Update of the BIPM comparison BIPM.RI(II)-K1.Ho-166m activity measurements to include the IRA and the NPL and a re-evaluation of the degrees of equivalence for the APMP.RI(II)-K2.Ho-166m comparison

C. Michotte[1], G. Ratel[1], S. Courte[1], Y. Nedjadi[2], C. Bailat[2], L. Johansson[3], Y. Hino[4]
[1]BIPM, [2]IRA, Switzerland, [3]NPL, UK and [4]NMIJ, Japan

Abstract

The IRA and the NPL have submitted ampoules of ^{166}Ho^{m} to the International Reference System (SIR) for activity comparison at the Bureau International des Poids et Mesures, thus becoming the third and fourth participants since 1989. The five samples of known activity of ^{166}Ho^{m} now recorded in the SIR have activities between about 70 kBq and 500 kBq. The new results have enabled a re-evaluation of the key comparison reference value and the degrees of equivalence between each equivalent activity measured in the SIR and the key comparison reference value (KCRV) have been calculated. The results are given in the form of a matrix for these four NMIs together with the re-calculated degrees of equivalence of an APMP regional comparison held in 2000, comparison identifier APMP.RI(II)-K2.Ho-166m for six other NMIs. A graphical presentation is also given.

1. Introduction

The SIR for activity measurements of γ-ray-emitting radionuclides was established in 1976. Each NMI may request a standard ampoule from the BIPM that is then filled (3.6 g) with the radionuclide in liquid form. For radioactive gases, a different standard ampoule is used. 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 2008, the SIR has measured 914 ampoules to give 670 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 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.Ho-166m key comparison and the results were first published in 2003 [3].

In addition, an APMP comparison for this radionuclide, APMP.RI(II)-K2.Ho-166m, was held in 2000 with the NMIJ as the pilot laboratory [4]. Although eleven laboratories took part in this comparison, only six NMIs in addition to the NMIJ are eligible to be linked to the BIPM key comparison through the NMIJ to the new key comparison reference value (KCRV).

2. Participants

Four NMIs have submitted five ampoules to the SIR for the comparison of $^{166}\text{Ho}^{\text{m}}$ activity measurements since 1989. The laboratory details are given in Table 1a. In cases where the laboratory has changed its name since the original submission, both the earlier and the current acronyms are given, as the latter are used in the KCDB.

Table 1a. Details of the participants in the BIPM.RI(II)-K1.Ho-166m

Original acronym	**NMI**	**Full name**	**Country**	**Regional metrology organization**	**Date of measurement at the BIPM**
LMRI	LNE-LNHB	Laboratoire national de métrologie et d'essais-Laboratoire national Henri Becquerel	France	EURAMET	1989-11-17
ETL	NMIJ	National Metrology Institute of Japan	Japan	APMP	1999-03-01
–	IRA	Institut de Radiophysique Appliquée	Switzerland	EURAMET	2006-12-22
–	NPL	National Physical Laboratory	United Kingdom	EURAMET	2009-03-02

The six eligible NMIs that took part in the APMP regional comparison, APMP.RI(II)-K2.Ho-166m in 2000 are shown overleaf in Table 1b.

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 for each laboratory, the activities submitted and the relative standard uncertainties ($k = 1$) are given in Table 2. The uncertainty budgets provided by the IRA and the NPL are given in Appendix 1 attached to this report.

Table 1b. Details of the participants in the APMP.RI(II)-K2.Ho-166m of 2000

NMI	**Full name**	**Country**
CNEA	Comisión Nacional de Energía Atómica	Argentina
INER	Institute of Nuclear Energy Research	Chinese Taipei
KRISS	Korea Research Institute of Standards and Science	Korea
LNMRI	Laboratorio Nacional de Metrologia das Radiaçoes Ionizantes	Brazil
NIM	National Institute of Metrology	China
OAP	Office of Atoms for Peace	Thailand

The half-life used by the BIPM is 1200 (200) years [5]. The value in Monographie 5 Volume 2 is 1200 (180) years [6] but the small difference in the uncertainty would not affect any of the SIR measurement results.

Table 2. Standardization methods of the SIR participants for $^{166}\mathrm{Ho}^{\mathrm{m}}$

NMI	Method used and acronym (see Appendix 2)	Half-life / a	Activity A_i / kBq	Reference date YY-MM-DD	Relative standard uncertainty / 10^{-2} by method of evaluation	
					A	B
LNE-LNHB	4πγ(NaI(Tl)) 4P-NA-GR-00-00-00	1200 (200) [5]	110.7 110.9[#]	1989-10-21 2 h UT	0.13	0.13
NMIJ	4πβ-γ coincidence 4P-PC-BP-NA-GR-CO	1200	471	1999-03-01 0 h UT	0.31	0.15
IRA	4πβ-γ coincidence 4P-PC-BP-NA-GR-CO	1200 (180) [6]	161.4	2006-02-01 0 h UT	0.10	0.19
NPL	4πβ(PPC)-γ coincidence* 4P-PP-BP-NA-GR-CO	1200 (200) [5]	69.06	2009-02-15 12 h UT	0.07	0.25
	4πβ(LS)-γ coincidence 4P-LS-BP-NA-GR-CO		68.91		0.07	0.25

[#] two ampoules submitted

* method selected by the NPL for the KCDB

Details of the standardization methods used in the APMP comparison may be obtained from [4]. The uncertainty budgets for the five laboratories, the CNEA, INER, KRISS, LNMRI and the NIM are given in [3]. The OAP uncertainty budget, being designated since this previous publication is given in Appendix 1.

Details regarding the solution 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. The BIPM standard method for evaluating the activity of impurities using a calibrated Ge(Li) spectrometer is described in [7]. The CCRI(II) agreed in 1999 [8] that this method should be followed according to the protocol described in [9] when an NMI makes such a request or when there appear to be discrepancies. For the IRA solution, trace impurities of $^{152, 154, 155}$Eu had been removed by ion-exchange chromatography and the repeated results from the SIR as well as the BIPM impurity check are consistent with no impurity being present (see section 4 below).

Details of the solution issued for the APMP comparison are given in [4] but are identical to the NMIJ ampoule in Table 3.

Table 3. Details of the solution of ^{166}Ho^{m} submitted to the SIR

NMI	Chemical composition	Solvent conc. / (mol dm^{-3})	Carrier: conc. /(µg g^{-1})	Density /(g cm^{-3})	Relative activity of impurity [1]
LNE-LNHB 1989	Ho in HCl	1	–	0.998	^{134}Cs : 1.19 (5) % ^{160}Tb : 0.18 (1) % ^{154}Eu : 0.21 (5) % ^{152}Eu : 0.32 (2) %
NMIJ[2] 1999	$HoCl_3$ in HCl	0.1	$HoCl_3$: 7700	1.01	^{152}Eu : 0.15 (5) % ^{154}Eu : 0.60 (10) %
IRA 2006	$HoCl_3$ in HCl	0.15	$HoCl_3$: 2300	–	–
NPL 2009	$HoCl_3$ in HCl	1	$HoCl_3$: 100	1	^{152}Eu : 0.122 (12) % ^{154}Eu : 0.239 (24) %

[1] the ratio of the activity of the impurity to the activity of ^{166}Ho^{m} at the reference date

[2] the same solution as used in the APMP comparison.

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 ^{166}Ho^{m} arise from five ampoules and the SIR equivalent activity for each ampoule, A_{ei}, is given in Table 4a for each NMI, i. 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. Although activities submitted are compared with a given source of ^{226}Ra, all the SIR results are normalized to the radium source number 5 [1].

The IRA ampoule was measured ten months after the reference date, again three months later and recently re-measured, two years later. All three SIR results agree to within 5 × 10^{-4} which is within the SIR uncertainty.

The SIR correction for impurities is 2.6 × 10^{-3} for the NPL ampoule.

The results of the APMP comparison have been published [3, 4]. The six laboratories to be added to the matrix of degrees of equivalence from this publication are those given in Table 1b. The results for these six NMIs are all linked to the SIR through the result of the NMIJ using the simple ratio
$A_{ei} = \left[(A/m)_i / (A/m)_{\text{NMIJ}} \right] \times A_{e\text{NMIJ}} = (A/m)_i \times 77.08$ as shown in Table 4b.

The uncertainties for the APMP comparison linked to the SIR are comprised of the original NMI uncertainties (given in Table 4b) together with the uncertainty in the link, 11 × 10^{-4}, given by the uncertainty in the SIR measurement of the NMIJ ampoule of this APMP.RI(II)-K2 comparison.

Table 4a. Results of SIR measurements of ^{166}Ho^{m}

NMI	Mass of solution m_i / g	Activity submitted A_i / kBq	N° of Ra source used	SIR A_e / kBq	Relative uncertainty from SIR	Combined uncertainty $u_{c,i}$ / kBq
LNE-LNHB 1989	3.667 74 3.674 32	110.7 110.9	1 1	9 995 10 017	19 × 10^{-4} 15 × 10^{-4}	26 24
				10 015[a] 10 012[a,b]	18 × 10^{-4}	26 26
NMIJ 1999	3.612 12	471	2	10 051	11 × 10^{-4}	36
IRA 2006	3.536 2 (1)	161.4	1	9 913	14 × 10^{-4}	26
NPL 2009	3.598 29	69.06[c] 68.91	1	9 932[c] 9 909	15 × 10^{-4}	30 30

[a] second measurement on 26/02/03 of the same ampoules, with an SIR impurity correction 10 times lower (see [3])

[b] the mean of the two A_e values is used with an averaged uncertainty, as attributed to an individual entry [10].

[c] result from the method 4P-PP-BP-NA-GR-CO designated for the KCDB.

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[1];
b) each NMI 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.

The KCRV for ^{166}Ho^{m} has been evaluated as 9978 (33) kBq now using the results from the LNE-LNHB, NMIJ, IRA and the NPL to make it more robust.

Table 4b. Results of APMP measurements of ^{166}Ho^{m} and links to the SIR

NMI	Measurement method	Date reported to pilot laboratory	Measured activity concentration $(A/m)_i$ / (kBq g^{-1}) $(u_{\mathrm{rel}})_i$	Equivalent SIR activity A_{ei} /kBq	Combined standard uncertainty $u_{c,i}$ / kBq
NMIJ	4πβ–γ coincidence	01-Mar-99	130.4 (0.35 %)	10 051*	36
CNEA	4πβ–γ coincidence	03-Jun-99	128.5 (2.5 %)	9 905	250
INER	4πβ–γ coincidence	13-Jul-99	130.5 (0.45 %)	10 059	47
KRISS	4πβ–γ coincidence	17-Jan-00	128.8 (0.2 %)	9 928	23
LNMRI	4πβ–γ coincidence	30-Jun-00	132.5 (0.4 %)	10 213	42
NIM	Ge spectrometry	23-Jun-00	131.2 (0.66 %)	10 113	68
OAP	Pressurized IC#	30-Jun-00	130.0 (1.3 %)	10 020	130

* SIR measured value, see Table 4a
\# using the IC response curve traceable to the NIST and the NMIJ

---

[1] Rule modified at the CCRI(II) meeting in 2005.

4.2 Degrees of equivalence

Every NMI that has submitted ampoules to the SIR is entitled to have one result included in Appendix B of the KCDB 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. An 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 ($k = 2$). 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

$$D_i = A_{ei} - \mathrm{KCRV} \qquad (1)$$

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

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

taking correlations into account as appropriate [11].

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

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

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

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

where any obvious correlations between the NMIs (such as a traceable calibration) are subtracted using the covariance $u(A_{\mathrm{e}i}, A_{\mathrm{e}j})$, 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 manner 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 appear in Appendix B of 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. This 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 known correlations into account where possible.

The results of the APMP comparison have been linked to those of the SIR through the NMIJ. The degrees of equivalence to the KCRV and between the pairs of NMIs are shown as the extension of the matrix in Table 5. The correlations associated with having a linking laboratory have been taken into account but the correlations associated with the distribution of the same solution have been ignored in the analysis as the overall uncertainties are quite large.

5. Conclusion

The BIPM ongoing key comparison for $^{166}\mathrm{Ho}^{\mathrm{m}}$, BIPM.RI(II)-K1.Ho-166m currently comprises four results. The KCRV for this radionuclide has been re-evaluated and the results have been analysed with respect to the new KCRV, 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 six other NMIs in the APMP key comparison for $^{166}\mathrm{Ho}^{\mathrm{m}}$ have been linked to the BIPM ongoing key comparison through the common participant, the NMIJ. 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 $^{166}\mathrm{Ho}^{\mathrm{m}}$ activity measurements to the SIR comparison or take part in other linked regional comparisons.

Acknowledgements
The authors would like to thank the NMIs for their participation in this comparison and Dr P.J. Allisy-Roberts of the BIPM for editorial assistance.

References

[1] Ratel G., The Système International de Référence and its application in key comparisons, *Metrologia*, 2007, **44**(4), S7-S16

[2] 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.

[3] Ratel G., Michotte C., Hino Y., (2003) BIPM comparison BIPM.RI(II)-K1.Ho-166m of activity measurements of the radionuclide $^{166}Ho^{m}$ and links for the 2000 international comparison APMP.RI(II)-K2.Ho-166m, *Metrologia* **40** 06016.

[4] Hino Y., Results from APMP comparison on radioactivity measurements of ^{58}Co, ^{88}Y and $^{166}Ho^{m}$, *Applied Radiation and Isotopes*, **56**, (2002) 421-427.

[5] BNM-CEA/DTA/DAMRI/LPRI, *Nucléide*, Nuclear and Atomic Decay Data Version : 1-98 19/12/98 CD ROM, BNM-LNHB, Gif-sur-Yvette.

[6] Bé M.-M., Chisté V., Dulieu C., Browne E., Chechev V., Kuzmenko N., Helmer R., Nichols A., Schönfeld E., Dersch R., 2004, Table of radionuclides, *Monographie BIPM-5*, vol **2**.

[7] Michotte C., Efficiency calibration of the Ge(Li) detector of the BIPM for SIR-type ampoules, *Rapport BIPM*-1999/03, 15 pp.

[8] *Comité Consultatif pour les Étalons de Mesures des Rayonnements Ionisants* 16th meeting (1999), 2001, CCRI(II) 81-82.

[9] Michotte C., Protocol on the use of the calibrated spectrometer of the BIPM for the measurement of impurities in ampoules submitted to the SIR, *CCRI(II)/01-01*, 2001, 2p.

[10] Woods M.J., Reher D.F.G. and Ratel G., Equivalence in radionuclide metrology, *Applied Radiation and Isotopes*, **52**, (2000) 313-318.

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

Table 5. Introductory text and table of degrees of equivalence for $^{166}\mathrm{Ho}^{\mathrm{m}}$

Key comparison BIPM.RI(II)-K1.Ho-166m

MEASURAND : **Equivalent activity of $^{166}\mathrm{Ho}^{\mathrm{m}}$**

Key comparison reference value: the SIR reference value for this radionuclide is $x_{R} =$ 9.978 MBq
with a standard uncertainty, u_R = 0.033 MBq.
x_R is the mean of the SIR 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
$U_i = 2((1 - 2/n)u_i^2 + (1/n^2)\Sigma u_j^2)^{1/2}$ 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 APMP.RI(II)-K2.Ho-166m to BIPM.RI(II)-K1.Ho-166m

The value x_i is the equivalent activity for laboratory i participant in APMP.RI(II)-K2.Ho-166m
having been normalized to the value of the NMIJ as the linking laboratory.

The degree of equivalence of laboratory i participant in APMP.RI(II)-K2. 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 as none of these laboratories contributed to the KCRV.

The degree of equivalence between two laboratories i and j, one participant in BIPM.RI(II)-K1.Ho-166m and one in APMP.RI(II)-K2.Ho-166m,
or both participants in APMP.RI(II)-K2.Ho-166m, is given by a pair of terms expressed in MBq: $D_{ij} = D_i - D_j$ 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 l being the linking laboratory when each laboratory is from the APMP
and f is the correlation coefficient.

These statements make it possible to extend the BIPM.RI(II)-K1.Ho-166m matrices of equivalence to all participants in APMP.RI(II)-K2.Ho-166m.

Table 5 continued. Degrees of equivalence for $^{166}\mathrm{Ho}^{\mathrm{m}}$

Lab *j* ⇒

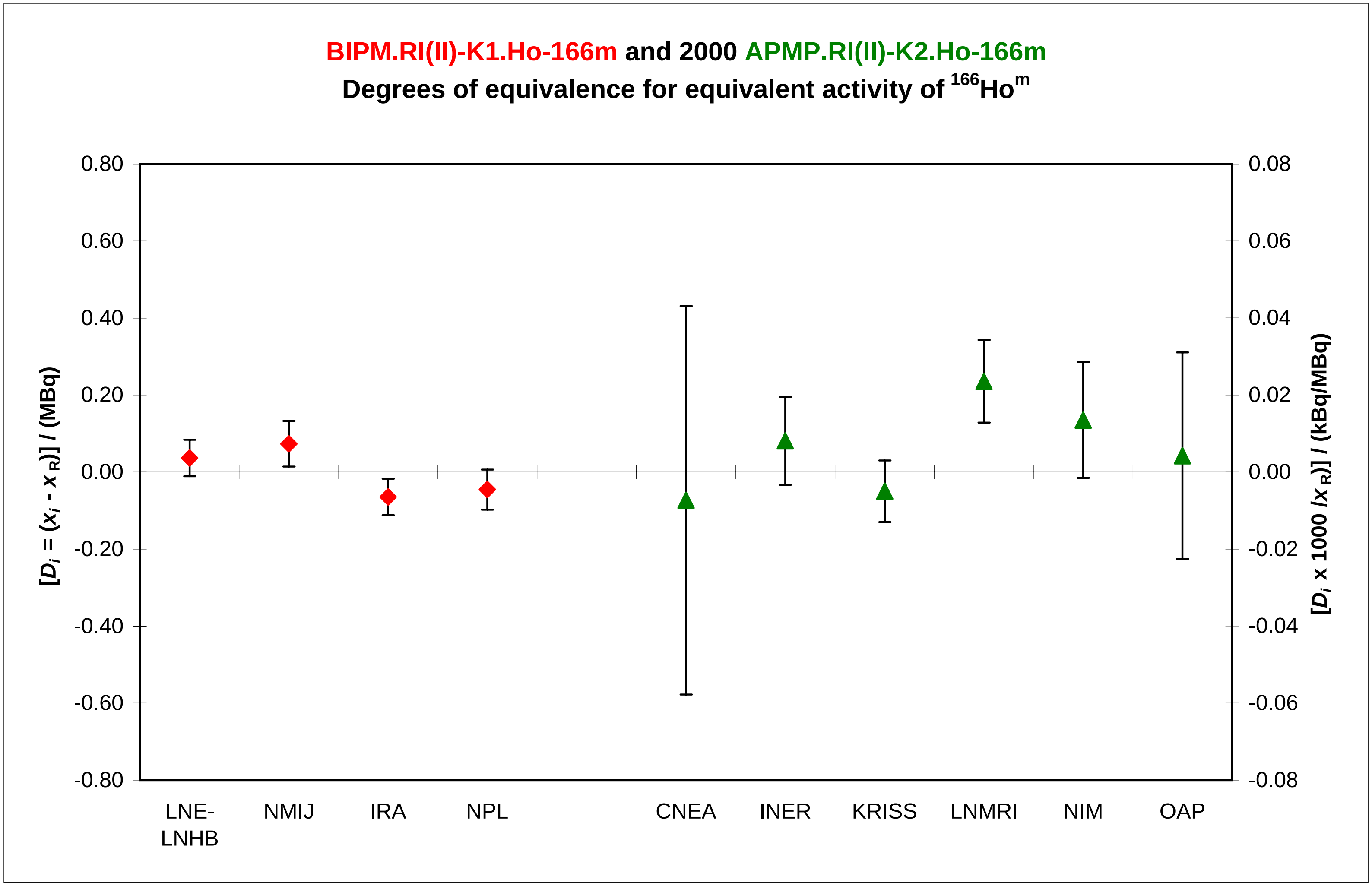
Lab *i* ⇓

			LNE-LNHB		NMIJ		IRA		NPL		CNEA		INER		KRISS	
	D_i / MBq	U_i	D_{ij} / MBq	U_{ij}	D_{ij} / MBq	U_{ij}	D_{ij} / MBq	U_{ij}	D_{ij} / MBq	U_{ij}	D_{ij} / MBq	U_{ij}	D_{ij} / MBq	U_{ij}	D_{ij} / MBq	U_{ij}
LNE-LNHB	**0.04**	0.05			**-0.04**	0.09	**0.10**	0.07	**0.08**	0.08	**0.11**	0.50	**-0.04**	0.11	**0.09**	0.07
NMIJ	**0.07**	0.06	**0.04**	0.09			**0.14**	0.09	**0.12**	0.09	**0.15**	0.50	**-0.01**	0.11	**0.12**	0.08
IRA	**-0.06**	0.05	**-0.10**	0.07	**-0.14**	0.09			**-0.02**	0.08	**0.01**	0.50	**-0.15**	0.11	**-0.01**	0.07
NPL	**-0.05**	0.05	**-0.08**	0.08	**-0.12**	0.09	**0.02**	0.08			**0.03**	0.50	**-0.13**	0.11	**0.00**	0.08
CNEA	**-0.07**	0.50	**-0.11**	0.50	**-0.15**	0.50	**-0.01**	0.50	**-0.03**	0.50			**-0.15**	0.51	**-0.02**	0.50
INER	**0.08**	0.11	**0.04**	0.11	**0.01**	0.11	**0.15**	0.11	**0.13**	0.11	**0.15**	0.51			**0.13**	0.10
KRISS	**-0.05**	0.08	**-0.09**	0.07	**-0.12**	0.08	**0.01**	0.07	**0.00**	0.08	**0.02**	0.50	**-0.13**	0.10		
LNMRI	**0.24**	0.11	**0.20**	0.10	**0.16**	0.11	**0.30**	0.10	**0.28**	0.10	**0.31**	0.51	**0.15**	0.12	**0.29**	0.09
NIM	**0.14**	0.15	**0.10**	0.14	**0.06**	0.15	**0.20**	0.14	**0.18**	0.15	**0.21**	0.52	**0.05**	0.16	**0.18**	0.14
OAP	**0.04**	0.27	**0.01**	0.27	**-0.03**	0.15	**0.11**	0.27	**0.09**	0.27	**0.12**	0.56	**-0.04**	0.27	**0.09**	0.26

			LNMRI		NIM		OAP	
	D_i / MBq	U_i	D_{ij} / MBq	U_{ij}	D_{ij} / MBq	U_{ij}	D_{ij} / MBq	U_{ij}
LNE-LNHB	**0.04**	0.05	**-0.20**	0.10	**-0.10**	0.14	**-0.01**	0.27
NMIJ	**0.07**	0.06	**-0.16**	0.11	**-0.06**	0.15	**0.03**	0.15
IRA	**-0.06**	0.05	**-0.30**	0.10	**-0.20**	0.14	**-0.11**	0.27
NPL	**-0.05**	0.05	**-0.28**	0.10	**-0.18**	0.15	**-0.09**	0.27
CNEA	**-0.07**	0.50	**-0.31**	0.51	**-0.21**	0.52	**-0.12**	0.56
INER	**0.08**	0.11	**-0.15**	0.12	**-0.05**	0.16	**0.04**	0.27
KRISS	**-0.05**	0.08	**-0.29**	0.09	**-0.18**	0.14	**-0.09**	0.26
LNMRI	**0.24**	0.11	**0.00**	0.00	**0.10**	0.16	**0.19**	0.27
NIM	**0.14**	0.15	**-0.10**	0.16			**0.09**	0.29
OAP	**0.04**	0.27	**-0.19**	0.27	**-0.09**	0.29		

Figure 1. Graph of degrees of equivalence with the KCRV for ^{166}Ho^{m}

(as it appears in Appendix B of the MRA)



N.B. Right-hand axis shows approximate relative values

Appendix 1. Uncertainty budget for the activity of ^{166}Ho^{m} for the IRA

Relative standard uncertainties	$u_i \times 10^4$ evaluated by method	
Contributions due to	**A**	**B**
counting statistics	10	–
weighing	–	17
dead time	–	0.1
background	–	7
timing	–	0.2
half-life	–	0.6
linear extrapolation (4πβ–γ coincidence)	3	–
radionuclide impurities (^{152}Eu and ^{154}Eu)	–	–
Quadratic summation	**10**	**19**
Relative combined standard uncertainty, u_c	**21**	

Uncertainty budget for the activity of ^{166}Ho^{m} for the NPL

(4πβ(PPC)-γ coincidence 4P-PP-BP-NA-GR-CO)

Relative standard uncertainties	$u_i \times 10^4$ evaluated by method	
Contributions due to	**A**	**B**
counting statistics	6.8	–
weighing	–	7
dead time	–	3
background	–	1
pile-up	–	5
counting time	–	1
impurities	–	3.6
extrapolation of efficiency	–	12
other effects	–	20
Quadratic summation	**6.8**	**25**
Relative combined standard uncertainty, u_c	**26**	

Uncertainty budget for the activity of ^{166}Ho^{m} for the NPL
(4πβ(LS)-γ coincidence 4P-LS-BP-NA-GR-CO)

Relative standard uncertainties	$u_i \times 10^4$ evaluated by method	
Contributions due to	**A**	**B**
counting statistics	7	–
weighing	–	7
dead time	–	3
background	–	1
pile-up	–	5
counting time	–	1
impurities	–	3.6
extrapolation of efficiency	–	12
other effects	–	20
Quadratic summation	**7**	**25**
Relative combined standard uncertainty, u_c	**26**	

Uncertainty budget for the activity of ^{166}Ho^{m} submitted by the OAP for the APMP.RI(I)-K2.Ho-166m comparison in 1999

Relative standard uncertainties	$u_i \times 10^4$ evaluated by method	
Contributions due to	**A**	**B**
IC current measurement	30	–
stability of IC system	25	–
background instability	–	40
calculated response	–	110
half-life	–	15
ampoule thickness	–	10
Quadratic summation	**39**	**119**
Relative combined standard uncertainty, u_c	**125**	

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