2.

Details regarding the solutions submitted are shown in Table 3, including any impurities, when present, as identified by the laboratories. When given, the standard uncertainties on the evaluations are shown.

Table 2. Standardization methods of the SIR participants for ^{68}Ge

NMI	Method used and acronym (see Appendix 2)	Half-life / d	Activity A_i / kBq	Reference date	Relative standard uncertainty / 10^{-2} by method of evaluation	
				YYYY-MM-DD	A	B
LNMRI/ IRD	4π(LS)β$^+$-γ anti-coinc. counting 4P-LS-PO-NA-GR-AC	270.95(16)	867.0	2012-04-03 12h UTC	0.05	0.17
NIST	4P-LS-PO-NA-GR-AC	270.95	2244	2014-11-14 12h UTC	0.19	0.59
NIM	Liquid scint. TDCR and CIEMAT/NIST 4P-LS-PO-00-00-TD 4P-LS-PO-00-00-CN	270.95(26) [4]	1448#	2014-11-14 12h UTC	0.57	
IRA-METAS	4π plastic scintill. - 4π well-type NaI coinc. counting 4P-SP-PO-NA-GR-CO	270.95(26) [4] *	697.7	2014-11-14 12h UTC	0.15	0.51
LNE-LNHB	4P-LS-PO-NA-GR-AC	270.95(26) [4]	2295	2014-11-14 12 h UT	0.18	0.47
TAEK	Pressurized 4πγ** 4P-IC-GR-00-00-00	270.95(26) [4]	481.3	2016-04-01 12 h UT	0.33	1.45

* Ga-68 half-life is 67.83(20) min
** calibrated at the Physikalisch-Technische Bundesanstalt, Germany in 2014
# arithmetic mean result from two measurements methods, and combined uncertainty

Table 3. Details of the solution of ^{68}Ge submitted

NMI/ SIR year	Chemical composition	Solvent conc. / (mol dm^{-3})	Carrier: conc. /(μg g^{-1})	Density /(g cm^{-3})	Relative activity of impurity[a]
LNMRI/ IRD 2013	HCl	0.1	–	0.99	–
NIST 2014[b]	Ge and Ga in HCl	0.5	Ge^{4+}: 65 Ga^{3+}: 62	1.006	–
NIM 2015[c]	Ge^{+4} and Ge^{+3} in HCl	0.5	Ge^{4+}: 65 Ga^{3+}: 65	1.0	–
IRA-METAS 2015[d]	Ge^{+4} and Ge^{+3} in HCl	0.5	Ge^{4+}: 65 Ga^{3+}: 65	1.007	–
LNE-LNHB 2015[b]	Ge and Ga in HCl	0.5	Ge^{4+}: 65 Ga^{3+}: 62	1.007	–
TAEK 2018	$GeCl_4$ and $GaCl_3$ in HCl	0.5	$GeCl_4$: 65 $GaCl_3$: 62	1.006	–

[a] The ratio of the activity of the impurity to the activity of ^{68}Ge at the reference date.
[b] Same solution as for the CCRI(II)-K2.Ge-68 comparison.
[c] solution from the CCRI(II)-K2.Ge-68 comparison diluted by a factor of 1.504 00(8)
[d] solution from the CCRI(II)-K2.Ge-68 comparison diluted by a factor of 3.185 50(13)

4. Results

All the submissions to the SIR since its inception in 1976 are maintained in a database known as the "master-file". The recent submissions have provided six ampoules for the activity measurements for ^{68}Ge. The SIR equivalent activity, A_{ei}, for each ampoule for the previous and new results is given in Table 4a for each NMI, *i*. The relative standard uncertainty arising from the measurements in the SIR is also shown. This uncertainty is additional to that declared by the NMI for the activity measurement shown in Table 2. Although submitted activities are compared with a given source of ^{226}Ra, all the SIR results are normalized to the radium source number 5 [1].

The half-life used by the BIPM is 270.95(26) d from the BIPM Monographie 5 [4] and is the same half-life used in the CCRI(II)-K2.Ge-68 comparison.

Table 4a. Results of SIR measurements of ^{68}Ge

NMI/ SIR year	Mass of solution *m* /g	Activity submitted *A* / kBq	No. of Ra source used	SIR A_e / kBq	Relative standard uncertainty from SIR /10^{-4}	Combined uncertainty $u(A_e)$ / kBq
LNMRI/ IRD 2013	3.486 97	867.0	2	15 772	13	36
NIST 2014	3.595 5	2244	3	15 829 [b]	5	98
NIM 2015	3.596 88	1448	3	15 338 [b]	8	88
IRA-METAS 2015	3.566 10(21)	697.7	2	15 797 [b]	10	86
LNE-LNHB 2015	3.6702	2295	3	15 855 [b]	8	81
TAEK 2018	3.6164	481.3	1	15 960	22[a]	240

[a] Uncertainty dominated by the contribution of the decay correction for ^{68}Ge
[b] Results used to link the CCRI(II)-K2 comparison

No recent submission has been identified as a pilot study so the result of each NMI is normally eligible for the key comparison database (KCDB) of the CIPM MRA.

An international comparison for this radionuclide, CCRI(II)-K2.Ge-68 was held in 2015 [3] and the twelve laboratories from this comparison to be added to the matrix of degrees of equivalence are given in Table 1b. The LNMRI/IRD used the CCRI(II) comparison to update their degree of equivalence from earlier SIR participation.

The results $(A/m)_i$ of the CCRI(II) comparison have been linked to the BIPM.RI(II)-K1.Ge-68 comparison through the measurement in the SIR of four ampoules of the CCRI(II) solution (or a dilution of this solution), standardized by the NIST, NIM, IRA-METAS and LNE-LNHB. The linking factor L_j for each linking laboratory j is shown in Table 4b and is defined to be $L_j = A_{e,j} / d_j(A/m)_j$ where the activity, mass and equivalent activity are taken from Table 4a and the dilution factor d_j for the NIM and IRA-METAS from Table 3 . The uncertainty of L_j shown in Table 4b is obtained by combining in quadrature the uncertainty of the dilution factor and the uncertainty from the SIR measurement. The linking factor for the CCRI(II) comparison is finally obtained as the weighted mean of the factors L_j, where $w_j = 1/u(L_j)^2$:

$$A_{e,\,i} = (A/m)_i \times \sum_{j=1}^{4} w_j \left[A_{e,j} \big/ d_j (A/m)_j \right] = (A/m)_i \times 25.355(9) ,$$

Table 4b. Details of the link calculation

NMI/ SIR year	**Activity conc. corrected for dilution $(A/m)_j \times d_j$ / kBq g^{-1}**	**Relative uncertainty of dilution factor d_j /10^{-4}**	**SIR $A_{e,j}$ / kBq**	**Relative standard uncertainty from SIR /10^{-4}**	**Linking factor L_j**
NIST 2014	624	–	15 829	5	25.37(1)
NIM 2015	605.7	0.5	15 338	8	25.32(2)
IRA-METAS 2015	623.3	0.4	15 797	10	25.35(3)
LNE-LNHB 2015	625.2	–	15 855	8	25.36(2)

The linked results are detailed in Table 4c. The uncertainties for the CCRI(II) comparison results linked to the SIR are comprised of the original uncertainties together with the relative uncertainty in the link, 4×10^{-4}, given by the internal standard deviation of the linking values in Table 4b. Further details of the results of the CCRI(II)-K2.Ge-68 comparison are available in [3].

Table 4c. Results of the 2015 CCRI(II) comparison of ^{68}Ge and links to the SIR

NMI	Measurement method acronym (see Appendix 2)	Activity* concentration measured $(A/m)_i$ / (kBq g^{-1})	Standard uncertainty u_i / (kBq·g^{-1})	Equivalent SIR activity A_{ei} / MBq	Combined standard uncertainty u_i / MBq
ANSTO	4P-LS-PO-NA-GR-CO	620.2	3.4	15 725	86
BARC	Mean result of 4P-LS-PO-NA-GR-CO (3 setups) and 4P-LS-MX-00-00-CN (see [3])	617.4	1.7	15 655	42
CIEMAT	Mean result of 4P-LS-MX-00-00-TD 4P-LS-MX-NA-GR-CO	618.5	2.2	15 682	56
IFIN-HH	4P-PC-PO-NA-GR-CO	613.4	5.8	15 550	150
INER	4P-LS-MX-00-00-CN	618.3	1.9	15 677	49
KRISS	4P-LS-PO-NA-GR-CO	629.5	4.0	15 960	100
LNMRI/ IRD	4P-LS-PO-NA-GR-AC	622.2	3.3	15 777	84
NMIJ	4P-LS-MX-00-00-CN	624.1	4.4	15 820	110
NPL	4P-LS-MX-GH-GR-CO	625.7	4.3	15 860	110
POLATOM	4P-LS-PO-NA-GR-CO	625.4	4.0	15 860	100
PTB	Mean result of 4P-CD-PO-NA-GR-CO using double or triple coincidences in the beta channel	626.4	5.1	15 880	130
SMU	4P-LS-PO-00-00-TD	689.7	2.8	17 487	71
TAEK**	Weighted mean of 4P-NA-GR-00-00-HE 4P-IC-GR-00-00-00	628.0	4.0	15 920	100

* referenced to 12:00 UTC 14 November 2014
** result superseded by the SIR participation of this laboratory in 2018

4.1 The Key Comparison Reference Value

In May 2013 the CCRI(II) decided to calculate the key comparison reference value (KCRV) using the power-moderated weighted mean [5] rather than an unweighted mean, as had been the policy. This type of weighted mean is similar to a Mandel-Paule mean in that the NMIs' uncertainties may be increased until the reduced chi-squared value is one. In addition, it allows for a power smaller than two in the weighting factor.

Therefore, all SIR key comparison results can be selected for the KCRV with the following provisions:

a) only results for solutions standardized by primary techniques are accepted, with the exception of radioactive gas standards (for which results from transfer instrument measurements that are directly traceable to a primary measurement in the laboratory may be included);
b) each NMI or other laboratory has only one result (normally the most recent result or the mean if more than one ampoule is submitted);
c) results more than 20 years old are included in the calculation of the KCRV (but are not included in data shown in the KCDB or in the plots in this report as they have expired);
d) possible outliers can be identified on a mathematical basis and excluded from the KCRV using the normalized error test with a test value of 2.5 and using the modified uncertainties;
e) results can also be excluded for technical reasons; and
f) the CCRI(II) is always the final arbiter regarding excluding any data from the calculation of the KCRV.

The data set used for the evaluation of the KCRVs is known as the "KCRV file" and is a reduced data set from the SIR master-file. Although the KCRV may be modified when other NMIs participate, on the advice of the Key Comparison Working Group of the CCRI(II), such modifications are made only by the CCRI(II) during one of its biennial meetings, or by consensus through electronic means (e.g., email) as discussed at the CCRI(II) meeting in 2013.

Consequently, the KCRV for ^{68}Ge has been calculated for the first time and is equal to 15 800(31) kBq with the power $\alpha = 1.25$ on the basis of the SIR results from the NIST, IRA-METAS, LNE-LNHB and LNMRI/IRD. The NIM result is not included as it has been identified as an outlier using the normalized error test as detailed in bullet d) above.

4.2 Degrees of equivalence

Every participant in a comparison is entitled to have one result included in the KCDB as long as the NMI is a signatory or designated institute listed in the CIPM MRA, and the result is valid (i.e., not older than 20 years). Normally, the most recent result is the one included. An NMI may withdraw its result only if all other participants agree.

The degree of equivalence of a given measurement standard is the degree to which this standard is consistent with the KCRV [2]. The degree of equivalence is expressed quantitatively in terms of the deviation from the key comparison reference value and the expanded uncertainty of this deviation ($k = 2$). The degree of equivalence between any pair of national measurement standards is expressed in terms of their difference and the expanded uncertainty of this difference and is independent of the choice of key comparison reference value.

4.2.1 *Comparison of a given NMI result with the KCRV*

The degree of equivalence of the result of a particular NMI, *i*, with the key comparison reference value is expressed as the difference D_i between the values

$$D_i = A_{\mathrm{e}\,i} - \mathrm{KCRV} \quad (1)$$

and the expanded uncertainty (k = 2) of this difference, U_i, known as the equivalence uncertainty; hence

$$U_i = 2u(D_i)\,. \quad (2)$$

When the result of the NMI *i* is included in the KCRV with a weight w_i, then

$$u^2(D_i) = (1\text{-}2w_i)\, u_i^2 + u^2(\mathrm{KCRV})\,. \quad (3)$$

However, when the result of the NMI *i* is not included in the KCRV, then

$$u^2(D_i) = u_i^2 + u^2(\mathrm{KCRV}). \quad (4)$$

4.2.2 *Comparison between pairs of NMI results*

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

$$D_{ij} = D_i - D_j = A_{\mathrm{e}\,i} - A_{\mathrm{e}\,j} \quad (5)$$

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

$$u_{D\,ij}^{\;2} = u_i^{\;2} + u_j^{\;2} - 2u(A_{\mathrm{e}i}, A_{\mathrm{e}j}) \quad (6)$$

where any obvious correlations between the NMIs (such as a traceable calibration, or correlations normally coming from the SIR or from the linking factor in the case of linked comparison) are subtracted using the covariance $u(A_{\mathrm{e}i}, A_{\mathrm{e}j})$ (see [6] for more detail). However, the CCRI decided in 2011 that these “pair-wise degrees of equivalence” no longer need to be published as long as the methodology is explained.

Table 5 shows the matrix of all the degrees of equivalence as they will appear in the KCDB. It should be noted that for consistency within the KCDB, a simplified level of nomenclature is used with $A_{\mathrm{e}i}$ replaced by x_i. The introductory text is that agreed for the comparison. The graph of the results in Table 5, corresponding to the degrees of equivalence with respect to the KCRV (identified as x_{R} in the KCDB), is shown in Figure 1 in relative terms. This graphical representation indicates in part the degree of equivalence between the NMIs but obviously does not take into account the correlations between the different NMIs. It should be noted that the final data in this paper, while correct at the time of publication, will become out-of-date as NMIs make new comparisons. The formal results under the CIPM MRA [2] are those available in the KCDB.

Conclusion

The BIPM ongoing key comparison for ^{68}Ge, BIPM.RI(II)-K1.Ge-68 currently comprises five valid results. The key comparison reference value has been evaluated using the power-moderated weighted mean to include the NIST, IRA-METAS, LNE-LNHB and the LNMRI/IRD results. The SIR results have been analysed with respect to the first KCRV determined for this radionuclide, providing degrees of equivalence for five participants.

The results of twelve other NMIs that took part in the CCRI(II)-K2.Ge-68 comparison in 2015 have been linked to the BIPM ongoing key comparison through four ampoules of the comparison measured in the SIR. These results superseded one earlier result from the BIPM.RI(II)-K1.Ge-68 comparison. The linked results are included in the matrix of degrees of equivalence and shown on the graph. This has enabled the table of degrees of equivalence to include 17 results in total.

The degrees of equivalence have been approved by the CCRI(II) and are published in the BIPM key comparison database. Further results may be added when other NMIs contribute ^{68}Ge activity measurements to the ongoing K1 comparison or take part in other linked comparisons.

References

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Table 5. Table of degrees of equivalence and introductory text for ^{68}Ge

Key comparison BIPM.RI(II)-K1.Ge-68

MEASURAND : **Equivalent activity of ^{68}Ge**

Key comparison reference value: the SIR reference value for this radionuclide is x_R = 15 800 kBq with a standard uncertainty, u_R = 31 kBq (see Section 4.1 of the Final Report).
The value x_i is the equivalent activity for laboratory *i*.

The degree of equivalence of each laboratory with respect to the reference value is given by a pair of terms:
$D_i = (x_i - x_R)$ and U_i, its expanded uncertainty (k = 2), both expressed in MBq, and
$U_i = 2((1 - 2w_i)u_i^2 + u_R^2)^{1/2}$, where w_i is the weight of laboratory *i* contributing to the calculation of x_R.

Linking CCRI(II)-K2.Ge-68 (2015) to BIPM.RI(II)-K1.Ge-68

The value x_i is the equivalent activity for laboratory *i* participant in CCRI(II)-K2.Ge-68 having been normalized using the NIST, NIM, IRA-METAS and LNE-LNHB as linking laboratory (see Section 4 of the Final report).

The degree of equivalence of laboratory *i* participant in CCRI(II)-K2.Ge-68 with respect to the key comparison reference value is given by a pair of terms: $D_i = (x_i - x_R)$ and U_i, its expanded uncertainty (k = 2), both expressed in MBq.
The approximation $U_i = 2(u_i^2 + u_R^2)^{1/2}$ is used in the following table.

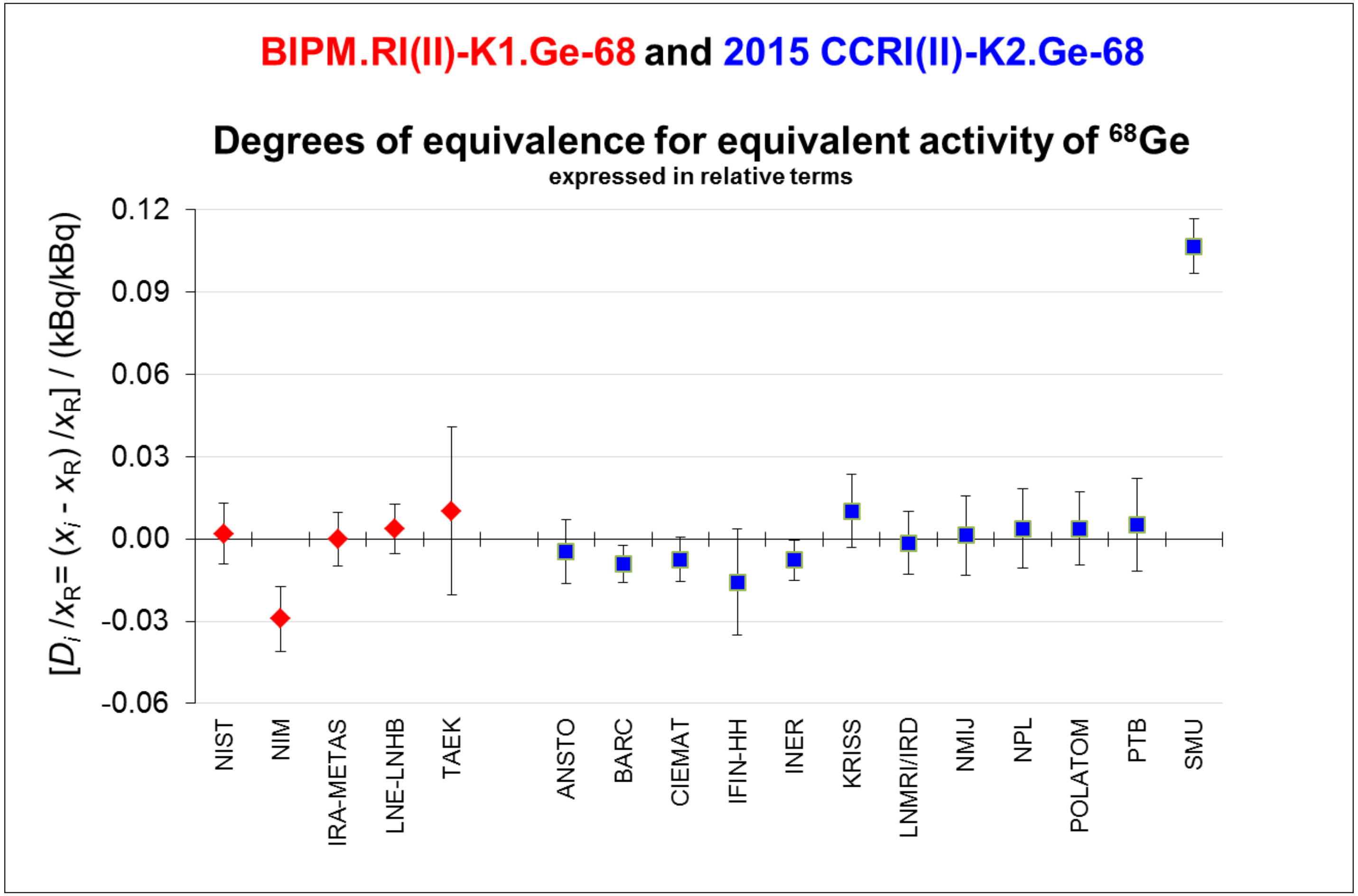
These statements make it possible to extend the BIPM.RI(II)-K1.Ge-68 matrices of equivalence to the other participants in CCRI(II)-K2.Ge-68.

Table 5 continued

Lab *i*	D_i / MBq	U_i / MBq
NIST	0.03	0.18
NIM	-0.46	0.19
IRA-METAS	0.00	0.15
LNE-LNHB	0.06	0.14
TAEK	0.16	0.48

ANSTO	-0.07	0.18
BARC	-0.14	0.10
CIEMAT	-0.12	0.13
IFIN-HH	-0.25	0.31
INER	-0.12	0.11
KRISS	0.16	0.21
LNMRI/IRD	-0.02	0.18
NMIJ	0.02	0.23
NPL	0.06	0.23
POLATOM	0.06	0.21
PTB	0.08	0.27
SMU	1.69	0.16

Figure 1. **Graph of degrees of equivalence with the KCRV for ^{68}Ge, expressed in relative terms**
(as it appears in Appendix B of the MRA)



Appendix 1. Uncertainty budgets for the activity of ^{68}Ge submitted to the SIR

The LNMRI/IRD submitted a detailed uncertainty budget as follows:

Relative standard uncertainties	$u_{rel,i} \times 10^4$ evaluated by method	
Contributions due to	**A**	**B**
counting statistics	2	–
weighing, dilution	–	5
dead time	–	1
decay scheme parameters	–	13
decay correction	–	3
extrapolation	5	–
interference of 1077 keV gamma-ray in the γ-counting	–	10
Quadratic summation	**5**	**17**
Relative combined standard uncertainty, u_c	**18**	

The TAEK submitted a detailed uncertainty budget as follows:

Relative standard uncertainties	**Comment**	$u_{rel,i} \times 10^4$ evaluated by method	
Contributions due to		**A**	**B**
counting statistics	Current measurement	22	–
weighing, dilution	2 µg precision microbalance	–	0.3
background	Included in counting statistics	–	–
Cs-137 ref. source current measurement		25	
ionization chamber calibration factor			145
adsorption	Negligible (rinsed ampoules counting with HPGe detector)	–	–
impurities	Negligible (not detectable at 20 cm with HPGe detector)	–	–
Decay correction		–	12
Quadratic summation		**33**	**145**
Relative combined standard uncertainty, u_c		**150**	

Appendix 2. Acronyms used to identify different measurement methods

Each acronym has six components, geometry-detector (1)-radiation (1)-detector (2)-radiation (2)-mode. When a component is unknown, ?? is used and when it is not applicable 00 is used.

Geometry	acronym	Detector	acronym
4π	4P	proportional counter	PC
defined solid angle	SA	press. prop counter	PP
2π	2P	liquid scintillation counting	LS
undefined solid angle	UA	NaI(Tl)	NA
		Ge(HP)	GH
		Ge(Li)	GL
		Si(Li)	SL
		CsI(Tl)	CS
		ionization chamber	IC
		grid ionization chamber	GC
		Cerenkov detector	CD
		calorimeter	CA
		solid plastic scintillator	SP
		PIPS detector	PS
Radiation	**acronym**	**Mode**	**acronym**
positron	PO	efficiency tracing	ET
beta particle	BP	internal gas counting	IG
Auger electron	AE	CIEMAT/NIST	CN
conversion electron	CE	sum counting	SC
mixed electrons	ME	coincidence	CO
bremsstrahlung	BS	anti-coincidence	AC
gamma rays	GR	coincidence counting with efficiency tracing	CT
X - rays	XR	anti-coincidence counting with efficiency tracing	AT
photons (x + γ)	PH	triple-to-double coincidence ratio counting	TD
alpha - particle	AP	selective sampling	SS
mixture of various radiation	MX	high efficiency	HE

Examples method	acronym
4π(PC)β–γ-coincidence counting	4P-PC-BP-NA-GR-CO
4π(PPC)β–γ-coincidence counting eff. trac.	4P-PP-MX-NA-GR-CT
defined solid angle α-particle counting with a PIPS detector	SA-PS-AP-00-00-00
4π(PPC)AX-γ(Ge(HP))-anticoincidence counting	4P-PP-MX-GH-GR-AC
4π CsI-β,AX,γ counting	4P-CS-MX-00-00-HE
calibrated IC	4P-IC-GR-00-00-00
internal gas counting	4P-PC-BP-00-00-IG