Update of the BIPM comparison BIPM.RI(II)-K1.Cr-51 to include new activity measurements for the LNE-LNHB (France) and the pilot study result of the LNMRI (Brazil)

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Abstract

In 2006, two national metrology institutes (NMI) submitted samples of known activity of ^{51}Cr solution to the International Reference System (SIR) for activity comparison at the Bureau International des Poids et Mesures (BIPM). Consequently, twenty-eight samples have been submitted since 1977, from nine NMI and three other laboratories. The activities ranged from about 3 MBq to 90 MBq. The key comparison reference value (KCRV) has been updated and the degrees of equivalence between each equivalent activity measured in the SIR and the KCRV have been calculated. The results are given in the form of a matrix for eight laboratories to which the APMP.RI(II)-K2.Cr-51 results have been added. 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 2007, the SIR has measured 905 ampoules to give 662 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.Cr-51 key comparison and updates the previous reports [3, 4].

2. Participants

Nine NMIs and three other laboratories have submitted twenty-eight ampoules for the comparison of ^{51}Cr activity measurements since 1977, of which one result was withdrawn. All the laboratory details are given in Table 1 as the KCRV is updated. 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. The AECL was an invited participant in various SIR comparisons, as in the early years, J.G.V. Taylor of the AECL was a personal member of the predecessor to the CCRI(II). The submission from the LNMRI is a pilot study.

Table 1. Details of the participants in the BIPM.RI(II)-K1.Cr-51

Original acronym	NMI	Full name	Country	Regional metrology organization	Date of measurement at the BIPM
NBS	NIST	National Institute of Standards and Technology	United States	SIM	1977-01-24 1978-12-15 1981-08-12 1999-05-03
UVVVR	CMI-IIR	Český Metrologický Institut/Czech Metrological Institute, Inspectorate for Ionizing Radiation	Czech Republic	EUROMET	1978-04-13 1982-06-30
IAEA	–	International Atomic Energy Agency	–	–	1978-05-19
AAEC	ANSTO	Australian Nuclear Science and Technology Organisation	Australia	APMP	1978-08-30
ASMW *	PTB	Physikalisch-Technische Bundesanstalt	Germany	EUROMET	1979-03-01 1983-01-14 1995-03-24 1998-04-24
OMH	MKEH	Magyar Kereskedelmi Engedélyezési Hivatal	Hungary	EUROMET	1980-05-22 1989-10-09

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Table 1 continued. Details of the participants in the BIPM.RI(II)-K1.Cr-51

Original acronym	NMI	Full name	Country	Regional metrology organization	Date of measurement at the BIPM
AECL	–	Atomic Energy of Canada Ltd	Canada	–	1980-07-09
–	NPL	National Physical Laboratory	United Kingdom	EUROMET	1980-12-01 2004-05-28
CBNM now IRMM	–	Institute for Reference Materials and Measurements	European Union	EUROMET	1981-06-17
LMRI LPRI BNM-LNHB	LNE-LNHB	Laboratoire national de métrologie et d'essais - Laboratoire national Henri Becquerel	France	EUROMET	1984-12-20 1994-04-15 2006 -07-17
ETL	NMIJ	National Metrology Institute of Japan	Japan	APMP	1993-11-24 2004-03-15
–	LNMRI	Laboratorio Nacional de Metrologia das Radiaçoes Ionizantes	Brazil	SIM	2006 -10-10

* Another laboratory in the country

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 for the two recent comparisons are given in Appendix 1. The uncertainty budgets that were submitted previously are given in [3, 4].

The half-life previously used by the BIPM was 27.70 (4) days [5]. All the results in the present report have been recalculated using the recommended half-life value of 27.703 (3) d [6] as the new uncertainty is significantly smaller. As the SIR measurements are generally performed within one month of the reference date, the use of the recommended value did not change the results significantly except for the LNMRI result which was received more than 3 months after the reference date,

Table 2. Standardization methods of the participants for ^{51}Cr

NMI	Method used and acronym (see Appendix 2)	Half-life / d	Activity A_i / kBq	Reference date YY-MM-DD	Relative standard uncertainty × 100 by method of evaluation	
					A	B
NIST	Pressurized IC* 4P-IC-GR-00-00-00	–	10 260	76-12-07 17 h UT	0.05	1.35
		27.73	3 936	78-12-06 17 h UT	0.01	0.64
	Pressurized IC ** 4P-IC-GR-00-00-00	27.73	6 082	81-07-28 16 h UT	0.01	0.34
		27.702 (4)	24 449	99-04-22 19 h UT	0.10	0.24
CMI-IIR	4π x-γ coincidence 4P-PC-PE-NA-GR-CO	27.75	3 570	78-02-23 11 h UT	0.20	0.47
	4π(PC)-γ coincidence 4P-PC-PE-NA-GR-CO	27.71	7 233	82-06-09 12 h UT	0.10	0.23
IAEA/ UVVVR	x-γ coincidence 00-00-XR-00-GR-CO	27.75	3 781	78-02-23 11 h UT	0.20	0.47
ANSTO	4πx-γ coincidence 4P-PC-XR-NA-GR-CO	–	7 368	78-08-01	0.1	0.1
PTB	Pressurized IC † 4P-IC-GR-00-00-00	–	15 428	79-03-01	0.02	0.15
	4π(e_A,x)-γ coincidence 4P-PP-PE-NA-GR-CO	–	13 984 14 041	82-11-29 12 h UT	0.26	0.36
	Pressurized IC ‡ 4P-IC-GR-00-00-00	–	8 425 8 403	95-04-01	0.03	0.40
	4π(PPC)EC-γ coincidence 4P-PP-PE-NA-GR-CO	27.706 (7) [7]	7 485	98-05-01	0.05	0.13
MKEH	4π(e,x)-γ coincidence 4P-PP-PE-NA-GR-CO	27.70 (4)	23 570	80-06-01 12 h UT	0.03	0.61
		27.703 (4)	89 410	89-10-15 12 h UT	0.08	0.24
AECL	4π(PC)-γ coincidence 4P-PC-MX-NA-GR-CO	–	39 683	80-06-04 17 h UT	0.06	0.18

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Table 2 continued. Standardization methods of the participants for ^{51}Cr

NMI	Method used and acronym (see Appendix 2)	Half-life / d	Activity A_i / kBq	Reference date YY-MM-DD	Relative standard uncertainty × 100 by method of evaluation A	B
NPL	4πβ-γ coincidence 4P-PC-BP-NA-GR-CO	–	15 533	80-12-05 0 h UT	0.24	0.33
		27.7009 (20)	3 803	04-05-25 12 h UT	0.10	0.66
IRMM	4π(e_A,x)-γ coincidence 4P-PC-PE-NA-GR-CO	–	10 414 10 339	81-06-01	0.03	0.17
LNE-LNHB	4πx-γ coincidence 4P-PP-XR-NA-GR-CO	27.706 (7) [7]	3 373 3 375	84-12-17	0.13	0.13
			13 813 13 675	94-04-20 12 h UT	0.20	0.05
	4π(PC) β-γ 4P-PC-MX-GE-GR-AC	27.703 (3) [6]	10 820	06-07-01 12 h UT	0.10	0.15
NMIJ	4π(e,x)-γ coincidence 4P-PC-PE-NA-GR-CO	–	5 938	93-11-01 0 h UT	0.04	0.30
		27.702 (3) [8]	7 896	04-03-01 0 h UT	0.18	0.21
LNMRI	Pressurized IC ‡ 4P-IC-GR-00-00-00	27.703 (3) [6]	38 153‡‡	06-06-22 00 h UT	0.24	0.39

* calibrated by 4πx-γ coincidence 4P-??-XR-??-GR-CO
**calibrated on 28 July 1981 using a ^{51}Cr solution whose activity was determined by the 4π(e+x)-γ anti-coincidence efficiency-extrapolation technique
† calibrated for ^{51}Cr in 1978 by 4p(PPC)EC-g coincidence (4P-PP-PE-NA-GR-CO) by the PTB
‡ calibrated in 1978 for the PTB and 2006 by the LNMRI using an absolute measurement for the nuclide considered
‡‡ pilot study

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 [9]. The CCRI(II) agreed in 1999 [10] that this method should be followed according to the protocol described in [11] when an NMI makes such a request or when there appear to be discrepancies. No such requests or measurements were made for the latest two submissions.

Table 3. Details of the solution of ^{51}Cr submitted

NMI	Chemical composition	Solvent conc. / (mol dm^{-3})	Carrier: conc. /(µg g^{-1})	Density /(g cm^{-3})	Relative activity of impurity†
NIST	Cr in HCl	1	Cr : 13	–	^{192}Ir : 0.015 (3) %
			Cr : 7	1.015 (2)	^{54}Mn : 6.1 10^{-5} % ^{58}Co : 7.9 10^{-4} % ^{59}Fe : 2.1 10^{-4} % ^{60}Co : 4.8 10^{-4} % ^{65}Zn ; ^{137}Cs : traces
			Cr : 10	1.016 (2)	^{65}Zn : 3 10^{-4} % ^{75}Se : 6.2 10^{-3} %
	$CrCl_2$ in HCl	1	$CrCl_2$: 1000	1.017 (1)	–
CMI-IIR	$Cr(NO_3)_3$ in HCl	0.08	$Cr(NO_3)_3$: 50	–	< 0.01 %
					< 0.1 %
IAEA/ UVVVR	$Cr(NO_3)_3$ in HCl	0.08	$Cr(NO_3)_3$: 50	–	< 0.01 %
ANSTO	$CrCl_2$ in HCl	1	–	1	< 0.1 %
PTB	$CrCl_2$ in HCl	0.1	$CrCl_2$: 50	1.000	< 0.01 %
	$CrCl_3$ in HCl	0.1	$CrCl_3$: 20	1.0005	< 0.1 %
			$CrCl_3$: 50	1.00	–
			$CrCl_3$: 40	0.9995	–
MKEH	Cr in HCl	0.1	Cr: 25	–	^{124}Sb: 1.5(6) 10^{-3} %
			Cr: 28	–	^{60}Co : 2 (1) 10^{-4} %
AECL	$CrCl_3$ in HCl	0.3	$CrCl_3$: 30	1	< 0.1 %
NPL	$CrCl_3$ in HCl	0.1	Cr : 30	1.001	–
	Na_2CrO_4 in H_2O	–	Na_2CrO_4 : 10	1	–
IRMM	$Na_2{}^{51}CrO_4$ in HCl (with NaCl: 450 µg/g)	0.002	–	1.00 (1)	–

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Table 3 continued. Details of the solution of ^{51}Cr submitted

NMI	Chemical composition	Solvent conc. / (mol dm^{-3})	Carrier: conc. /(μg g^{-1})	Density /(g cm^{-3})	Relative activity of impurity†
LNE-LNHB	$CrCl_2$ in HCl	0.1	$CrCl_2$: 10	0.999	–
	$CrCl_3$ in HCl	0.1	$CrCl_3$: 100	1.00	^{124}Sb : 0.0024 (4) %
	$CrCl_3 .6H_2O$ in HCl	0.1	$CrCl_3 .6H_2O$: 100	1.00	–
NMIJ	$CrCl_2$ in HCl	0.1	$CrCl_2$: 50	1.00	–
			$CrCl_2$: 100	1.002	–
LNMRI	$CrCl_3 .6H_2O$ in HCl	0.1	$CrCl_3 .6H_2O$: 10	1.03	^{54}Mn : 1.00 (6) 10^{-3} % ^{60}Co : 1.20 (6) 10^{-3} %

† the ratio of the activity of the impurity to the activity of ^{51}Cr at the reference date.

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 ^{51}Cr arise from twenty-seven ampoules and the SIR equivalent activity for each ampoule, A_{ei}, is given in Table 4 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 corrections for impurity are generally very small, except in the case of the LNMRI which is 1.6×10^{-2} in relative terms.

Each of the NMIs with results submitted after 1978 is eligible to be included in the KCDB except the LNMRI value that has been identified as a pilot study.

An APMP regional comparison for this radionuclide was held in 2004 and the result for the VNIIM was linked to the BIPM.RI(II)-K1.Cr-51 comparison through the result for the NMIJ [4].

Table 4. Results of SIR measurements of ^{51}Cr

NMI	Mass of solution m_i / g	Activity submitted A_i / kBq	N° of Ra source used	SIR[#] A_e / MBq	Relative uncertainty from SIR	Combined uncertainty $u_{c,i}$ / MBq
NIST	5.072 5	10 260	1	494.5	22×10^{-4}	6.8
	3.762 75	3 936	1	495.2	15×10^{-4}	3.2
	3.726 64	6 082	1	488.3	16×10^{-4}	1.8
	3.759 6 (2)	24 449	2	489.4	10×10^{-4}	1.4
CMI-IIR	3.703 82	3 570	1	485.8	17×10^{-4}	2.6
	3.643 67	7 233	1	488.7	12×10^{-4}	1.4
IAEA[+]	3.604 58	3 781	1	486.0	21×10^{-4}	2.7
ANSTO	3.605 79	7 368	1	489.9	16×10^{-4}	1.0
PTB	3.732 9 (1)	15 428	2	488.1	9×10^{-4}	0.9
	3.596 8 (1) 3.611 4 (1)	13 984 14 041	1	488.7 488.3 *	13×10^{-4} 12×10^{-4}	2.3 2.2
	3.544 8 3.535 7	8 425 8 403	2	487.3 487.3	9×10^{-4} 10×10^{-4}	2.0
	3.656 28	7 485	1	487.6	12×10^{-4}	0.9
MKEH	3.603 9	23 570	3	487.4	9×10^{-4}	3.0
	3.618 3	89 410	4	487.3	7×10^{-4}	1.3
AECL	1.304 0	39 683	2	486.5	10×10^{-4}	1.1
NPL	3.390 1	15 533	2	488.3	9×10^{-4}	2.0
	3.537 36	3 803	1	487.0	19×10^{-4}	3.4
IRMM	2.883 20 (2) 2.862 52 (2)	10 414 10 339	1	484.0 483.9 *	15×10^{-4} 14×10^{-4}	1.1 1.0
LNE-LNHB	3.615 64 3.618 62	3 373 3 375	1	494.0 493.3	16×10^{-4} 17×10^{-4}	1.2
	3.543 6 3.508 2	13 813 13 675	2	488.4 488.3	10×10^{-4} 11×10^{-4}	1.1
	3.571 0 (6)	10 820	1	489.2	14×10^{-4}	1.1
NMIJ	3.654 09	5 938	1	484.7	13×10^{-4}	1.6
	3.602 52	7 896	1	487.1	18×10^{-4}	1.6
LNMRI	3.810 712	38 153	1	486.7	19×10^{-4}	2.4

[#] results updated using the new ^{51}Cr half-life [6]
[*] the mean of the two A_e values is used with an averaged uncertainty, as attributed to an individual entry [12]
[+] traceable to the UVVVR

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 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. For example, for ^{51}Cr the ampoules of the IRMM contained a significantly low mass and the CCRI(II) decided in 2007 that the result should not be included in the KCRV.

Consequently, the KCRV for ^{51}Cr has been identified as 488.0 (3) MBq using the results from the ANSTO, AECL (1980), NPL (2004), CMI-IIR (1982), ASMW (1983), MKEH (1989), NMIJ (2004), PTB (1998), LNE-LNHB (2006) and the NIST (1981 as this is the closest to the primary method evaluation).

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 and the result is less than 30 years old[1]. 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 ($k = 2$). 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.

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

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 as appropriate [13].

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 $u(A_{ei}, A_{ej})$, 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 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, is shown in Figure 1 where, following the advice of the CCRI, measurements made prior to 1989 are indicated by black squares and those made prior to 1979 are no longer visible in the KCDB. 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 the known correlations into account.

Conclusion

The BIPM ongoing key comparison for ^{51}Cr, BIPM.RI(II)-K1.Cr-51 currently comprises eight results to which the result of the VNIIM in the APMP 2004 comparison is linked. These results have all been analysed with respect to the updated 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. Other results may be added as and when other NMIs contribute ^{51}Cr activity measurements to this comparison.

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Table 5. Table of degrees of equivalence and introductory text for ^{51}Cr

Key comparison BIPM.RI(II)-K1.Cr-51

MEASURAND : **Equivalent activity of ^{51}Cr**

Key comparison reference value: the SIR reference value x_R for this radionuclide is 488.0 MBq, with a standard uncertainty of 0.3 MBq (see Section 4.1 of the Report), the value x_i is taken as 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
$U_i = 2((1 - 2/n)u_i^2 + (1/n^2)\Sigma u_i^2)^{1/2}$ when each laboratory has contributed to the calculation of x_R,
with n the number of laboratories.

The degree of equivalence between two laboratories is given by a pair of numbers:
$D_{ij} = D_i - D_j = (x_i - x_j)$ and U_{ij}, its expanded uncertainty ($k = 2$), both expressed in MBq.
The approximation $U_{ij}^2 \sim 2^2(u_i^2 + u_j^2)$ is used in the following table.

Linking APMP.RI(II)-K2.Cr-51 (2004) to BIPM.RI(II)-K1.Cr-51

The value x_i is the equivalent activity for laboratory *i* participant in APMP.RI(II)-K2.Cr-51 having been normalized to the value of the NMIJ as the linking laboratory (see Final report).

The degree of equivalence of laboratory *i* participant in APMP.RI(II)-K2.Cr-51 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*, is given by a pair of terms: $D_{ij} = D_i - D_j$ and U_{ij}, its expanded uncertainty ($k = 2$), both expressed in MBq, where the approximation $U_{ij} = 2(u_i^2 + u_j^2 - 2fu_l^2)^{1/2}$ is used where *l* is the NMIJ and *f* is the correlation coefficient.

These statements make it possible to extend the BIPM.RI(II)-K1.Cr-51 matrices of equivalence to the participant in the APMP.RI(II)-K2.Cr-51 comparison

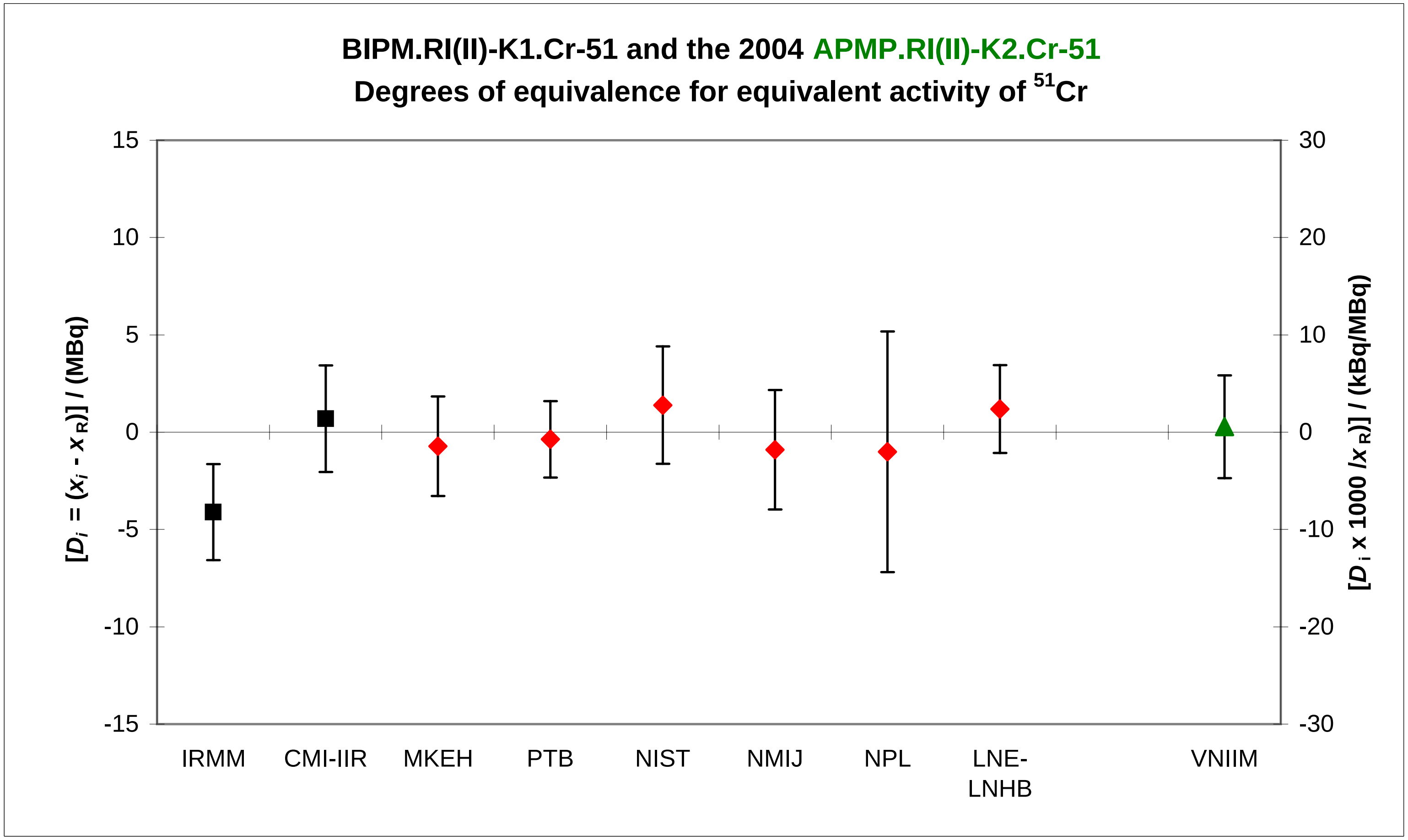
Table 5 continued

Lab *j* ⇒

Lab *i* ⇓	D_i / MBq	U_i / MBq	IRMM D_{ij} / MBq	IRMM U_{ij} / MBq	CMI-IIR D_{ij} / MBq	CMI-IIR U_{ij} / MBq	MKEH D_{ij} / MBq	MKEH U_{ij} / MBq	PTB D_{ij} / MBq	PTB U_{ij} / MBq	NIST D_{ij} / MBq	NIST U_{ij} / MBq
IRMM	-4.1	2.5			-4.8	3.6	-3.4	3.4	-3.7	2.9	-5.5	3.6
CMI-IIR	0.7	2.7	4.8	3.6			1.4	3.8	1.1	3.3	-0.7	4.0
MKEH	-0.7	2.6	3.4	3.4	-1.4	3.8			-0.4	3.2	-2.1	3.8
PTB	-0.4	2.0	3.7	2.9	-1.1	3.3	0.4	3.2			-1.8	3.3
NIST	1.4	3.0	5.5	3.6	0.7	4.0	2.1	3.8	1.8	3.3		
NMIJ	-0.9	3.1	3.2	3.9	-1.6	4.3	-0.2	4.1	-0.5	3.7	-2.3	4.3
NPL	-1.0	6.2	3.1	7.1	-1.7	7.4	-0.3	7.3	-0.6	7.0	-2.4	7.4
LNE-LNHB	1.2	2.3	5.3	3.1	0.5	3.6	1.9	3.4	1.6	2.9	-0.2	3.6
VNIIM	0.3	2.6	4.4	3.3	-0.4	3.7	1.0	3.5	0.6	3.0	-1.1	3.7

Lab *i* ⇓	D_i / MBq	U_i / MBq	NMIJ D_{ij} / MBq	NMIJ U_{ij} / MBq	NPL D_{ij} / MBq	NPL U_{ij} / MBq	LNE-LNHB D_{ij} / MBq	LNE-LNHB U_{ij} / MBq	VNIIM D_{ij} / MBq	VNIIM U_{ij} / MBq
IRMM	-4.1	2.5	-3.2	3.9	-3.1	7.1	-5.3	3.1	-4.4	3.3
CMI-IIR	0.7	2.7	1.6	4.3	1.7	7.4	-0.5	3.6	0.4	3.7
MKEH	-0.7	2.6	0.2	4.1	0.3	7.3	-1.9	3.4	-1.0	3.5
PTB	-0.4	2.0	0.5	3.7	0.6	7.0	-1.6	2.9	-0.6	3.0
NIST	1.4	3.0	2.3	4.3	2.4	7.4	0.2	3.6	1.1	3.7
NMIJ	-0.9	3.1			0.1	7.5	-2.1	3.9	-1.2	3.1
NPL	-1.0	6.2	-0.1	7.5			-2.2	7.1	-1.3	7.2
LNE-LNHB	1.2	2.3	2.1	3.9	2.2	7.1			0.9	3.3
VNIIM	0.3	2.6	1.2	3.1	1.3	7.2	-0.9	3.3		

Figure 1. Graph of degrees of equivalence with the KCRV for ^{51}Cr
(as it appears in Appendix B of the MRA)



N.B. The right-hand scale gives approximate relative values only

Appendix 1. Uncertainty budgets for the activity of ^{51}Cr submitted to the SIR

Uncertainty budget for the LNE-LNHB

Relative standard uncertainties	$u_i \times 10^4$ evaluated by method	
Contributions due to	**A**	**B**
counting statistics	10	-
weighing	-	10
dead time	-	<1
background	-	5
counting time	-	1
half-life	-	<1
extrapolation of efficiency curve	-	10
Quadratic summation	**10**	**15.1**
Relative combined standard uncertainty, u_c	**18.1**	

Uncertainty budget for the LNMRI

Relative standard uncertainties	$u_i \times 10^4$ evaluated by method	
Contributions due to	**A**	**B**
counting statistics	24	-
weighing	-	5
counting time	-	1
half-life	-	<1
calibration factor	-	39
Quadratic summation	**24**	**39.3**
Relative combined standard uncertainty, u_c	**46**	

Appendix 2. Acronyms used in the SIR database for the 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