BIPM comparison BIPM.RI(II)-K1. Np-237 of activity measurements of the radionuclide ^{237}Np and links for the 1998 regional comparison EUROMET.RI(II)-K2.Np-237

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Abstract

In 1998, five national metrology institutes (NMI), an international laboratory and the Bureau International des Poids et Mesures (BIPM) took part in a comparison of activity measurements of ^{237}Np as part of the EUROMET project No. 416 comparison identifier EUROMET.RI(II)-K2.Np-237. The nominal activity per mass of the ^{237}Np solution distributed was 150 kBq g^{-1}. The three ampoules received by the BIPM for this comparison were also measured in the International Reference System (SIR) for activity comparison at the BIPM (identifier BIPM.RI(II)-K1.Np-237). Two other participants to the EUROMET comparison also submitted ampoules of the same ^{237}Np solution to the SIR. These SIR measurements enable the EUROMET comparison to be linked to the BIPM.RI(II)-K1.Np-237. The degrees of equivalence between each laboratory and the key comparison reference value (KCRV) have been calculated and the results are given in the form of a graph and matrix for the three SIR participants and four other NMIs from the EUROMET comparison.

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 (3.6 g) with the radionuclide in liquid form or a different standard ampoule for radioactive gases. The NMI completes a submission 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 2006, the SIR has measured 894 ampoules to give 655 independent results for 63 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 realizations of activity. 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.Np-237 key comparison.

An international comparison was held in 1998 of activity measurements for the radionuclide Np-237, EUROMET.RI(II)-K2.Np-237 [3], piloted by the NPL. This comparison was given the status of provisional equivalence in the KCDB in 2001 by the CCRI(II). The comparison was held, not just for activity measurements but also to improve the nuclear data related to the decay scheme (e.g. [4 to 7]). Seven laboratories took part in this comparison including the NPL. Three of them also participated in the SIR using the same ^{237}Np solution and the four other NMIs are eligible to be linked to the BIPM key comparison.

2. Participants

One NMI, one international organization and the BIPM have submitted five ampoules for the comparison of ^{237}Np activity measurements since 1998. The laboratory details are given in Table 1a.

The five NMIs and two other laboratories that took part in the regional comparison, EUROMET.RI(II)-K2.Np-237 in 1998 are shown in Table 1b. In cases where the laboratory has changed its name since the original submission, both the earlier and the current acronyms are given, as it is the latter that are used in the KCDB.

Table 1a. Details of the participants in the BIPM.RI(II)-K1.Np-237

NMI or laboratory	**Full name**	**Country**	**Regional metrology organization**	**Date of measurement at the BIPM** YYYY-MM-DD
BIPM	Bureau International des Poids et Mesures	International	–	1998-06-12
PTB	Physikalisch-Technische Bundesanstalt	Germany	EUROMET	2006-02-02
IRMM	Institute for Reference Materials and Measurements	European Union	EUROMET	2006-11-29 and 2007-02-27

Table 1b. Details of the participants in the EUROMET.RI(II)-K2.Np-237

Original acronym	NMI or laboratory	Full name	Country	Regional metrology organization	Date of measurement YYYY-MM-DD
–	BIPM	Bureau International des Poids et Mesures	International	–	1998-06-23
BNM-LNHB	LNE-LNHB	Bureau national de métrologie-Laboratoire national Henri Becquerel	France	EUROMET	1998-07-01 to 1999-02-28
–	CIEMAT	Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas	Spain	EUROMET	1999-09-01
–	IRMM	Institute for Reference Materials and Measurements	European Union	EUROMET	1998-07-01 to 1999-04-30
–	NPL	National Physical Laboratory	United Kingdom	EUROMET	1998-10-06
–	NRC	National Research Council	Canada	SIM	1998-07-01 to 1998-09-30
–	PTB	Physikalisch-Technische Bundesanstalt	Germany	EUROMET	1998-07-03 to 1998-09-25

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 is clearly identified to ensure that any correlations are taken into account.

A brief description of the standardization methods for each laboratory, the activities submitted and the relative standard uncertainties (k = 1) are given in Table 2. The uncertainty budgets for the SIR results are in Appendix 1. The list of acronyms used to summarize the measurement methods is given in Appendix 2.

Details of the standardization methods used in the EUROMET comparison are given in [3, 8], together with the uncertainty budgets.

The half-life used for the EUROMET comparison was 2.14 (1) × 10^6 a [9] and the same value is used at the BIPM for the SIR measurements. The half-lives given in Table 2 are the values (and standard uncertainties) as used by the participants.

Table 2. Standardization methods of the participants for ^{237}Np

NMI	Method used and acronym (see Appendix 3)	Half-life	Activity / kBq	Reference date	Relative standard uncertainty × 100 by method of evaluation	
				YY-MM-DD	A	B
BIPM	γ spectrometry UA-GL-GR-00-00-00	[9]	611.2 611.0 613.4*	1998-09-01 12 h UT	0.9	0.5
PTB	Defined solid angle SA-PS-AP-00-00-00	7.831 (26) × 10^8 d	536.8**	1998-09-01 0 h UT	0.08	0.33
	Liquid scintillation CIEMAT-NIST 4P-LS-AP-00-00-CN				0.02	0.24
IRMM	Defined solid angle SA-PS-AP-00-00-00	[9]	525.2	1998-09-01 12 h UT	0.03	0.20

* three ampoules submitted
** mean of the results obtained using the two methods. The relative standard uncertainty of the mean evaluated by the PTB is 2.4 × 10^{-3}.

Details regarding the EUROMET solution are shown in Table 3, including any impurities, as this may be important for the SIR evaluation. The standard uncertainties on the evaluations are also shown. The values given are mean values of the determinations by three different laboratories using alpha spectrometry. No gamma-emitting contaminants in the region 10 keV to 2.7 MeV were detected by the PTB using a Ge spectrometer. The ampoules submitted to the SIR by the BIPM, PTB and IRMM contain aliquots of the same EUROMET solution.

Table 3. Details of the solution of ^{237}Np used in the EUROMET comparison

Chemical composition	Solvent conc. / (mol dm^{-3})	Carrier: conc. /(μg g^{-1})	Density /(g cm^{-3})	Relative activity of impurity†
$NpCl_4$ + $(COOH)_2$ in HCl	5.8	$NpCl_4$: 8 570 $(COOH)_2$: 33	1.11	^{238}Pu: 0.055 (7) % ^{239}Pu: 0.048 (4) % ^{240}Pu: 0.022 (9) % ^{243}Am: 0.018 % other: 0.041 %

† the mean ratios of the activity of the impurity to the activity of ^{237}Np at the reference date measured by the IRMM, CIEMAT and the PTB using alpha spectrometry.

4. Results

All the submissions to the SIR since its inception in 1976 are maintained in a database known as the "Master-file". The activity measurements for ^{237}Np arise from five ampoules and the SIR equivalent activity for each ampoule, A_{ei}, is given in Table 4a for each NMI i. Although ampoules submitted are compared with a given source of ^{226}Ra, all the SIR results are normalized to the radium source number 5 [2]. The dates of measurement in the SIR are given in Table 1.

The relative standard uncertainties arising from the measurements in the SIR are also shown. This uncertainty is additional to that declared by the NMI for the activity measurement shown in Table 2.

A potential problem with any measurement of ^{237}Np is the state of equilibrium between the ^{237}Np and its daughter radionuclide ^{233}Pa ($T_{1/2}$ of 27.0 (1) d [9]). Stability measurements made at the NPL, NRC and the LNE-LNHB using ionization chambers and Ge spectrometers indicated that the solutions were indeed in equilibrium [8]. Similarly, the measurements of the SIR ampoules from the PTB and the IRMM were repeated at the BIPM after a period of about 4 months and produced results in agreement, within the combined standard uncertainty. The daughter radionuclide ^{233}U ($T_{1/2}$ of 1.59 (3) × 10^5 a) has a negligible influence on the SIR measurement.

The impurities indicated in Table 3 have a negligible influence on the SIR measurements.

The mass of solution in the EUROMET ampoules submitted by the BIPM is higher than the 3.6 g required for the SIR and this may produce a bias in the A_e result due to a different level of self-attenuation in the ampoule. In consequence, the IRMM provided a set of four ampoules of the same EUROMET solution but with different masses, in other to study the influence of the mass of solution on the SIR result. This enabled a correction factor of 0.9992 (6) to be deduced for the BIPM SIR result [10].

Table 4a. Results of SIR measurements of ^{237}Np

Laboratory	Mass of solution m / g	Activity per mass (A / m) / (kBq / g)	N° of Ra source used	SIR A_e / kBq	Relative uncertainty from SIR	Combined uncertainty $u_{c,i}$ / kBq
BIPM	4.0528 4.0520 4.0674	150.8	1	75 760 75 310 75 510 #	30×10^{-4} 16×10^{-4} 20×10^{-4} #	810 790 790
PTB	3.60023 (9)	149.1	1	74 740	16×10^{-4}	220
IRMM	3.5109 (4)	149.6	1	74 950*	12×10^{-4} *	180

results corrected for self-attenuation effect related to the larger mass of solution in the ampoule; weighted mean is 75 440 (790) kBq

* mean result of two SIR measurements of the same ampoule

No result has been withdrawn from the SIR and no recent submission has been identified as a pilot study so the results of each NMI are eligible for the key comparison database of the CIPM MRA.

The results of the regional comparison EUROMET(II)-K2.Np-237 have been published [3]. The participants to be included in the matrix of degrees of equivalence for this regional comparison are those given in Table 1b, except the BIPM, PTB, and the IRMM for which SIR results are available. The results $(A/m)_i$ for the EUROMET participants are linked to the SIR through the measurement in the SIR of 5 ampoules of the same solution. The link is taken as the weighted mean of normalization ratios deduced from the lines indicated in Table 4a:

$$A_{ei} = (A/m)_i \times \frac{\sum_{l=1}^{5} w_l \, A_{el} / (A/m)_l}{\sum_{l=1}^{5} w_l} = (A/m)_i \times 500.7 \qquad (1)$$

where the weights w_l are deduced from the standard uncertainty of each SIR ionization chamber measurement. The details of the links are given in Table 4b. The uncertainties for the regional comparison linked to the SIR are comprised of the original uncertainties together with the uncertainty in the link, 8.4×10^{-4} in relative terms, given by the external uncertainty of the weighted mean.

Table 4b. Results of 1998 EUROMET.RI(II) measurements of ^{237}Np

NMI	Activity per mass [§] $(A/m)_i$ / (kBq g^{-1})	Relative standard uncertainty × 100	Equivalent SIR activity A_{ei} / kBq	Combined standard uncertainty $u_{c\,i}$ / kBq
BIPM	150.8	1.0	75 510 ♦	760
LNE-LNHB	150.2 #	0.3	75 210	230
CIEMAT +	150.8 *	0.5	75 510	380
IRMM	149.6	0.20 ♦♦	74 910 ♦	160
NPL	148.2	0.6	74 210	450
NRC	147.9	1.1	74 060	820
PTB	149.16 **	0.16	74 690 ♦	140

§ referenced to 1998-09-01 12 h UT
♦ results superseded in the KCDB by the results in Table 4a
weighted mean and external standard uncertainty of two primary measurement results
+ an earlier result submitted by CIEMAT in 1998 has been withdrawn
* weighted mean as given in [8]
♦♦ revised uncertainty budget (see Appendix 1)
** weighted mean and internal uncertainty of three primary measurement results, as given in [8]

4.1 The key comparison reference value

The key comparison reference value is derived from the unweighted mean of all the results submitted to the SIR with the following provisions:

a) only primary standardized solutions 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) any outliers are identified using a reduced chi-squared test and, if necessary, excluded from the KCRV using the normalized error test with a test value of four;
d) exclusions must be approved by the CCRI(II).

The reduced data set used for the evaluation of the KCRVs is known as the KCRV file and is the 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 only made by the CCRI(II), normally during one of its biennial meetings.

Consequently, the KCRV for ^{237}Np has been identified as 74 850 (110) kBq using the results from the PTB and the IRMM.

The KCRV is in agreement within one standard uncertainty with the equivalent activity calculated using the efficiency curve of the SIR obtained with the program SIRIC [11] and the photon emission probabilities from [12] for ^{237}Np and from [13] for ^{233}Pa: A_e = 74 510 kBq, u = 400 kBq.

4.2 Degrees of equivalence

Every NMI that has submitted ampoules to the SIR or taken part in a CCRI or RMO comparison is entitled to have one result included in the key comparison database of the CIPM MRA as long as the NMI is a signatory or designated institute listed in the CIPM MRA. Normally, the most recent result is the one included. Any NMI may withdraw its result only if all the participants agree.

The degree of equivalence of a given measurement standard is the degree to which this standard is consistent with the key comparison reference value [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) although this cannot be calculated for this comparison. 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 with the KCRV*

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

$$D_i = A_{ei} - \text{KCRV} \quad (1)$$

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

$$U_i = 2u_{D_i}, \quad (2)$$

taking correlations into account as appropriate [14].

4.2.2 *Comparison of any two NMIs with each other*

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

$$D_{ij} = D_i - D_j = A_{e\,i} - A_{e\,j} \quad (3)$$

and the expanded uncertainty of this difference U_{ij} where

$$u_{D_{ij}}{}^2 = u_i{}^2 + u_j{}^2 - 2u(A_{e,i}, A_{e,j}) \quad (4)$$

where any obvious correlations between the NMIs (such as a traceable calibration) are subtracted using the covariance $u(A_{ei}, A_{ej})$, as are normally those correlations coming from the SIR.

The uncertainties of the differences between the values assigned by individual NMIs and the key comparison reference value (KCRV) are not necessarily the same uncertainties that enter into the calculation of the uncertainties in the degrees of equivalence between a pair of participants. Consequently, the uncertainties in the table of degrees of equivalence cannot be generated from the column in the table that gives the uncertainty of each participant with respect to the KCRV. However, the effects of correlations have been treated in a simplified way as the degree of confidence in the uncertainties themselves does not warrant a more rigorous approach.

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_{ei} replaced by x_i. The introductory text is that agreed for the comparison. The graph of the first column of 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. The graphical representation indicates in part the degree of equivalence between the NMIs but does not take into account the correlations between the different NMIs. However, the matrix of degrees of equivalence shown in yellow in Table 5 does take the known correlations into account.

The results of the 1998 EUROMET.RI(II)-K2.Np-237 regional comparison, linked through the SIR measurement of the BIPM, PTB and IRMM, are given for four NMIs as an extension of the matrix in Table 5 and as the second set of values in Figure 1. The correlations associated with the distribution of the same solution in the regional comparison have been ignored in the analysis as the overall uncertainties are quite large. The correlation coming from the link to the SIR has been taken into account.

Conclusion

The BIPM ongoing key comparison for ^{237}Np, BIPM.RI(II)-K1.Np-237 currently comprises three results. All the results have been analysed with respect to the KCRV determined for this radionuclide, and with respect to each other. The matrix of degrees of equivalence has been approved by the CCRI(II) and is published in the BIPM key comparison database.

The results of four other NMIs that took part in the EUROMET.RI(II)-K2.Np-237 comparison in 1998 have been linked to the BIPM ongoing comparison through five ampoules of the comparison solution measured in the SIR. These linked results are included in the matrix of degrees of equivalence approved by the CCRI(II).

Other results may be added as and when other NMIs contribute ^{237}Np activity measurements to this comparison or take part in other linked comparisons.

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References

[1] Ratel G. The international reference system for activity measurements of γ-emitting radionuclides (SIR), *BIPM Monograph XX*, (in preparation).

[2] 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.

[3] Woods M.J. et al, Standardization and decay data of ^{237}Np, 2002, *Applied Radiation and Isotopes*, **56**, 415-420.

[4] Luca A., Etcheverry M., Morel J., 2000, Emission probabilities of the main γ-rays of ^{237}Np in equilibrium with ^{233}Pa, *Applied Radiation and Isotopes*, **52,** 481-486.

[5] Schötzig U., Schönfeld E., Janszen H., 2000, Standardization and photon emission probabilities in the decay of ^{237}Np / ^{233}Pa, *Applied Radiation and Isotopes*, **52,** 883-889.

[6] Sibbens G., Deneke B., 2000, Determination of the absolute alpha-particle emission probabilities of ^{237}Np, *Applied Radiation and Isotopes*, **52**, 467-470.

[7] Woods S.A., Woods D.H., de Lavison P., Jerome S.M., Makepeace J.L., Woods M.J., Husband L.J., Lineham S., 2000, Standardisation and measurement of the decay scheme data of ^{237}Np, *Applied Radiation and Isotopes*, **52**, 475-479.

[8] Smith D., Woods M.J., Woods D.H., 2001, Results from the ^{237}Np exercise EUROMET action 416, *NPL Report CIRM* **43**, 76 pp.

[9] Ellis-Akovali Y.A., 1986, *Nuclear Data Sheets*, **49**, 206.

[10] Michotte C., Courte S., Sibbens G., Camps J. Paepen J., Study of self-attenuation in a solution of ^{237}Np measured in ionization chambers (in preparation).

[11] Michotte C., Pearce A., K. Cox M. G., Gostely J.-J., 2006, An approach based on the SIR measurement model for determining ionisation chamber efficiency curves, and a study of ^{65}Zn and ^{201}Tl photon emission intensities. *Applied Radiation and Isotopes*, **64** (10-11), 1147-1155.

[12] BNM-CEA/DTA/DAMRI/LPRI, *Nucléide*, Nuclear and Atomic Decay Data Version 2000, 30/06/2004 CD ROM, BNM-LNHB, Gif-sur-Yvette.

[13] Bé M.-M., Chisté V., Dulieu C., Browne E., Baglin C., Chechev V., Kuzmenko N., Helmer R., Kondev F., MacMahon D., Lee K.B., 2006, Table of radionuclides, *BIPM Monographie 5*, volume 3, 123-130.

[14] Ratel G., Evaluation of the uncertainty of the degree of equivalence, 2005, *Metrologia*, **42**, 140-144.

Table 5.

Key comparison BIPM.RI(II)-K1.Np-237

MEASURAND : **Equivalent activity of ^{237}Np**

Key comparison reference value: the SIR reference value for this radionuclide is x_R = 74.85 MBq
with a standard uncertainty, u_R = 0.11 MBq.
x_R is the mean of two of the three results (see section 4.1 of the Report).

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 with n the number of laboratories
$U_i = 2((1 - 2/n)u_i^2 + (1/n^2)\Sigma u_i^2)^{1/2}$ when each laboratory has contributed to the calculation of x_R.

The degree of equivalence between two laboratories is given by a pair of terms:
$D_{ij} = D_i - D_j = (x_i - x_j)$ and U_{ij}, its expanded uncertainty (k = 2), both expressed in MBq.

The approximation $U_{ij} \sim 2(u_i^2 + u_j^2)^{1/2}$ is used in the following table.

Linking EUROMET.RI(II)-K2.Np-237 to BIPM.RI(II)-K1.Np-237

The value x_i is the equivalent activity for laboratory i participant in EUROMET.RI(II)-K2.Np-237
having been normalized using the SIR measurements of the BIPM, PTB and the IRMM as linking laboratories.

The degree of equivalence of laboratory i participant in EUROMET.RI(II)-K2.Np-237 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.

The degree of equivalence between two laboratories i and j, one participant in BIPM.RI(II)-K1.Np-237 and one in EUROMET.RI(II)-K2.Np-237,
or both participant in EUROMET.RI(II)-K2.Np-237, is given by a pair of terms: $D_{ij} = D_i - D_j$ and U_{ij}, its expanded uncertainty (k = 2),
approximated by $U_{ij} = 2(u_i^2 + u_j^2 - 2fu_l^2)^{1/2}$ with u_l being the standard uncertainty of the link when each laboratory is from the EUROMET
and f is the correlation coefficient. D_{ij} and U_{ij} are expressed in MBq.

These statements make it possible to extend the BIPM.RI(II)-K1.Np-237 matrices of equivalence to all participants in EUROMET.RI(II)-K2.Np-237.

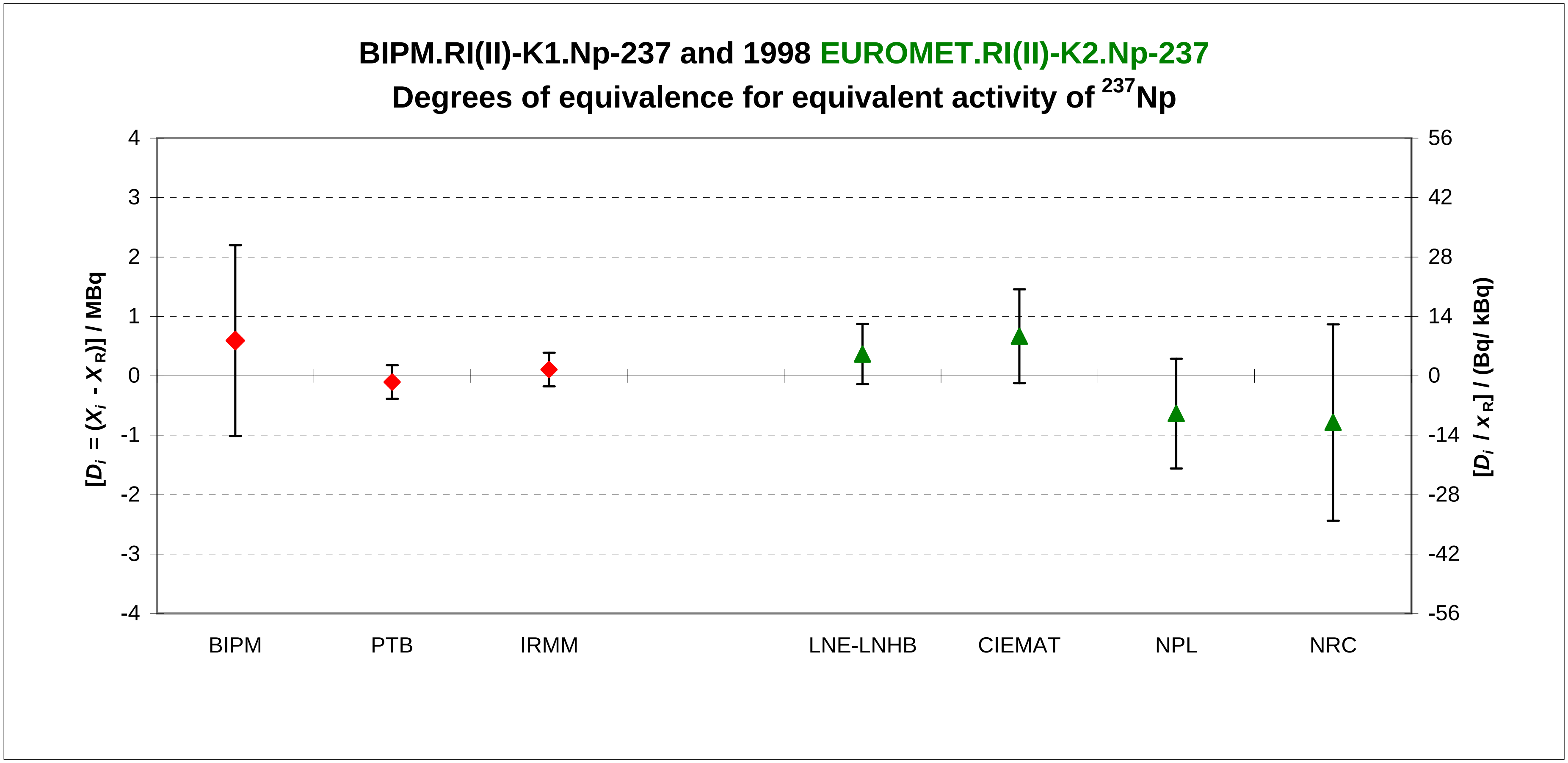
Table 5 Degrees of equivalence

Lab *j* ⇒

Lab *i* ⇓

Lab *i*	D_i / MBq	U_i / MBq	BIPM D_{ij} / MBq	BIPM U_{ij} / MBq	PTB D_{ij} / MBq	PTB U_{ij} / MBq	IRMM D_{ij} / MBq	IRMM U_{ij} / MBq	LNE-LNHB D_{ij} / MBq	LNE-LNHB U_{ij} / MBq	CIEMAT D_{ij} / MBq	CIEMAT U_{ij} / MBq	NPL D_{ij} / MBq	NPL U_{ij} / MBq	NRC D_{ij} / MBq	NRC U_{ij} / MBq
BIPM	**0.6**	1.6			**0.7**	1.6	**0.5**	1.6	**0.2**	1.6	**-0.1**	1.8	**1.2**	1.8	**1.4**	2.3
PTB	**-0.1**	0.3	**-0.7**	1.6			**-0.2**	0.6	**-0.5**	0.6	**-0.8**	0.9	**0.5**	1.0	**0.7**	1.7
IRMM	**0.1**	0.3	**-0.5**	1.6	**0.2**	0.6			**-0.3**	0.6	**-0.6**	0.8	**0.7**	1.0	**0.9**	1.7
LNE-LNHB	**0.4**	0.5	**-0.2**	1.6	**0.5**	0.6	**0.3**	0.6			**-0.3**	0.9	**1.0**	1.0	**1.2**	1.7
CIEMAT	**0.7**	0.8	**0.1**	1.8	**0.8**	0.9	**0.6**	0.8	**0.3**	0.9			**1.3**	1.2	**1.5**	1.8
NPL	**-0.6**	0.9	**-1.2**	1.8	**-0.5**	1.0	**-0.7**	1.0	**-1.0**	1.0	**-1.3**	1.2			**0.2**	1.9
NRC	**-0.8**	1.7	**-1.4**	2.3	**-0.7**	1.7	**-0.9**	1.7	**-1.2**	1.7	**-1.5**	1.8	**-0.2**	1.9		

Figure 1 Graph of degrees of equivalence with the KCRV for ^{237}Np
(as it appears in the KCDB of the CIPM MRA)



Note that the right-hand axis shows approximate values only

Appendix 1. Uncertainty budgets for the SIR submissions

BIPM Uncertainty budget for the gamma spectrometry measurements

Relative standard uncertainties	$u_i \times 10^4$ evaluated by method	
Contributions due to	**A**	**B**
Counting statistics, gamma emission probabilities and interpolation of the efficiency curve	86	–
Weighing	–	0.1
Dead-time	–	10
Pile up	–	30
Background	–	<10
Self-absorption in solution	–	10
Self-absorption in glass	–	35
Source position	–	10
Quadratic summation	**86**	**49**
Relative combined standard uncertainty, u_c	**99**	

PTB Uncertainty budget for the 4P-LS-MX-00-00-CN method

Relative standard uncertainties	$u_i \times 10^4$ evaluated by method	
Contributions due to	**A**	**B**
Counting statistics ($n > 50$)	2	–
Weighing	–	6
Dead-time	–	10
Background	–	5
Time measurement (time and duration)	–	< 1
Impurities (corrections for ^{238}Pu and ^{239}Pu)	–	5
Tracer	–	< 2
Alpha efficiency	–	15
Decay data and model	–	12
Quenching	–	3
Half-life	–	< 1
Dilution factor by weighing	–	3
Quadratic summation	**2**	**24**
Relative combined standard uncertainty, u_c	**24**	

PTB Uncertainty budget for the SA-PS-AP-00-00-00 method

Relative standard uncertainties	$u_i \times 10^4$ evaluated by method	
Contributions due to	**A**	**B**
Counting statistics (n = 8)	8	–
Weighing	–	22
Dead-time	–	1
Background	–	5
Pile-up	–	5
Time measurement	–	< 1
Input parameters and statistical model including geometry factors of the spectrometer	–	21
Decay scheme parameters	–	2
Other effects (scattering in the spectrometer)	–	10
Half-life	–	< 1
Dilution factor by weighing	–	3
Quadratic summation	**8**	**33**
Relative combined standard uncertainty, u_c	**34**	

Revised uncertainty budget for the activity of ^{237}Np measured by IRMM in the EUROMET comparison

Relative standard uncertainties	$u_i \times 10^4$ evaluated by method	
Contributions due to	**A**	**B**
Counting statistics	3	–
Geometry factor	–	15
Detector efficiency	–	1
Scattering at diaphragm and wall	–	1
Back scattering at source support	–	1
Extrapolation to zero volts	–	3
Extrapolation to zero solid angle	–	3
Self-absorption	–	< 3
Dead-time	–	1
Weighing	–	10
Dilution	–	1
Background	–	4
Impurities	–	3
Quadratic summation	**3**	**20**
Relative combined standard uncertainty, u_c	**20**	

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
		bolometer	BO
		calorimeter	CA
		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
photons + electrons	PE	selective sampling	SS
alpha - particle	AP	high efficiency	HE
mixture of various radiation	MX	digital coincidence counting	DC

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(GeHP)-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