Update of the BIPM comparison BIPM.RI(II)-K1.Co-57 of activity measurements of the radionuclide ^{57}Co to include the 2013 result of the POLATOM (Poland), the 2015 result of the NMISA (South Africa), the 2021 result of the CMI (Czech Republic), and to link the CCRI(II)-S6.Co-57 comparison

C. Michotte[1], S. Courte[1], M. Nonis[1], R. Coulon[1], G. Ratel[1], T. Dziel[2], A. Muklanowicz[2], T. Ziemek[2], M.J. van Staden[3], M.W. van Rooy[3], J. Lubbe[3], J. Sochorová[4], P. Auerbach[4], B. Zimmerman[5,#]

[1] Bureau International des Poids et Mesures, Sèvres
[2] National Centre for Nuclear Research Radioisotope Centre POLATOM, 05-400 Otwock, Poland
[3] National Metrology Institute of South Africa, Cape Town, South Africa
[4] Czech Metrological Institute - Inspectorate for Ionizing Radiation, Czech Republic
[5] National Institute of Standards and Technology, Gaithersburg, USA

Abstract

Three new participations in the BIPM.RI(II)-K1.Co-57 comparison have been added to the previous results and this has produced a revised value for the key comparison reference value (KCRV), calculated using the power-moderated weighted mean. A link has been made to the CCRI(II)-S6.Co-57 comparison piloted by the International Atomic Energy Agency (IAEA) in 2008 for which one sample of the ^{57}Co radioactive solution was sent to the SIR. Two NMIs used the S6 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 seven NMIs in the BIPM.RI(II)-K1.Co-57 comparison and the three eligible participants in the CCRI(II)-S6.Co-57 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

[#] Pilot of the 2008 CCRI(II)-S6.Co-57 comparison, as a Consultant to the IAEA 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 2021, the SIR has measured 1033 ampoules to give 788 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.Co-57 key comparison and includes results published previously [3 - 6].

In addition, an international comparison piloted by the International Atomic Energy Agency (IAEA) was held in 2004 for this radionuclide, CCRI(II)-S6.Co-57 [7]. Nine laboratories took part in this comparison from which five are signatories/designated institutes of the MRA. A link to the SIR has been evaluated thanks to the participation of the NIST in both comparisons. The IFIN-HH and LNMRI/IRD had previously participated in the SIR and have updated their results through this CCRI(II) comparison.

2. Participants in the BIPM.RI(II)-K1.Co-57

In addition to the ampoules submitted by the NMISA and the CMI, which replace their earlier SIR submissions, the POLATOM has submitted an ampoule for inclusion in this comparison. The details of the laboratories that have participated in the BIPM.RI(II)-K1 comparison are given in Table 1a, with the earlier submissions being taken from [3 - 6]. 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 is used in the KCDB. The AECL (Atomic Energy of Canada Ltd) is not part of the NMI in Canada but 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 date of measurement in the SIR is also given in Table 1a and is used in the KCDB and all references in this report.

Table 1a. Details of the participants in the BIPM.RI(II)-K1.Co-57

NMI	Original acronym	Full name	Country	Regional metrology organization	Date of measurement at the BIPM YYYY-MM-DD
NPL		National Physical Laboratory	United Kingdom	EURAMET	1976-12-28
CMI	UVVVR CMI-IIR	Český Metrologický Institut	Czechia	EURAMET	1977-02-23 1980-01-07 1991-08-20 2021-12-10

Table continued thereafter

Table 1a continued. Details of the participants in the BIPM.RI(II)-K1.Co-57

NMI	Original acronym	Full name	Country	Regional metrology organization	Date of measurement at the BIPM YYYY-MM-DD
BKFH	MKEH OMH	Magyar Kereskedelmi Engedélyezési Hivatal	Hungary	EURAMET	1977-06-15 1983-02-09 1996-07-12
ANSTO		Australian Nuclear Science and Technology Organisation	Australia	APMP	1978-01-12
NIST	NBS	National Institute of Standards and Technology	United States	SIM	1978-07-03 1981-03-06 1985-11-13 1999-05-05 2002-04-15 2010-05-21
IAEA		International Atomic Energy Agency	–	–	1979-02-09 1979-02-12
LNE-LNHB	LMRI LPRI BNM-LNHB	Laboratoire national de métrologie et d’essais - Laboratoire national Henri Becquerel	France	EURAMET	1979-04-09 1985-07-09 1990-11-13 1995-07-18 1999-10-18 2007-06-20
IRA	IER	Institut de Radiophysique Appliquée	Switzerland	EURAMET	1980-04-29 1996-09-20 2000-12-04
AECL*		Atomic Energy of Canada Ltd	Canada	–	1980-06-16 1982-05-11
PTB		Physikalisch-Technische Bundesanstalt	Germany	EURAMET	1983-03-09 2005-03-31
NIRH		National Institute of Radiation Hygiene	Denmark	EURAMET	1985-04-29

Table continued hereafter

Table 1a continued. Details of the participants in the BIPM.RI(II)-K1.Co-57

NMI	**Original acronym**	**Full name**	**Country**	**Regional metrology organization**	**Date of measurement at the BIPM** YYYY-MM-DD
NMISA	NAC[§] CSIR-NML	National Metrology Institute, South Africa	South Africa	AFRIMET	1985-10-08 2015-09-15
NMIJ	ETL	National Metrology Institute of Japan	Japan	APMP	1986-02-06 1996-04-05 2004-03-17 2006-09-19
LNMRI/IRD		Laboratorio Nacional de Metrologia das Radiaçoes Ionizantes	Brazil	SIM	1991-02-28
PTKMR	PSPKR P3KRBiN	Pusat Teknologi Keselamatan dan Metrologi Radiasi	Indonesia	APMP	1992-07-02
VNIIM		D.I. Mendeleyev Institute for Metrology	Russian Federation	COOMET	1992-07-10
BEV		Bundesamt für Eich- und Vermessungswesen	Austria	EURAMET	1998-06-24
KRISS		Korea Research Institute of Standards and Science	Republic of Korea	APMP	1999-01-05
IFIN-HH		Institutul de Fizica si Inginerie Nucleara- "Horia Hulubei"	Romania	EURAMET	2008-07-21**
POLATOM	RC	National Centre for Nuclear Research Radioisotope Centre POLATOM	Poland	EURAMET	2013-11-19

* Federal Crown corporation, not part of the NMI in Canada (see text)
**Participation superseded by the participation in the CCRI(II)-S6.Co-57 comparison
[§] NAC is another institute in the country now named iThemba LABS

The NMIs who took part in the CCRI(II) international comparison, CCRI(II)-S6.Co-57 organized by the Comité Consultatif des Rayonnements Ionisants – section II and piloted by the IAEA in 2008 and who are eligible for the KCDB are shown in Table 1b including the NIST, the linking laboratory.

Table 1b. Details of the participants in the 2008 CCRI(II)-S6.Co-57 to be linked to BIPM.RI(II)-K1.Co-57 comparison

NMI	Full name	Country	Regional metrology organization
BARC	Bhaba Atomic Research Centre	India	APMP
CMI*	Český Metrologický Institut	Czechia	EURAMET
IFIN-HH	Institutul de Fizica si Inginerie Nucleara - "Horia Hulubei"	Romania	EURAMET
LNMRI/IRD	Laboratorio Nacional de Metrologia das Radiaçoes Ionizantes/ Instituto de Radioproteção e Dosimetria	Brazil	SIM
NIST**	National Institute of Standards and Technology	United States	SIM

* Participation superseded by a more recent SIR submission; the full acronym in 2008 was CMI-IIR
** Linking laboratory

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 standard uncertainties (k = 1) and the half-life used by the participants in the SIR are given in Table 2. The uncertainty budgets for the three new submissions are given in Appendix 1a, previous uncertainty budgets are given in the earlier K1 reports [3 –6]. The uncertainty budgets for the eligible participants in the CCRI(II)-S6.Co-57 comparison are given in Appendix 1b. The acronyms used for the measurement methods are given in Appendix 2.

Table 2. Standardization methods of the SIR participants for ^{57}Co

NMI or laboratory	**Method used and acronym (see Appendix 2)**	**Half-life / d**	**Activity A_i / kBq**	**Reference date** YYYY-MM-DD	**Relative standard uncertainty / 10^{-2} by method of evaluation** A	B
NPL	Pressurized IC *	–	428.8 435.5	1976-12-20 0 h UT	0.04	2.03
CMI	4π(e,x)-γ coincidence	270	35 740	1977-01-20 11 h UT	0.03	1.30#
		270	4 101	1979-08-30 10 h UT	0.10	0.53
		–	5 685	1991-08-05 12 h UT	0.07	0.07
	4π(PC)(e,x)-γ coincidence 4P-PC-MX-NA-GR-CO	271.81(4)	5 406	2021-12-10 11 h UT	0.15	0.46
BKFH	4π(e,x)-γ coincidence	271.4(3)	5 516 5 518	1977-06-01 12 h UT	0.10	0.49
		271.4(3)	3 726	1983-05-01 12 h UT	0.03	0.29
		271.79(9) [9]	5 065	1996-07-01 0 h UT	0.03	0.30
ANSTO	4π(e,x)-γ coincidence	270.9	8 579	1978-01-15 0 h UT	0.3	0.8
NIST	Pressurized IC calibrated in 1978 by 4π(e,x)-γ coincidence for the nuclide considered	272.4(1)	2 867	1978-06-19 17 h UT	0.01	0.58
		272.2(2)	1 738	1981-01-16 21 h UT	0.01	0.39
		–	6 146	1985-10-28 17 h UT	0.02	0.31
		271.7(2)	16 810	1999-04-22 19 h UT	0.04	0.31
		271.74(6)	8 623	2002-04-01 12 h UT	0.05	0.29
	4π(LS)(e,x)-γ anti-coincidence 4P-LS-PE-NA-GR-AC	271.80(5)	125 640	2008-04-01 12 h UT	0.08	0.34
IAEA /NBS	NBS Pressurized IC *	272.4(1)	2 805	1978-06-19 17 h UT	0.01	0.58
IAEA /RCC †	-	270.9	17 230	1978-12-07 12 h UT	0.07	0.30

* calibrated by 4π(e,x)-γ coincidence for the nuclide considered
# maximum error instead of standard uncertainty
† The Radiochemical Centre Ltd, Amersham

Table continued hereafter

Table 2 continued. Standardization methods of the participants for ^{57}Co

NMI or laboratory	Method used and acronym (see Appendix 2)	Half-life / d	Activity A_i / kBq	Reference date YYYY-MM-DD	Relative standard uncertainty / 10^{-2} by method of evaluation A	B
LNE-LNHB	4π(e,x)-γ coincidence	–	1 373 1 371	1979-02-09 0 h UT	0.05	0.05
	Pressurized IC *	–	1 538 1 525	1985-06-25 12 h UT	0.07	0.26
	4π(e,x)-γ coincidence	–	4 447 4 501	1990-10-09 12 h UT	0.05	0.01
	Pressurized IC *	–	3 146 3 141	1995-06-15 12 h UT	0.02	0.15
	4π(e,x)-γ coincidence	271.79(9) [9]	2 160	1999-06-25 12 h UT	0.50	< 0.01
	4πγ well-type crystal 4P- NA-GR-00-00-00	271.8(5)	3 669[a] 3 653[b]	2007-06-01 12 h UT	0.06	0.46
	4π(LS)(e,x)-γ anti-coincidence 4P-LS-MX-NA-GR-AC		3 667[a] 3 651[b]		0.21	0.11
IRA	4π(PC)(e,x)-γ coincidence	–	6 416 6 416	1980-04-01 0 h UT	0.05	0.30
	Pressurized IC traceable to the 1980 primary measurement	–	2 746	1996-09-01 0 h UT	0.01	0.31
		271.79(9)	1 955	2000-12-01 12 h UT	0.04	0.31
AECL	4π(PC)-γ coincidence	–	16 411 15 071	1980-03-20 17 h UT	0.03	0.11
		–	2 357 1 662	1982-03-25 17 h UT	0.08	0.15
PTB	Pressurized IC calibrated by 4π(PC)-γ and 4π(PPC)-γ coinc. for the nuclide considered	–	4 062	1983-03-01 0 h UT	0.09	0.27
	Pressurized IC 4P-IC-GR-00-00-00 calibrated in 2003 by 4π(PPC)e_c-γ 4P-PP-MX-NA-GR-CO coinc. for the nuclide considered	271.83(8)	1289.1 1284.4	2005-04-01 0 h UT	0.06	0.29

* calibrated by 4π(e,x)-γ coincidence for the nuclide considered
[a] same ampoule measured by two different methods
[b] same ampoule measured by two different methods

Table continued hereafter

Table 2 continued. Standardization methods of the participants for ^{57}Co

NMI or laboratory	Method used and acronym (see Appendix 2)	Half-life / d	Activity A_i / kBq	Reference date YYYY-MM-DD	Relative standard uncertainty / 10^{-2} by method of evaluation	
					A	B
NIRH	Pressurized IC	–	54 120	1985-05-01 0 h UT	0.13	1.90
NMISA	4π(LS)(e,x)-γ coincidence	271.77(10) [8]	58 900	1985-08-27 12 h UT	0.16	0.19
	4π(LS)(e,x)-γ coincidence 4P-LS-MX-NA-GR-CO	271.80(5)	2 220.1	2015-03-24 10 h UT	0.04	0.21
NMIJ	4π(PC)(e,x)-γ coincidence	–	1 913 1 921	1986-02-04 12 h UT	0.11	0.23
		–	3 632	1996-03-01 12 h UT	0.12	0.28
	Pressurized IC 4P-IC-GR-00-00-00 traceable to the 1996 measurement above	271.79	1 771.5	2004-02-01 0 h UT	0.08	0.32
	4π(PC)(e,x)-γ coincidence 4P-PC-MX-NA-GR-CO	271.4(3)	1 684	2006-06-01 0 h UT	0.28	0.04
LNMRI /IRD	4π(PPC)-γ coincidence	–	1 497 1 510	1990-10-01 12 h UT	0.39	0.46
PTKMR	–	–	6 776 6 948	1992-03-01 5h UT	0.51	–
VNIIM	4π(e,x)-γ coincidence	–	4 998	1992-06-10 12 h UT	0.14	0.29
BEV	Pressurized IC traceable to the NPL	271.79	1 093	1998-06-01 0 h UT	0.80	0.67
KRISS	4π(PPC)-γ coincidence	271.77(10)	2 671	1998-09-01 0 h UT	0.11	0.15
IFIN-HH	4πβ-γ coincidence method with extrapolation 4P-PC-MX-NA-GR-CO	271.80(5)	3 254	2008-07-01 0 h UT	0.75	0.19
POLATOM	4P-LS-MX-NA-GR-CO/AC	271.80(5)	17 143	2013-11-01 12 h UT	0.14	0.40

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 3. Details of the solution of ^{57}Co 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]
NPL 1976	$CoCl_2$ in HCl	0.1	$CoCl_2$: 100	–	–
CMI 1977	$CoCl_2$ in HCl	0.01	$CoCl_2$: 20 000	–	^{56}Co : 0.10(5) %
1980		0.08	$CoCl_2$: 20 000	–	^{56}Co : 0.098(10) % ^{58}Co : 0.0096(10) %
1991		0.1	$CoCl_2$: 20	1	^{56}Co : 0.090(9) % ^{58}Co : 0.050(5) % ^{60}Co : 0.0003(2) %
2021				1.000	^{56}Co : 0.0390(31) % ^{58}Co : 0.0150(18) %
BKFH 1977	$CoCl_2$ in HCl	0.1	$CoCl_2$: 25	–	^{56}Co : 0.015 (3) % ^{58}Co : 0.020 (4) % ^{60}Co : 0.025 (5) %
1983					^{56}Co : 0.002 (1) % ^{58}Co : 0.0015 (8) % ^{60}Co : 0.050 (15) %
1996					–
ANSTO 1978	$CoCl_2$ in HCl	0.1	CoCl2 : 100	1.00	^{56}Co : 0.093 (30) % ^{58}Co : 0.010 (30) %
NIST 1978	Solvent: HCl	1	Co : 110	1.016(2)	^{56}Co : 0.128(6) % ^{58}Co : 0.032(2) %
1981			Co : 100	1.016(2)	^{56}Co : 0.0995(30) % ^{58}Co : 0.0285(14) %
1985	$CoCl_2$ in HCl	1	$CoCl_2$: 480	1.016	^{56}Co : $8.2(8) \times 10^{-3}$ % ^{58}Co : $9.9(5) \times 10^{-4}$ % ^{65}Zn : $5.5(3) \times 10^{-4}$ %
1999			$CoCl_2$: 1000	1.016(1)	^{56}Co : 0.035(4) % ^{58}Co : 0.0093(9) %
2002			$CoCl_2$: 200	1.016(1)	^{56}Co : 0.0132(2) % ^{58}Co : 0.0019(4) %
2010 [b]		0.1	$CoCl_2$: 44	1.000	^{56}Co : 0.056(4) % ^{58}Co : 0.021(3) %
IAEA /NBS 1979	Solvent: HCl	1	Co : 110	1.016(2)	^{56}Co : 0.128(6) % ^{58}Co : 0.032(2) %
IAEA /RCC 1979	–	–	Co : 100	–	^{56}Co : 0.011(1) % ^{58}Co : 0.0010(5) %

Table continued hereafter

Table 3 continued. Details of the solution of ^{57}Co 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]
LNE-LNHB 1979	$CoCl_2$ in HCl	0.1	$CoCl_2$: 10	0.999	^{56}Co : 0.055(5) % ^{58}Co : 0.092(7) % ^{60}Co : 0.012(2) %
1985					^{56}Co : 0.025(2) % ^{58}Co : 0.015(1) %
1990					^{56}Co : 0.113(2) % ^{58}Co : 0.050(1) %
1995			$CoCl_2$: 50	1	^{56}Co : 0.089(3) % ^{58}Co : 0.019(1) %
1999			Co: 10	1.001	^{56}Co : 0.047(5) % ^{58}Co : 0.008(1) %
2007			$CoCl_2$: 60	1.0001	^{56}Co : 0.0226(6) % ^{58}Co : 0.0060(4) %
IRA 1980	$CoCl_2$ in HCl	0.1	$CoCl_2$: 25	–	^{56}Co : 0.030(5) % ^{58}Co : 0.0028(5) %
1996			$CoCl_2$: 60	–	^{56}Co : 4.1(8) × 10^{-4} % ^{58}Co : 5.6(11) × 10^{-5} % ^{60}Co : 1.3(4) × 10^{-3} %
2000			$CoCl_2$: 25	1.000(7)	^{56}Co : 7.0(1.3) × 10^{-4} % ^{58}Co : 1.2(0.2) × 10^{-4} %
AECL 1980	$CoCl_2$ in HCl	0.3	$CoCl_2$: 10	1.0	^{56}Co : 0.11 % ^{58}Co : 0.029 % ^{60}Co : < 0.005 %
1982			$CoCl_2$: 20	1.00	^{56}Co : 0.03(1) % ^{58}Co : 0.010(5) %
PTB 1983	$CoCl_2$ in HCl	0.1	$CoCl_2$: 50	1.00	^{56}Co : 5.1(5) × 10^{-3} % ^{58}Co : 0.5(2) × 10^{-3} % ^{60}Co : 0.5(2) × 10^{-3} %
2005			$CoCl_2$: 50	1.00	^{56}Co : 1.94(4) × 10^{-4} % ^{58}Co : 4.59(9) × 10^{-5} % ^{65}Zn : 6.9(21) × 10^{-4} %
NIRH 1985	$CoCl_2$ in HCl	0.1	–	–	^{56}Co : 0.098(2) % ^{58}Co : 0.021(1) %
NMISA 1985	$CoCl_2$ in HCl	1	Co: 223	1.0169	^{56}Co : 0.0620(5) % ^{58}Co : 0.0130(4) %
2015	$CoCl_2$ in HCl	0.1	Co: 10	1.0	–
NMIJ 1986	$CoCl_2$ in HCl	0.1	$CoCl_2$: 50	1.000	–
1996				1.00	–
2004			$CoCl_2$: 100	1.002	–
2006					–

Table continued hereafter

Table 3 continued. Details of the solution of ^{57}Co 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 1991	$CoCl_2$ in HCl	0.1	$CoCl_2$: 100	1.003	^{56}Co : < 0.3 %
PTKMR 1992	$CoCl_2$ in HCl	1	$CoCl_2$: 10	1	–
VNIIM 1992	$CoCl_2$ in HCl	0.1	Co: 10	1.001	^{56}Co : 0.010(2) % ^{58}Co : 0.030(3) %
BEV 1998	$CoCl_2$ in HCl	0.1	$CoCl_2$: 50	1	^{56}Co : 1.5 × 10^{-5} %
KRISS 1999	$CoCl_2$ in HCl	0.1	$CoCl_2$: 60	1.0015	–
IFIN-HH 2008	$CoCl_2$ in HCl	0.1	$CoCl_2$: 20	1	^{56}Co : 0.065(36) % ^{58}Co : 0.026(18) %
POLATOM 2013	$CoCl_2$ in HCl	0.1	$CoCl_2$: 55	1.0	< 0.1 %

[a] The ratio of the activity of the impurity to the activity of ^{57}Co at the reference date.
[b] Same solution as for the CCRI(II)-S6.Co-57 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 latest submissions have added three ampoules for the activity measurements for ^{57}Co giving rise to 58 ampoules in total. 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].

No recent submission has been identified as a pilot study so the result of each NMI is normally eligible for inclusion on the KCDB platform of the CIPM MRA [2].

The half-life used by the BIPM is 271.80(5) d from the BIPM Monographie 5 [8]. The same half-life value has been used in the CCRI(II)-S6.Co-57 comparison.

Table 4a. Results of SIR measurements of ^{57}Co

NMI / SIR year	Mass of solution m_i/g	Activity submitted A_i	No. of Ra source used	SIR $A_{e,i}$ / kBq	Relative standard uncertainty from SIR	Combined uncertainty $u(A_e)$ / kBq
NPL 1976	3.624 9 3.681 2	428.8 435.5	1	168 000 [c] 167 600	15×10^{-4} 18×10^{-4}	3400 3400
CMI 1977	0.957 41[d]	35 740	4	168 600	$130^{e} \times 10^{-4}$	3100
1980	3.603 90	4 101	2	168 600	18×10^{-4}	1000
1991	3.603 5	5 685	2	170 000	$29^{e} \times 10^{-4}$	500
2021	3.595 70	5 406	2	168 620	15×10^{-4}	850
BKFH 1977	3.602 6 3.604 0	5 516 5 518	2	168 800 168 700	19×10^{-4} 19×10^{-4}	900 900
1983	3.603 0	3 726	2	168 900	$32^{e} \times 10^{-4}$	700
1996	3.612 6	5 065	2	169 300	10×10^{-4}	500
ANSTO 1978	3.591 23	8 579	2	165 900	$110^{e} \times 10^{-4}$	2300
NIST 1978	3.751 63	2 867	2	170 100	$22^{e} \times 10^{-4}$	1100
1981	3.660 50	1 738	1	169 700	15×10^{-4}	700
1985	3.602 74	6 146	2	170 300	11×10^{-4}	600
1999	3.758 6(2)	16 810	3	171 400	14×10^{-4}	600
2002	3.609 5(2)	8 623	3	171 300	11×10^{-4}	500
2010	3.570 30	125 640	3	168 900[h]	9.6×10^{-4}	600
IAEA/NBS 1979	3.670 63	2 805	1	169 800	14×10^{-4}	1000
IAEA/RCC 1979	3.557 5	17 230	3	168 600	9×10^{-4}	500

Table continued hereafter

Table 4a continued. Results of SIR measurements of ^{57}Co

NMI / SIR year	Mass of solution m_i /g	Activity submitted A_i	No. of Ra source used	SIR $A_{e,i}$ / kBq	Relative standard uncertainty from SIR	Combined uncertainty $u(A_e)$ / kBq
LNE-LNHB 1979	3.621 40 3.616 79	1 373 1 371	1	168 550 168 160	21×10^{-4} 23×10^{-4}	500 500
1985	3.600 58 3.570 64	1 538 1 525	1	168 030 167 950	16×10^{-4}	500 500
1990	3.575 17 3.618 68	4 447 4 501	2	169 210 169 118	12×10^{-4}	210 220
1995	3.627 1 3.621 7	3 146 3 141	2	168 980 168 820	13×10^{-4} 14×10^{-4}	340 350
1999	3.587 49	2 160	1	167 400	16×10^{-4}	900
2007	3.590 2	3 669 3 667	2	168 690 [a] 168 590[bc]	11×10^{-4} 11×10^{-4}	800 400
	3.574 6	3 653 3 651	2	168 640[a] 168 540[bc]	11×10^{-4} 11×10^{-4}	800 400
IRA 1980	3.602 0 3.601 8	6 416 6 416	2	167 730 167 660	17×10^{-4} 18×10^{-4}	600 600
1996	3.641 0	2 746	1	168 500	12×10^{-4}	600
2000	3.588 9(1)	1 955	1	168 000	16×10^{-4}	600
AECL 1980	0.293 35[f] 0.269 41	16 411 15 071	3	170 440 170 470	21×10^{-4} 21×10^{-4}	400 400
1982	0.177 194[f] 0.124 928	2 357 1 662	1	168 840 169 130	29×10^{-4} 28[e] $\times 10^{-4}$	600 600
PTB 1983	3.713 2	4 062	2	168 900	11×10^{-4}	500
2005	3.635 4(9) 3.622 2(9)	1289.1 1284.4	1	169 490 [c] 169 340	18×10^{-4} 14×10^{-4}	600 500
NIRH 1985	3.425 5	54 120	4	170 400	11×10^{-4}	3200
NMISA 1985	2.777 5 [g]	58 900	4	170 800	8×10^{-4}	400
2015	3.523 19	2 220.1	1	170 640	15×10^{-4}	450

Table continued hereafter

Table 4a continued. Results of SIR measurements of ^{57}Co

NMI / SIR year	Mass of solution m_i /g	Activity submitted A_i	No. of Ra source used	SIR $A_{e,i}$ / kBq	Relative standard uncertainty from SIR	Combined uncertainty $u(A_e)$ / kBq
NMIJ 1986	3.608 1 3.623 1	1 913 1 921	1	169 500 169 150	13×10^{-4} 15×10^{-4}	500 500
1996	3.584 0	3 632	2	167 900	10×10^{-4}	500
2004	3.750 74	1771.5	1	165 200	17×10^{-4}	600
2006	3.619 79	1684.3	1	168 500	14×10^{-4}	500
LNMRI /IRD 1991	3.606 28 3.624 70	1 497 1 510	1 1	169 400 169 300	13×10^{-4} 14×10^{-4}	1000 1000
PTKMR 1992	3.575 3.666	6 776 6 948	2	152 420 152 250	10×10^{-4} 10×10^{-4}	800 800
VNIIM 1992	3.562 40	4 998	2	167 300	12×10^{-4}	600
BEV 1998	3.642	1 093	1	168 800	19×10^{-4}	1800
KRISS 1999	3.608 16	2 671	1	169 710	13×10^{-4}	390
IFIN-HH 2008	3.602 64	3 254	1	171 200 169 500 [i]	$105^{e} \times 10^{-4}$ 19×10^{-4}	2200 1400
POLATOM 2013	3.664 29	17 143	3	170 180	9×10^{-4}	730

[a] activity measurement using 4P-NA-GR-00-00-00
[b] activity measurement using 4P-LS-MX-NA-GR-AC; these values are used for the KCRV and the KCDB
[c] the mean of the two A_e values is used with an averaged uncertainty as attributed to an individual entry [12]
[d] mass and activity after transfer to a NBS-type ampoule at the BIPM, with addition of HCl (0.01 mol/dm^3)
[e] the uncertainty from the SIR reflects the NMI uncertainty of the impurities
[f] mass of solution before dilution
[g] mass of solution before dilution. Mass after dilution = 3.599 75 g.
[h] Result used to link the CCRI(II)-S6 comparison
[i] result of a further SIR measurement carried about one year later when the impurity correction in the SIR is reduced by a factor 10. Result used for the KCRV. See [6] for more detail.

The NMISA and CMI SIR measurements were repeated after 120 days and 54 days respectively giving a result in agreement within standard uncertainty. The impurity correction factor for the CMI SIR measurement amounts to 1.015(1) and is dominated by the contribution of ^{56}Co. The SIR is more sensitive to ^{56}Co, a high-energy gamma-emitter than to ^{57}Co by a factor 33.

An international comparison for this radionuclide, CCRI(II)-S6.Co-57 was held in 2008 [7] and the three laboratories from this comparison to be added to the matrix of degrees of equivalence are given in Table 1b, together with the NIST participation that served to link the comparison to the BIPM.RI(II)-K1 comparison. The IFIN-HH and the LNMRI/IRD used the CCRI(II) comparison to update their degree of equivalence from earlier SIR participation. The CMI result in the CCRI(II) comparison is superseded by their recent participation in the SIR.

The results $(A/m)_i$ of the CCRI(II) comparison have been linked to the BIPM.RI(II)-K1.Co-57 comparison through the measurement in the SIR of one ampoule of the CCRI(II) solution standardized by the NIST. The linking factor L_j is defined to be

$$L_j = A_{e,j} \,/\, (A/m)_j = 4799.7(46)\ \text{mg} \qquad \text{(a)}$$

where the activity (MBq), mass (g) and equivalent activity (kBq) are taken from the row indicated in Table 4a for the NIST (2010). The relative standard uncertainty of L_j is 9.6×10^{-4}, the uncertainty from the SIR measurement of the linking ampoule, also given in Table 4a.

The linked results are evaluated as

$$A_{ei} = (A/m)_i \, L_j$$

where the primary activity concentration measured by the participants in the CCRI(II)-S6 comparison are taken from the Final report [7] and are shown in Table 4b. The uncertainties for the CCRI(II) comparison results linked to the SIR are comprised of the original uncertainties combined quadratically with the uncertainty in the link.

Table 4b. Results of the 2008 CCRI(II)-S6 comparison of ^{57}Co including the linking laboratory

NMI	**Measurement method and acronym (see Appendix 2 and [7])**	**Activity* concentration measured $(A/m)_i$ / (MBq g^{-1})**	**Standard uncertainty u_i / (MBq·g^{-1})**	**Equivalent SIR activity A_{ei} / kBq**	**Combined standard uncertainty u_i / kBq**
BARC	4P-PC-MX-NA-GR-CO 4P-IC-GR-00-00-00 &	35.95 36.12	0.12 0.38	172 550	600
CMI-IIR**	4P-PC-MX-NA-GR-AC 4P-IC-GR-00-00-00 § 4P-IC-GR-00-00-00 &	35.35 35.44 36.46	0.06 0.33 0.38	169 670	330
IFIN-HH	4P-PC-MX-NA-GR-CO	35.25	0.27	169 200	1300
LNMRI /IRD	4P-PC-MX-NA-GR-AC 4P-IC-GR-00-00-00 §	35.94 35.87	0.12 0.11	172 500	600
NIST	4P-LS-MX-NA-GR-AC 4P-IC-GR-00-00-00 §	35.19 35.71	0.12 0.12	168 900	600

*referenced to 12:00 UTC 1 April 2008
** participation superseded by a more recent SIR submission
§ Ionization chamber calibrated by 4π(e,x)–γ coincidence counting, not used for equivalence
& Ionization chamber calibrated by third party or using third-party calibration source, not used for equivalence

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 [10] 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 α smaller than two in the weighting factor. As proposed in [10], α is taken as $2 - 3/N$ where N is the number of results selected for the KCRV. 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 ^{57}Co has been calculated to be 168.99(25) MBq with the power α = 1.8 on the basis of the SIR results from the NPL, NIST (2010), ANSTO, IRA (1980), AECL (1982), LNMRI/IRD, VNIIM, MKEH (1996), KRISS, PTB (2005), NMIJ (2006), the LNE-LNHB (2007 anti- coincidence method), the IFIN-HH (2009 SIR measurement with a reduced impurity correction), POLATOM (2013), NMISA (2015) and CMI (2021). This can be compared with the previous KCRV values of 168.7(4) MBq published in 2003 [3], 168.77(35) MBq published in 2009 [5], 168.79(32) MBq published in 2012 [6], and and has been approved by the CCRI(II).

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

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

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

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

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

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

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

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

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 [11] 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. 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 ^{57}Co, BIPM.RI(II)-K1.Co-57 currently comprises seven valid results. The key comparison reference value has been updated using the power-moderated weighted mean to include the POLATOM, NMISA and CMI latest results. The SIR results have been analysed with respect to the updated KCRV determined for this radionuclide, providing degrees of equivalence for these seven participants.

The results of three other NMIs that took part in the CCRI(II)-S6.Co-57 comparison in 2008 have been linked to the BIPM ongoing key comparison through one ampoule of the comparison measured in the SIR. These results superseded 2 earlier results from the BIPM.RI(II)-K1.Co-57 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 ten 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 ^{57}Co activity measurements to the ongoing K1 comparison or take part in other linked comparisons.

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Table 5. Table of degrees of equivalence and introductory text for ^{57}Co

Key comparison BIPM.RI(II)-K1.Co-57

MEASURAND : **Equivalent activity of ^{57}Co**

Key comparison reference value: the SIR reference value x_R for this radionuclide is 168.99 MBq,
with a standard uncertainty u_R of 0.25 MBq (see section 4.1 of the Final repo
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
$U_i = 2((1 - 2w_i)u_i^2 + u_R^2)^{1/2}$ when each laboratory has contributed to the calculation of x_R.

Linking CCRI(II)-S6.Co-57 to BIPM.RI(II)-K1.Co-57

The value x_i is the equivalent activity for laboratory *i* participant in CCRI(II)-S6.Co-57
having been normalized using the value of the NIST as the linking laboratory.

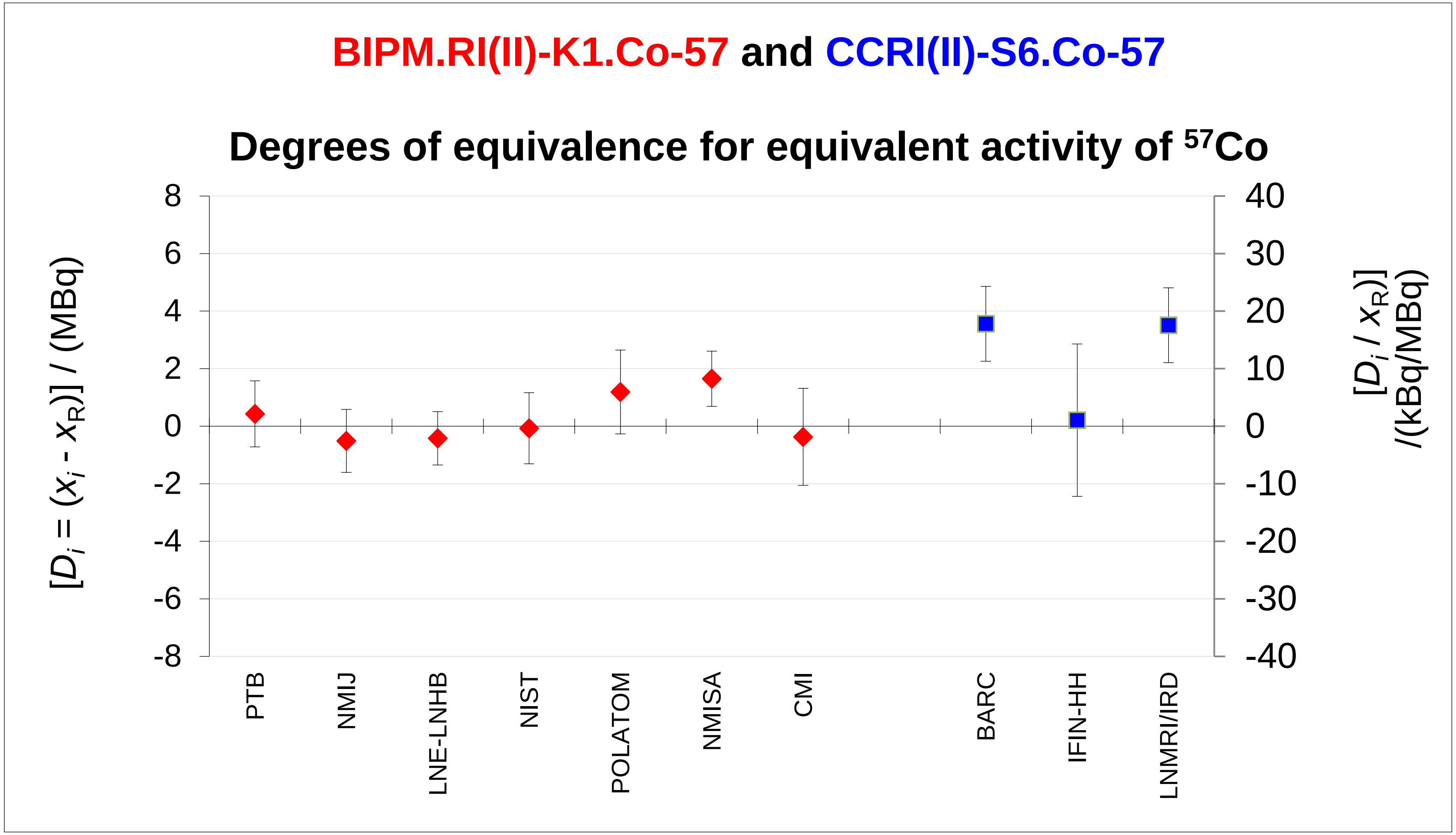
The degree of equivalence of laboratory *i* participant in CCRI(II)-S6.Co-57 with respect to the key comparison reference value is given
by a pair of terms: $D_i = (x_i - x_R)$ and U_i, its expanded uncertainty (k = 2), both expressed in MBq.
The approximation $U_i = 2(u_i^2 + u_R^2)^{1/2}$ is used in the following table as none of these D_i contributed to the KCRV.

These statements make it possible to extend the BIPM.RI(II)-K1.Co-57 matrices of equivalence to the participants in CCRI(II)-S6.Co-57.

Lab *i*	D_i	U_i
	/ MBq	
PTB	**0.4**	1.1
NMIJ	**-0.5**	1.1
LNE-LNHB	**-0.42**	0.93
NIST	**-0.1**	1.2
POLATOM	**1.2**	1.5
NMISA	**1.65**	0.96
CMI	**-0.4**	1.7

BARC	**3.6**	1.3
IFIN-HH	**0.2**	2.6
LNMRI/IRD	**3.5**	1.3

Figure 1. Graph of degrees of equivalence with the KCRV for ^{57}Co



N.B. The right-hand axis shows approximate values only

Appendix 1a. Uncertainty budgets for the activity of ^{57}Co submitted to the SIR

Detailed Uncertainty Budget

Laboratory: *Laboratory of Radioactivity Standards, Radioisotope Centre POLATOM, National Centre for Nuclear Research*;

Radionuclide: ^{57}Co; Ampoule number: *BW/31/13*

*Uncertainty components**, in % of the activity concentration, due to:

		Remarks	Evaluation type (A or B)
counting statistics	*0.136*	-------------	*A*
weighing	*0.259*	-------------	*B*
dead time	-----	-------------	-------
background	-----	-------------	-------
pile-up	-----	-------------	-------
counting time	*0.001*	-------------	*B*
adsorption	-----	-------------	-------
impurities	-----	-------------	-------
tracer	-----	-------------	-------
input parameters and statistical model	-----	-------------	-------
quenching	-----	-------------	-------
interpolation from calibration curve	-----	-------------	-------
decay-scheme parameters	-----	-------------	-------
half life ($T_{1/2}$ = *271.80 d*; *u* = *0.05 d*)	*0.001*	-------------	*B*
self absorption	-----	-------------	-------
extrapolation of efficiency curve	*0.3*	-------------	*B*
other effects (if relevant) (explain)	*0.012*	*coincidence gate*	*B*
combined uncertainty (as quadratic sum of all uncertainty components)	*0.419*	-------------	-------

* The uncertainty components are to be considered as approximations of the corresponding standard deviations (see also *Metrologia*, 1981, **17**, 73 and *Guide to expression of uncertainty in measurement*, ISO, corrected and reprinted 1995).

Detailed Uncertainty Budget

Laboratory: **NMISA**; Radionuclide: ^{57}**Co** ; Ampoule number: **NMISA Co-57 SIR 2015**.

*Uncertainty components**, in % of the activity concentration, due to

		Remarks	Evaluation type (A or B)	Relative Sensitivity Factors
counting statistics	0.04	Statistical analysis of 20 values	A	0.24
weighing	0.05	Mass for source prep.	B	1
	0.005	Mass for ampoule prep.	B	1
	0.002	Dilution	B	1
dead time	0.005	$\tau_D \pm 0.1$ µs	B	0.0005
background	0.004	Background square root statistics applied	A	0.004
counting time	0.001	Calibration of timer	B	1
impurities	0.003	Calculated from certificate values	B	1
half life ($T_{1/2}$ = 271.80 days ; u = 0.05 days)	0.0003		B	0.016
extrapolation of efficiency curve	0.2	Alternative fits to data	B	1
other effects (if relevant) (explain)				
	0.008	Coincidence resolving time $\tau_R \pm 0.01$ µs	B	0.004
	0.03	Afterpulse correction	B	0.003
combined uncertainty (as quadratic sum of all uncertainty components)	**0.22**	-----	--	---

* The uncertainty components are to be considered as approximations of the corresponding standard deviations (see also *Metrologia*, 1981, **17**, 73 and *Guide to expression of uncertainty in measurement*, ISO, corrected and reprinted 1995).

CMI (2021)

SIR/SIRTI reporting form - radioactive solution page 3a

BIPM.RI(II)-K1 or BIPM.RI(II)-K4

Measurement method	4π (PC) X,e-γ coincidence	
ACRONYM	4P-PC-MX-NA-GR-CO	**Comments:**
Activity concentration at reference date / kBq g^{-1}	1503.5000	
Relative standard uncertainty / 10^{-2}	0.48	
Date of measurement at the NMI (YYYY-MM-DD)	2021-12-01	n:

For relative methods:

Primary methods or standards used for calibration	
Date of calibration	
Date of primary measurement	

Uncertainty budget

Uncertainty component	Relative uncertainty / 10^{-2}	Evaluation type (A or B)	Comment
Counting statistics	0.150	A	
Background	0.030	B	
Weighing	0.010	B	
Dilution	0.050	B	
Dead time	0.010	B	
Resolving time	0.020	B	
Pile-up, afterpulse			
Adsorption			
Impurities	0.030	B	
Decay correction			
Decay data			
Extra-/Inter-polation of efficiency curve	0.450	B	
Quenching, kB value			
Tracer			
Reproducibility			
Combined standard uncertainty	**0.480**		

Appendix 1b. Uncertainty budgets for the activity of ^{57}Co in the 2008 CCRI(II)-S6.Co-57 comparison

Uncertainty budget for the **BARC** (4e/x-γ coincidence counting, HV variation; 4P-PC-MX-NA-GR-CO).

Relative standard uncertainties	u_i x 10^4 Evaluated by method	
Contributions due to	**A**	**B**
Counting statistics	22	-
Extrapolation of efficiency curve	26	-
Mass determinations	-	6
Deadtime	-	2
Background	-	1
Half-life	-	-
Resolving time of coincidence analyzer	-	13
Quadratic summation	34	14
Combined standard uncertainty	37	

Uncertainty budget for the **BARC** (4e/x-γ coincidence counting, threshold variation; 4P- PC-MX-NA-GR-CO).

Relative standard uncertainties	u_i x 10^4 Evaluated by method	
Contributions due to	**A**	**B**
Counting statistics	63	-
Extrapolation of efficiency curve	8	-
Mass determinations	-	6
Deadtime	-	2
Background	-	1
Half-life	-	1
Resolving time of coincidence analyzer	-	17
Quadratic summation	64	18
Combined standard uncertainty	66	

Uncertainty budget for the **BARC** (4πγ ionization chamber; 4P-IC-GR-00-00-00).

Relative standard uncertainties	u_i x 10^4 Evaluated by method	
Contributions due to	**A**	**B**
Counting statistics	5	-
Sensitivity factor	-	100
Current measurement for reference source	-	5
Source positioning	-	20
Source volume	-	20
Collection efficiency	-	10
Electrometer non-linearity		10
Source container wall thickness		15
Half-life		1
Quadratic summation	25	106
Combined standard uncertainty	106	

Uncertainty budget for the **CMI** (4e/x-γ coincidence counting; 4P- PC-MX-NA-GR-AC).

Relative standard uncertainties	u_i x 10^4 Evaluated by method	
Contributions due to	**A**	**B**
Impurities	-	2
Deadtime	-	5
Weighing	-	1
Extrapolation	-	17
Background	-	1
Quadratic summation	-	18
Combined standard uncertainty	18	

Uncertainty budget for the **CMI** (CMI 4πγ ionization chamber; 4P-IC-GR-00-00-00).

Relative standard uncertainties	u_i x 10^4 Evaluated by method	
Contributions due to	**A**	**B**
Repeatability	10	-
Background	2	-
Decay correction	-	6
Uncertainty in reference source	-	210
Linearity	-	16
Calibration factor	-	419
Scale resolution	-	4
Half-life	-	0.5
Quadratic summation	10	470
Combined standard uncertainty	470	

Uncertainty budget for the **CMI** (NPL-CRC ionization chamber; 4P-IC-GR-00-00-00).

Relative standard uncertainties	u_i x 10^4 Evaluated by method	
Contributions due to	**A**	**B**
Repeatability	10	-
Background	2	-
Decay correction	-	6
Calibration factor	-	513
Scale resolution	-	4
Half-life	-	0.5
Quadratic summation	10	513
Combined standard uncertainty	513	

Uncertainty budget for the **IFIN-HH (**4P- PC-MX-NA-GR-CO).

Relative standard uncertainties	u_i x 10^4 Evaluated by method	
Contributions due to	**A**	**B**
Type A evaluations	75	-
Extrapolation	-	11
Dead time	-	5
Resolving time	-	1.4
Background	-	2.1
Impurities	-	10
Weighing	-	10
Quadratic summation	75	19
Combined standard uncertainty	77	

Uncertainty budget for the **LNMRI/IRD** (4πe/x-γ anticoincidence counting; 4P- PC-MX-NA-GR-AC).

Relative standard uncertainties	u_i x 10^4 Evaluated by method	
Contributions due to	**A**	**B**
Counting statistics	21	-
Fitting procedure	23	-
Weighing	-	10
Half-life	-	2
Background	3	-
Livetime	-	1
Quadratic summation	31	10
Combined standard uncertainty	33	

Uncertainty budget for the **LNMRI/IRD** (calibrated ionization chamber; 4P-IC-GR-00-00-00).

Relative standard uncertainties	u_i x 10^4 Evaluated by method	
Contributions due to	**A**	**B**
Repeatability	5	-
Background	0.8	-
Decay correction	-	0.08
Reference source uncertainty	--	2
Linearity		100
Calibration factor		34
Mass transfer		5
Scale resolution		18
Half-life		0.08
Quadratic summation	5.1	107
Combined standard uncertainty	107	

Uncertainty budget for the **NIST** (4πe/x-γ anticoincidence counting; 4P- LS-MX-NA-GR-AC).

Relative standard uncertainties	u_i x 10^4 Evaluated by method	
Contributions due to	**A**	**B**
Measurement repeatability	8	-
Background variability	-	5
Extrapolation model	-	30
Live-time	-	10
Source masses	-	5
Dilution factor	-	10
Impurities	-	0.4
Half-life	-	0.01
Quadratic summation	8	34
Combined standard uncertainty	35	

Uncertainty budget for the **NIST** (4π ionization chamber; 4P-IC-GR-00-00-00).

Relative standard uncertainties	u_i x 10^4 Evaluated by method	
Contributions due to	**A**	**B**
Repeatability	2.4	-
Calibration factor	-	27
Mass transfer	-	0.05
Re-evaluation of uncertainty from original standardization to present standardization	-	18
Half-life	-	0.08
Radionuclidic impurities	-	6
Dilution factor	-	9
Quadratic summation	2.4	34
Combined standard uncertainty	34	

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