Activity measurements of the radionuclide ^{57}Co for the NMIJ, Japan and the LNE-LNHB, France in the ongoing comparison BIPM.RI(II)-K1.Co-57

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Abstract

In 2006 and 2007, the National Metrology Institute of Japan (NMIJ) and the Laboratoire national de métrologie et d'essais - Laboratoire national Henri Becquerel (LNE-LNHB) submitted samples of known activity of ^{57}Co to the International Reference System (SIR). The values of the activity submitted were about 1.7 MBq and 3.7 MBq respectively. The new key comparison results have replaced the previous results for Japan and France. These new results have enabled a re-evaluation of the key comparison reference value. The matrix of degrees of equivalence in the key comparison database that now contains twelve results, identifier BIPM.RI(II)-K1.Co-57 has been updated with the new results.

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 916 ampoules to give 673 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.Co-57 comparison.

2. Participants

Fifteen NMIs and three other laboratories have submitted 53 ampoules for the comparison of ^{57}Co activity measurements since 1976. As the KCRV has been re-evaluated, all the laboratory details are given in Table 1, the previous submissions being taken from [3, 4].

Table 1. Details of all the participations in the comparison BIPM.RI(II)-K1.Co-57

NMI	Full name	Country	Regional metrology organization	Date of measurement at the BIPM
NPL	National Physical Laboratory	United Kingdom	EURAMET	1976-12-28
CMI-IIR	Český Metrologický Institut/ Inspectorate for Ionizing Radiation	Czech Republic	EURAMET	1977-02-23 1980-01-07 1991-08-20
MKEH[1]	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	National Institute of Standards and Technology	United States	SIM	1978-07-03 1981-03-06 1985-11-13 1999-05-05 2002-04-15
–	International Atomic Energy Agency	–	–	1979-02-09 1979-02-12
LNE-LNHB[2]	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

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Table 1 continued

NMI	Full name	Country	Regional metrology organization	Date of measurement at the BIPM
IRA	Institut de Radiophysique Appliquée	Switzerland	EURAMET	1980-04-29 1996-09-20 2000-12-04
–	Atomic Energy of Canada Ltd	Canada	–	1980-06-16 1982-05-11
PTB	Physikalisch-Technische Bundesanstalt	Germany	EURAMET	1983-03-09 2005-03-31
–	National Institute of Radiation Hygiene	Denmark	EURAMET	1985-04-29
NMISA[3]	National Metrology Institute, South Africa	South Africa	SADCMET	1985-10-08
NMIJ	National Metrology Institute of Japan	Japan	APMP	1986-02-06 1996-04-05 2004-03-17 2006-09-19
LNMRI	Laboratorio Nacional de Metrologia das Radiaçoes Ionizantes	Brazil	SIM	1991-02-28
PTKMR[4]	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

[1]previously known as the OMH
[2] previously known as the BNM-LNHB
[3] previously known as the CSIR-NML
[4] previously known as the P3KRBiN

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 the laboratories, the activities submitted and the relative standard uncertainties (k = 1) are given in Table 2. The uncertainty budgets for the two new submissions are given in Appendix 1, previous budgets are given in [3, 4]. The acronyms used for the measurement methods are given in Appendix 2.

The half-life used by the BIPM is 271.4 (3) days [5]. The data could be revised using the half-life as published in *BIPM Monographie 5* [6], 271.80 (5) d. However, the results would not differ significantly as the SIR measurements are generally performed within one month following the reference date. For the NMIJ (2006), the relative change in A_e would be 4×10^{-4} and in the extreme case of 5 months, for the LNMRI, the relative change would be less than 7×10^{-4}.

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

NMI or laboratory	Method used	Half-life / d	Activity / kBq	Reference date YY-MM-DD	Relative standard uncertainty × 100 by method of evaluation	
					A	B
NPL	Pressurized IC *	–	428.8 435.5	76-12-20 0 h UT	0.04	2.03
CMI-IIR	4π(e,x)-γ coincidence	270	36 200	77-01-20 11 h UT	0.03	1.30#
		270	4 101	79-08-30 10 h UT	0.10	0.53
		–	5 685	91-08-05 12 h UT	0.07	0.07
MKEH	4π(e,x)-γ coincidence	271.4 (3)	5 516 5 518	77-06-01 12 h UT	0.10	0.49
		271.4 (3)	3 726	83-05-01 12 h UT	0.03	0.29
		271.79 (9) [6]	5 065	96-07-01 0 h UT	0.03	0.30
ANSTO	4π(e,x)-γ coincidence	270.9	8 579	78-01-15 0 h UT	0.3	0.8
IAEA /NBS	NBS Pressurized IC *	272.4 (1)	2 805	78-06-19 17 h UT	0.01	0.58
IAEA /RCC †	-	270.9	17 230	78-12-07 12 h UT	0.07	0.30

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

NMI or laboratory	Method used	Half-life / d	Activity / kBq	Reference date YY-MM-DD	Relative standard uncertainty × 100 by method of evaluation A	B
NIST	Pressurized IC calibrated in 1978 by 4π(e,x)-γ coincidence for the nuclide considered	272.4 (1)	2 867	78-06-19 17 h UT	0.01	0.58
		272.2 (2)	1 738	81-01-16 21 h UT	0.01	0.39
		–	6 146	85-10-28 17 h UT	0.02	0.31
		271.7 (2)	16 810	99-04-22 19 h UT	0.04	0.31
		271.74 (6)	8 623	02-04-01 12 h UT	0.05	0.29
LNE-LNHB	4π(e,x)-γ coincidence	–	1 373 1 371	79-02-09 0 h UT	0.05	0.05
	Pressurized IC *	–	1 538 1 525	85-06-25 12 h UT	0.07	0.26
	4π(e,x)-γ coincidence	–	4 447 4 501	90-10-09 12 h UT	0.05	0.01
	Pressurized IC *	–	3 146 3 141	95-06-15 12 h UT	0.02	0.15
	4π(e,x)-γ coincidence	271.79 (9) [6]	2 160	99-06-25 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]	07-06-01 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	80-04-01 0 h UT	0.05	0.30
	–	–	2 746	96-09-01 0 h UT	0.01	0.31
	Pressurized IC *	271.79 (9)	1 955	00-12-01 12 h UT	0.04	0.31
AECL	4π(PC)-γ coincidence	–	16 411 15 071	80-03-20 17 h UT	0.03	0.11
		–	2 357 1 662	82-03-25 17 h UT	0.08	0.15

* calibrated by 4π(e,x)-γ coincidence for the nuclide considered
[#] maximum error instead of standard uncertainty
[†] The Radiochemical Centre Ltd, Amersham
[a] same ampoule measured by two different methods
[b] same ampoule measured by two different methods

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

NMI or laboratory	Method used	Half-life / d	Activity / kBq	Reference date YY-MM-DD	Relative standard uncertainty × 100 by method of evaluation A	B
PTB	Pressurized IC calibrated by 4π(PC)-γ and 4π(PPC)-γ coincidences for the nuclide considered	–	4 062	83-03-01 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 coincidences for the nuclide considered	271.83 (8)	1289.1 1284.4	05-04-01 0 h UT	0.06	0.29
NIRH	Pressurized IC	–	54 120	85-05-01 0 h UT	0.13	1.90
NMISA	4π(LS)(e,x)-γ coincidence	271.77 (0.10) [7]	58 900	85-08-27 12 h UT	0.16	0.19
NMIJ	4π(PC)(e,x)-γ coincidence	–	1 913 1 921	86-02-04 12 h UT	0.11	0.23
		–	3 632	96-03-01 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	04-02-01 0 h UT	0.08	0.32
	4π(PC)(e,x)-γ coincidence 4P-PC-MX-NA-GR-CO	271.4 (3)	1 684	06-06-01 0 h UT	0.28	0.04
LNMRI	4π(PPC)-γ coincidence	–	1 497 1 510	90-10-01 12 h UT	0.39	0.46
PTKMR	–	–	6 776 6 948	92-03-01 5h UT	0.51	–
VNIIM	4π(e,x)-γ coincidence	–	4 998	92-06-10 12 h UT	0.14	0.29
BEV	Pressurized IC traceable to the NPL	271.79	1 093	98-06-01 0 h UT	0.80	0.67
KRISS	4π(PPC)-γ coincidence	271.77 (0.10)	2 671	98-09-01 0 h UT	0.11	0.15

Details regarding the solution submitted are shown in Table 3, including any impurities, when present, as identified by the laboratory. The BIPM has developed a standard method for evaluating the activity of impurities using a calibrated Ge(Li) spectrometer [8]. The CCRI(II) agreed in 1999 [9] that this method should be followed according to the protocol described in [10] when an NMI makes such a request or when there appear to be discrepancies.

Table 3. Details of the solution of ^{57}Co submitted

NMI	Chemical composition	Solvent conc. / (mol dm^{-3})	Carrier: conc. / (µg g^{-1})	Density /(g cm^{-3})	Relative activity of impurity *
NPL 1976	$CoCl_2$ in HCl	0.1	$CoCl_2$: 100	–	–
CMI-IIR 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) %
MKEH 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	$CoCl_2$: 100	1.00	^{56}Co : 0.093 (30) % ^{58}Co : 0.010 (30) %
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) %
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)×10^{-3} % ^{58}Co : 9.9 (5)×10^{-4} % ^{65}Zn : 5.5 (3)×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) %

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Table 3 continued. Details of the solution of ^{57}Co submitted

NMI	Chemical composition	Solvent conc. / (mol dm^{-3})	Carrier: conc. / (μg g^{-1})	Density /(g cm^{-3})	Relative activity of impurity *
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(1.1)×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) %
NMIJ 1986	$CoCl_2$ in HCl	0.1	$CoCl_2$: 50	1.000	–
1996				1.00	–
2004			$CoCl_2$: 100	1.002	–
2006					–

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Table 3. Details of the solution of ^{57}Co submitted

NMI	Chemical composition	Solvent conc. / (mol dm^{-3})	Carrier: conc. / (µg g^{-1})	Density /(g cm^{-3})	Relative activity of impurity *
LNMRI 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	–

* the ratio of the activity of the impurity to the activity of ^{57}Co at the reference date

The correction for impurities applied to the SIR measurements ranges up to 4 % (for the NIST in 1978 and the NIRH in 1985), reflecting the fact that the SIR ionization chamber is much more sensitive to the ^{56}Co, ^{58}Co and ^{60}Co impurities than to ^{57}Co.

4. Results

All the submissions to the SIR since its inception in 1976 are maintained in a database known as the "master-file". The previous activity measurements for ^{57}Co arise from twenty-seven ampoules and the SIR equivalent activity, A_{ei}, for each ampoule is given in [3, 4] for each NMI, *i*. The SIR equivalent activities for the previous and new results for the NMIJ and the LNE-LNHB are given in Table 4. The date of measurement in the SIR is given in Table 1 and is used in the KCDB and all references in this report. 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 activities submitted are compared with a given source of ^{226}Ra, all the SIR results are normalized to the radium source number 5 [1].

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

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
NPL 1976	3.624 9 3.681 2	428.8 435.5	1	168 000 [c] 167 600	18 × 10^{-4} 23 × 10^{-4}	3400 3400
CMI-IIR 1977	0.969 93 [d]	36 200	4	168 600	130[e] × 10^{-4}	3100
1980	3.603 90	4 101	2	168 500	18 × 10^{-4}	1000
1991	3.603 5	5 685	2	169 970	30[e] × 10^{-4}	530

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

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
MKEH 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	169 280	10×10^{-4}	540
ANSTO 1978	3.591 23	8 579	2	165 800	$110^{e} \times 10^{-4}$	2300
IAEA /NBS 1979	3.670 63	2 805	1	169 600	16×10^{-4}	1000
IAEA /RCC 1979	3.557 5	17 230	3	168 600	9×10^{-4}	500
NIST 1978	3.751 63	2 867	2	170 000	$22^{e} \times 10^{-4}$	1100
1981	3.660 50	1 738	1	169 700	15×10^{-4}	700
1985	3.602 74	6 146	2	170 200	11×10^{-4}	600
1999	3.758 6 (2)	16 810	3	171 370	14×10^{-4}	590
2002	3.609 5 (2)	8 623	3	171 270	11×10^{-4}	540
LNE-LNHB 1979	3.621 40 3.616 79	1 373 1 371	1	168 500 168 100	21×10^{-4} 23×10^{-4}	400 400
1985	3.600 58 3.570 64	1 538 1 525	1	168 000 167 900	16×10^{-4}	500 500
1990	3.575 17 3.618 68	4 447 4 501	2	169 200 169 100	12×10^{-4}	200 200
1995	3.627 1 3.621 7	3 146 3 141	2	169 000 168 800	13×10^{-4} 14×10^{-4}	300 300
1999	3.587 49	2 160	1	167 360	16×10^{-4}	880
2007	3.590 2	3 669 3 667	2	168 690[a] 168 590[bc]	11×10^{-4} 11×10^{-4}	800 430
	3.574 6	3 653 3 651	2	168 640[a] 168 540[bc]	11×10^{-4} 11×10^{-4}	800 430
IRA 1980	3.602 0 3.601 8	6 416 6 416	2	167 710 [c] 167 630	17×10^{-4} 18×10^{-4}	590 590
1996	3.641 0	2 746	1	168 500	12×10^{-4}	600
2000	3.588 9 (1)	1 955	1	168 020	16×10^{-4}	590

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

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
AECL 1980	0.293 35 [f] 0.269 41	16 411 15 071	3	170 400 170 400	21×10^{-4} 21×10^{-4}	400 400
1982	0.177 194 [f] 0.124 928	2 357 1 662	1	168 810 [c] 169 090	29×10^{-4} $28^{e} \times 10^{-4}$	560 550
PTB 1983	3.713 2	4 062	2	168 850	11×10^{-4}	520
2005	3.635 4 (9) 3.622 2 (9)	1289.1 1284.4	1	169 490 169 340 [c]	18×10^{-4} 14×10^{-4}	580 540
NIRH 1985	3.425 5	54 120	4	170 300	11×10^{-4}	3200
NMISA 1985	2.777 5 [g]	58 900	4	170 700	9×10^{-4}	450
NMIJ 1986	3.608 1 3.623 1	1 913 1 921	1	169 500 169 100	13×10^{-4} 15×10^{-4}	500 500
1996	3.584 0	3 632	2	167 900	10×10^{-4}	530
2004	3.750 74	1771.5	1	165 170	17×10^{-4}	610
2006	3.619 79	1684.3	1	168 410	14×10^{-4}	530
LNMRI 1991	3.606 28 3.624 70	1 497 1 510	1 1	169 300 [c] 169 200	14×10^{-4} 15×10^{-4}	1000 1100
PTKMR 1992	3.575 3.666	6 776 6 948	2	152 300 [c] 152 200	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	169 630	14×10^{-4}	390

[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 [11]
[d] mass before 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.

Repeat measurements of the LNE-LNHB (2007) ampoule made at the BIPM after a period of one year, produced a comparison result in agreement within the SIR standard uncertainty.

The NMIs that have sent ampoules over about 20 years, show relative standard deviations of 2×10^{-3} (PTB, IRA, MKEH) or 4×10^{-3} (NIST and LNE-LNHB).

Three earlier submissions were withdrawn and are not included here. As no recent submission has been identified as a pilot study, the most recent result of each NMI is normally eligible for the KCDB of the CIPM MRA. However, the result from the PTKMR is not included as Indonesia has not yet designated this laboratory for activity measurements. Neither is the result included from the AECL as it is not a designated laboratory of the NRC, Canada, nor from the NIRH and the IAEA as they no longer undertake the metrology of activity. In addition, two further results date more than 30 years ago and are no longer eligible for the KCDB.

No international or regional comparison for this radionuclide has been held to date so no linking data are identified.

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.

Consequently, the KCRV for ^{57}Co has been identified as 168 770 (350) kBq using the results from the NPL, NIST (1978), ANSTO, IRA (1980), AECL (1982), NMISA, LNMRI, CMI-IIR (1991), VNIIM, MKEH (1996), KRISS, PTB (2005), NMIJ (2006), and the LNE-LNHB (2007 coincidence method) . The KCRV has been modified in accordance with the criteria above and the value has been approved by the CCRI(II).

4.2 Degrees of equivalence

Every NMI that has submitted ampoules to the SIR 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 less than 30 years old. Normally, the

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

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.

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

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

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

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

taking correlations into account as appropriate [12].

4.2.2 *Comparison of any two NMIs with each other*

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

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

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

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

and any obvious correlations between the NMIs (such as a traceable calibration) are subtracted as are normally those correlations coming from the SIR.

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

Table 5 shows the matrix of all the degrees of equivalence as they will appear in the KCDB. It should be noted that for consistency within the KCDB, a simplified level of nomenclature is used with A_{ei} replaced by x_i. The introductory text is that agreed for the comparison. The graph of the first column of results in Table 5, corresponding to the degrees of equivalence with respect to the KCRV (identified as x_R in the KCDB), is shown in Figure 1 where following the advice of the CCRI(II) the black square indicates a result obtained prior to 1988. The graphical representation indicates in part the degree of equivalence between the NMIs but does not take into account the correlations between the different NMIs. However, the matrix of degrees of equivalence shown in yellow in Table 5 does take the known correlations into account.

Conclusion

The BIPM ongoing key comparison for ^{57}Co, BIPM.RI(II)-K1.Co-57 currently comprises twelve results. These have been analysed with respect to the new 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 NMIs contribute ^{57}Co activity measurements to this comparison or take part in 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 for this radionuclide is x_R = 168.8 MBq with a standard uncertainty, u_R = 0.3 MBq.
x_R is the mean of fourteen of the thirty-four 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, with n the number of laboratories,
$U_i = 2((1-2/n)u_i^2 + (1/n^2)\Sigma u_i^2)^{1/2}$ when each laboratory has contributed to the KCRV.

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.

Lab *j* ⇒

Lab *i* ⇓

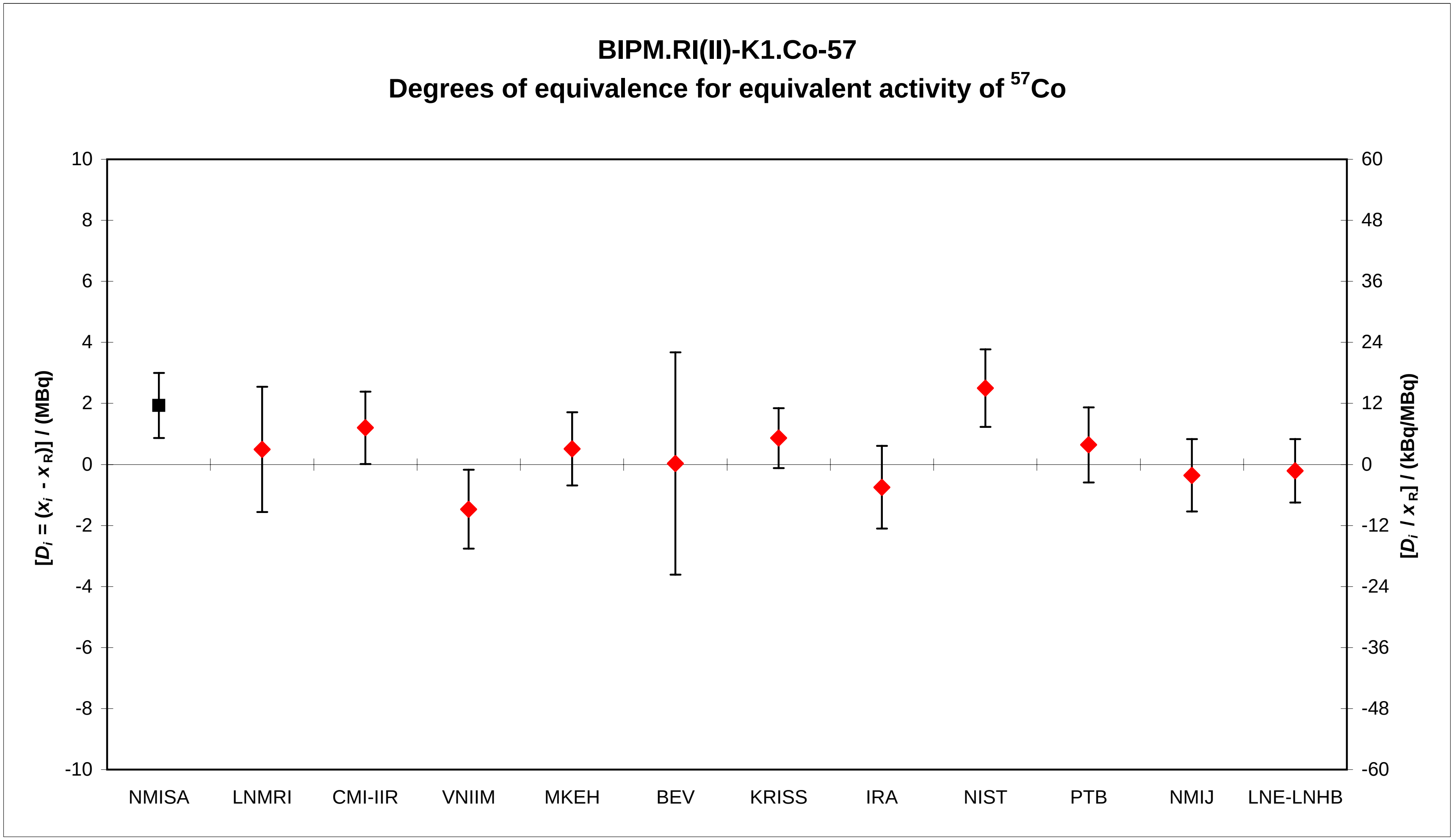
Lab *i*			NMISA		LNMRI		CMI-IIR		VNIIM		MKEH		BEV	
	D_i / MBq	U_i / MBq	D_{ij} / MBq	U_{ij} / MBq	D_{ij} / MBq	U_{ij} / MBq	D_{ij} / MBq	U_{ij} / MBq	D_{ij} / MBq	U_{ij} / MBq	D_{ij} / MBq	U_{ij} / MBq	D_{ij} / MBq	U_{ij} / MBq
NMISA	**1.9**	1.1			**1.4**	2.3	**0.7**	1.4	**3.4**	1.5	**1.4**	1.4	**1.9**	3.7
LNMRI	**0.5**	2.1	**-1.4**	2.3			**-0.7**	2.4	**2.0**	2.4	**0.0**	2.4	**0.5**	4.2
CMI-IIR	**1.2**	1.2	**-0.7**	1.4	**0.7**	2.4			**2.7**	1.6	**0.7**	1.5	**1.2**	3.7
VNIIM	**-1.5**	1.3	**-3.4**	1.5	**-2.0**	2.4	**-2.7**	1.6			**-2.0**	1.6	**-1.5**	3.8
MKEH	**0.5**	1.2	**-1.4**	1.4	**0.0**	2.4	**-0.7**	1.5	**2.0**	1.6			**0.5**	3.7
BEV	**0.0**	3.6	**-1.9**	3.7	**-0.5**	4.2	**-1.2**	3.7	**1.5**	3.8	**-0.5**	3.7		
KRISS	**0.9**	1.0	**-1.1**	1.2	**0.4**	2.2	**-0.3**	1.3	**2.3**	1.4	**0.4**	1.3	**0.8**	3.7
IRA	**-0.7**	1.4	**-2.7**	1.5	**-1.2**	2.4	**-2.0**	1.6	**0.7**	1.7	**-1.3**	1.6	**-0.8**	3.8
NIST	**2.5**	1.3	**0.6**	1.4	**2.0**	2.4	**1.3**	1.5	**4.0**	1.6	**2.0**	1.5	**2.5**	3.7
PTB	**0.6**	1.2	**-1.3**	1.4	**0.2**	2.4	**-0.6**	1.5	**2.1**	1.6	**0.1**	1.6	**0.6**	3.8
NMIJ	**-0.4**	1.2	**-2.3**	1.4	**-0.9**	2.4	**-1.6**	1.5	**1.1**	1.6	**-0.9**	1.5	**-0.4**	3.7
LNE-LNHB	**-0.2**	1.0	**-2.1**	1.2	**-0.7**	2.3	**-1.4**	1.4	**1.3**	1.5	**-0.7**	1.4	**-0.2**	3.7

Lab *i* ⇓

Lab *i*			KRISS		IRA		NIST		PTB		NMIJ		LNE-LNHB	
	D_i / MBq	U_i / MBq	D_{ij} / MBq	U_{ij} / MBq	D_{ij} / MBq	U_{ij} / MBq	D_{ij} / MBq	U_{ij} / MBq	D_{ij} / MBq	U_{ij} / MBq	D_{ij} / MBq	U_{ij} / MBq	D_{ij} / MBq	U_{ij} / MBq
NMISA	**1.9**	1.1	**1.1**	1.2	**2.7**	1.5	**-0.6**	1.4	**1.3**	1.4	**2.3**	1.4	**2.1**	1.2
LNMRI	**0.5**	2.1	**-0.4**	2.2	**1.2**	2.4	**-2.0**	2.4	**-0.2**	2.4	**0.9**	2.4	**0.7**	2.3
CMI-IIR	**1.2**	1.2	**0.3**	1.3	**2.0**	1.6	**-1.3**	1.5	**0.6**	1.5	**1.6**	1.5	**1.4**	1.4
VNIIM	**-1.5**	1.3	**-2.3**	1.4	**-0.7**	1.7	**-4.0**	1.6	**-2.1**	1.6	**-1.1**	1.6	**-1.3**	1.5
MKEH	**0.5**	1.2	**-0.4**	1.3	**1.3**	1.6	**-2.0**	1.5	**-0.1**	1.6	**0.9**	1.5	**0.7**	1.4
BEV	**0.0**	3.6	**-0.8**	3.7	**0.8**	3.8	**-2.5**	3.7	**-0.6**	3.8	**0.4**	3.7	**0.2**	3.7
KRISS	**0.9**	1.0			**1.6**	1.4	**-1.6**	1.3	**0.2**	1.4	**1.2**	1.3	**1.1**	1.2
IRA	**-0.7**	1.4	**-1.6**	1.4			**-3.3**	1.6	**-1.4**	1.6	**-0.4**	1.6	**-0.5**	1.5
NIST	**2.5**	1.3	**1.6**	1.3	**3.3**	1.6			**1.9**	1.6	**2.9**	1.5	**2.7**	1.4
PTB	**0.6**	1.2	**-0.2**	1.4	**1.4**	1.6	**-1.9**	1.6			**1.0**	1.5	**0.9**	1.4
NMIJ	**-0.4**	1.2	**-1.2**	1.3	**0.4**	1.6	**-2.9**	1.5	**-1.0**	1.5			**-0.2**	1.4
LNE-LNHB	**-0.2**	1.0	**-1.1**	1.2	**0.5**	1.5	**-2.7**	1.4	**-0.9**	1.4	**0.2**	1.4		

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

(as it appears in Appendix B of the MRA)



The black square indicates a result made more than 20 years ago.

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

<u>Uncertainty budget for the NMIJ measurement (2006)</u>

Relative standard uncertainties	$u_i \times 10^4$ evaluated by method	
Contributions due to	**A**	**B**
Counting statistics	10*	–
Weighing	5*	–
Dead time	–	<1
Background	–	2
Pile-up	–	–
Resolving time	–	3
Gandy effect	–	1
Counting time	–	1
Adsorption	–	–
Impurities	–	–
Tracer	–	–
Input parameters and statistical model	–	–
Quenching	–	–
Interpolation from calibration curve	–	–
Decay-scheme parameters	–	–
Half life	–	<1
Self absorption	–	–
Extrapolation of efficiency curve	28	–
Other effects	–	–
Quadratic summation	**28**	**4**
Relative combined standard uncertainty, u_c	**29**	

*Included in extrapolation.

Uncertainty budget for the LNE-LNHB measurement (2007), 4πγ well-type crystal method

Relative standard uncertainties	$u_i \times 10^4$ evaluated by method	
Contributions due to	**A**	**B**
Counting statistics	6	–
Weighing	–	5
Dead time	–	–
Background	–	–
Pile-up	–	–
Counting time	–	<1
Adsorption	–	–
Impurities	–	–
Input parameters and statistical model	–	–
Decay-scheme parameters	–	–
Half life	–	0.8
Self absorption	–	–
Extrapolation of efficiency curve	–	45
Other effects	–	6
Quadratic summation	**6**	**46**
Relative combined standard uncertainty, u_c	**46**	

Uncertainty budget for the LNE-LNHB measurement (2007), 4π(LS)(e,x)-γ anticoincidence

Relative standard uncertainties	$u_i \times 10^4$ evaluated by method	
Contributions due to	**A**	**B**
Counting Statistics	–	6
Weighing	–	5
Dead time	–	–
Background	5	–
Pile-up	–	–
Counting time	–	1
Adsorption	–	–
Impurities	–	5
Tracer	–	–
Input parameters and statistical model	–	–
Quenching	–	–
Decay-scheme parameters	–	–
Half life	–	1
Self absorption	–	–
Extrapolation of efficiency curve	20	–
Other effects	–	5
Quadratic summation	**21**	**11**
Relative combined standard uncertainty, u_c	**23**	

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 radiations	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(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