

# Update of the BIPM comparison BIPM.RI(II)-K1.Co-60 of activity measurements of the radionuclide $^{60}\text{Co}$ to include the 2019 result of the VNIIM (Russian Federation)

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**Abstract** Since 1976, 29 laboratories have submitted 73 samples of  $^{60}\text{Co}$  to the International Reference System (SIR) for activity comparison at the Bureau International des Poids et Mesures (BIPM), with comparison identifier BIPM.RI(II)-K1.Co-60. Recently, the VNIIM (Russian Federation) participated in the comparison and the key comparison reference value (KCRV) has been updated. The degrees of equivalence between each equivalent activity measured in the SIR and the updated KCRV have been calculated and the results are given in the form of a table. A graphical presentation is also given.

## 1. Introduction

The SIR for activity measurements of  $\gamma$ -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 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  $^{226}\text{Ra}$  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 2020, the SIR has been used to measure 1021 ampoules to give 776 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 continuous comparisons and the results form the basis of the BIPM key comparison database (KCDB) of the Comité International des Poids et Mesures Mutual Recognition Arrangement (CIPM MRA) [2]. The comparison described in this report is known as the BIPM.RI(II)-K1.Co-60 key comparison. The results of earlier participations in this key comparison were published previously [3–9].

## 2. Participants

Laboratory details are given in Table 1, with the earlier submissions being taken from [3–9]. The dates of measurement in the SIR given in Table 1 are used in the KCDB and all references in this report. 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).

Table 1: Details of the participants in the BIPM.RI(II)-K1.Co-60.

NMI or laboratory	Previous acronyms	Full name	Country	RMO	Date of SIR measurement yyyy-mm-dd
AECL <sup>a</sup>	-	Atomic Energy of Canada Ltd	Canada	SIM	1980-04-11  1993-12-20
ANSTO	AAEC	Australian Nuclear Science and Technology Organisation	Australia	APMP	1992-05-13
ASMW	-	Amt für Standardisierung, Meßwesen und Warenprüfung	former East Germany	-	1976-09-02
BARC	-	Bhabha Atomic Research Centre	India	APMP	1981-09-03  1994-06-20 2001-01-10 2012-01-09
BEV	IRK	Bundesamt für Eich- und Vermessungswesen	Austria	EURAMET	1998-10-14  2007-09-27
BIPM	-	Bureau International des Poids et Mesures			1976-07-22
BKFH	OMH, MKEH	Government Office of the Capital City Budapest	Hungary	EURAMET	1977-03-11  1979-12-13 1999-06-11

... Continuation of Table 1.

<b>NMI or laboratory</b>	<b>Previous acronyms</b>	<b>Full name</b>	<b>Country</b>	<b>RMO</b>	<b>Date of SIR measurement</b> yyyy-mm-dd
CIEMAT	-	Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas	Spain	EURAMET	1999-11-30
CMI-IIR	UVVVR	Czech Metrological Institute - Inspectorate for Ionizing Radiation	Czech Republic	EURAMET	1977-03-25 1978-04-18
CNEA	-	Comision Nacional de Energia Atomica	Argentina	SIM	1992-01-28 2003-01-17 2011-10-24
ENEA-INMRI	-	Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile - Istituto Nazionale di Metrologia delle Radiazioni Ionizzanti	Italy	EURAMET	1991-01-22
IAEA	-	International Atomic Energy Agency			1978-04-03 1978-05-25
IFIN-HH	-	Institutul National de Cercetare - Dezvoltare in Fizica si Inginerie Nucleara- "Horia Hulubei"	Romania	EURAMET	1983-12-15 2007-05-10
IRA	IER	Institut de Radiophysique	Switzerland	EURAMET	1979-05-17 2000-12-06
JRC	IRMM, CBNM	EC-JRC Institute for Reference Materials and Measurements	European Union	EURAMET	2005-01-27
KRISS	KSRI	Korea Research Institute of Standards and Science	Republic of Korea	APMP	1995-01-18
LNE-LNHB	LMRI, LPRI, BNM-LNHB	Laboratoire National de métrologie et d'Essais -Laboratoire National Henri Becquerel	France	EURAMET	1978-07-17 1986-12-19 1999-10-20
LNMRI-IRD	IEA, IPEN <sup>b</sup>	Laboratorio Nacional de Metrologia das Radiações Ionizantes	Brazil	SIM	1976-10-07 1984-11-21
NIM	-	National Institute of Metrology	China	APMP	1978-10-12 2014-07-01

... Continuation of Table 1.

NMI or laboratory	Previous acronyms	Full name	Country	RMO	Date of SIR measurement yyyy-mm-dd
NIST	NBS	National Institute of Standards and Technology	United States	SIM	1980-09-03  1997-01-24 2007-08-07
NMIJ	ETL	National Metrology Institute of Japan	Japan	APMP	1976-11-24  2004-03-17
NMISA	NAC, CSIR-NML <sup>c</sup>	National Metrology Institute of South Africa	South Africa	AFRIMETS	1981-07-15  1992-10-27 2002-05-30
NPL	-	National Physical Laboratory	United Kingdom	EURAMET	1977-01-05  2000-06-30
NRC	-	National Research Council	Canada	SIM	2012-08-29
POLATOM	IBJ, RC	National Centre for Nuclear Research Radioisotope Centre POLATOM	Poland	EURAMET	2003-06-17
PTB	-	Physikalisch-Technische Bundesanstalt	Germany	EURAMET	1977-09-16  1988-01-22 2001-07-02 2017-05-10
PTKMR	PDS, P3KRBiN	Pusat Teknologi Keselamatan dan Metrologi Radiasi	Indonesia	APMP	1984-06-22
TAEK	-	Turkish Atomic Energy Authority	Turkey	EURAMET	2018-01-08
VNIIM	-	D.I. Mendeleev Institute for Metrology	Russian Federation	COOMET	2019-06-28

<sup>a</sup> federal Crown corporation, not part of the NMI in Canada (see text)

<sup>b</sup> IEA, IPEN are other institutes of the country.

<sup>c</sup> NAC is another institute of 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 appropriate correlations are taken into account.

A brief description of the standardization methods used by the laboratories, the activities submitted, the relative standard uncertainties and the half-life used by the participants are given in Table 2. The uncertainty budget for the new submission is

given in [Appendix D](#) attached to this report; previous uncertainty budgets are given in the earlier K1 reports [3–9]. The list of acronyms used to summarize the methods is given in [Appendix E](#).

Since 2003, the half-life used by the BIPM is 1925.5(5) days as published in IAEA TECDOC-619 [10]. The half-life of 1924.8(10) days [11] was used for the earlier results.

Table 2: Standardization methods of the participants for  $^{60}\text{Co}$ .

NMI or laboratory	Method used and the acronym	Activity $A_i/\text{kBq}$	Relative standard uncertainty / $10^{-2}$		Reference date yyyy-mm-dd	Half-life /d
			A	B		
AECL	$4\pi\beta(\text{PC})-\gamma$ coincidence (4P-PC-BP-NA-GR-CO)	1183.4 <sup>j</sup>	0.02	0.02	1980-02-05 17:00 UT	-
		1189.3	0.02	0.02		
	$4\pi\beta-\gamma$ coincidence (4P-PC-BP-NA-GR-CO)	2069.9	0.05	0.05	1993-10-01 19:00 UT	
ANSTO	$4\pi\beta-\gamma$ coincidence (4P-PC-BP-NA-GR-CO)	1676	0.1	0.08	1992-04-08 23:00 UT	
ASMW	$4\pi\beta(\text{PC})-\gamma$ coincidence (4P-PC-BP-NA-GR-CO)	1867.8 <sup>j</sup>	0.04	0.1	1976-06-15 12:00 UT	
		1870.0	0.04	0.1		
BARC	$4\pi\beta-\gamma$ coincidence (4P-PC-BP-NA-GR-CO)	584.4	0.03	0.25	1981-06-01 06:30 UT	
	$4\pi\beta-\gamma$ coincidence (4P-PC-BP-NA-GR-CO)	676.1	0.04	0.11	1994-05-01 06:30 UT	
	$4\pi\beta-\gamma$ coincidence (4P-PC-BP-NA-GR-CO)	1072	0.6	0.3	2000-12-01 06:30 UT	1922
	$4\pi\beta(\text{LS})-\gamma$ coincidence (4P-LS-BP-NA-GR-CO)	1560	0.29	0.36	2011-03-15 06:30 UT	1925
BEV	Ionization chamber traceable to the NPL (4P-IC-GR-00-00-00)	2980	0.07	0.58	1998-10-01 12:00 UT	1925.5
		3081	0.08	0.22	2007-10-01 00:00 UT	1925.2 [12]
BIPM	$4\pi\beta(\text{PC})-\gamma$ coincidence (4P-PC-BP-NA-GR-CO)	2611.2	0.014	0.02	1973-06-06 12:00 UT	-
BKFH	$4\pi\beta-\gamma$ coincidence (4P-PC-BP-NA-GR-CO)	1345 <sup>j</sup>	0.02	0.32	1977-03-01 12:00 UT	1926(3)
		1345	0.02	0.32		
	$4\pi\beta-\gamma$ coincidence (4P-PC-BP-NA-GR-CO)	1490	0.1	0.26	1979-12-01 12:00 UT	
	$4\pi\beta(\text{PC})-\gamma$ coincidence (4P-PC-BP-NA-GR-CO)	1808	0.03	0.25	1999-06-01 12:00 UT	1925.5(5) [13]
CIEMAT	$4\pi\beta(\text{PC})-\gamma$ coincidence (4P-PC-BP-NA-GR-CO)	364.8 <sup>a</sup>	0.11	0.1	1999-10-05 12:00 UT	1925.2

... Continuation of Table 2.

NMI or laboratory	Method used and the acronym	Activity $A_i$ /kBq	Relative standard uncertainty / $10^{-2}$		Reference date yyyy-mm-dd	Half-life /d
			A	B		
	CIEMAT/NIST ( 4P-LS-BP-00-00-CN)					
CMI-IIR	$4\pi\beta$ - $\gamma$ coincidence (4P-PC-BP-NA-GR-CO)	37 680	0.05	0.8	1977-02-23 13:00 UT	-
	$4\pi\beta$ - $\gamma$ coincidence (4P-PC-BP-NA-GR-CO)	4190	0.1	0.3	1978-02-09 11:00 UT	1925(4)
CNEA	$4\pi\beta$ (PC)- $\gamma$ coincidence (4P-PC-BP-NA-GR-CO)	785.3	0.05	0.12	1992-01-01 12:00 UT	-
	CIEMAT/NIST (4P-LS-BP-00-00-CN) PPC coincidence ( 4P-PP-BP-NA-GR-CO)	641.2 <sup>b</sup>	0.21		2002-10-31 00:00 UT	1925.3
	$4\pi\beta$ (PC)- $\gamma$ coincidence (4P-PC-BP-NA-GR-CO)	175.5	0.38	0.37	2010-06-27	1925.2(3) [12]
	TDICR ( 4P-LS-BP-00-00-TD)	174.1	0.32	0.33	2010-07-12	
ENEA-INMRI	$4\pi\beta$ (PC)- $\gamma$ coincidence (4P-PC-BP-NA-GR-CO)	1053	0.2	0.3	1990-12-01 12:00 UT	-
IAEA	$4\pi\beta$ - $\gamma$ coincidence and anti-coincidence (4P-??-BP-??-GR-CO, 4P-??-BP-??-GR-AC) <sup>c</sup>	1770	0.07	0.13	1977-04-01 12:00 UT	1925(4)
	$4\pi\beta$ - $\gamma$ coincidence (4P-PC-BP-NA-GR-CO) <sup>d</sup>	3600	0.1	0.3	1978-02-09 11:00 UT	1925
IFIN-HH	$4\pi\beta$ (PC)- $\gamma$ coincidence (4P-PC-BP-NA-GR-CO) <sup>e</sup>	1444 <sup>j</sup>	0.05	0.09	1983-09-01 12:00 UT	-
		1424	0.05	0.09		
	$4\pi\beta$ (PC)- $\gamma$ coincidence (4P-PC-BP-NA-GR-CO)	2149	0.08	0.32	2006-10-06 00:00 UT	1925.2(4)
IRA	$4\pi\beta$ (PC)- $\gamma$ coincidence (4P-PC-BP-NA-GR-CO)	3007 <sup>j</sup>	0.02	0.1	1979-05-01 12:00 UT	-
		2982	0.02	0.1		
	Ionization chamber calibrated in 1979 by $4\pi\beta$ - $\gamma$ coincidence (4P-IC-GR-00-00-00)	2518	0.014	0.1	2000-12-01 12:00 UT	1925.3(2)
JRC	$4\pi$ (PPC)-NaI well digital coincidence (4P-PP-BP-NA-GR-CO)	1412	0.17	0.16	2004-05-01 00:00 UT	1925.2(4) [14]
KRISS	$4\pi\beta$ - $\gamma$ coincidence (4P-PP-BP-NA-GR-CO)	511.6	0.3		1994-10-01 12:00 UT	-
LNE-LNHB	$4\pi\beta$ - $\gamma$ coincidence (4P-PC-BP-GL-GR-CO)	3303.3 <sup>j</sup>	0.02	0.04	1978-06-15 12:00 UT	
		3296.3	0.02	0.04		

... Continuation of Table 2.

NMI or laboratory	Method used and the acronym	Activity $A_i$ /kBq	Relative standard uncertainty / $10^{-2}$		Reference date yyyy-mm-dd	Half-life /d
			A	B		
	$4\pi\beta$ - $\gamma$ (Ge(Li) coincidence) (4P-PC-BP-GL-GR-CO)	1777.5 <sup>j</sup>	0.03	0.05	1986-07-11 12:00 UT	
		1781.2	0.03	0.05		
	$4\pi\beta$ (PC)- $\gamma$ coincidence (4P-PC-BP-NA-GR-CO)	2838.9	0.05		1999-06-01 12:00 UT	1925.2(4)
LNMRI-IRD	$4\pi\beta$ (PC)- $\gamma$ coincidence (4P-PC-BP-NA-GR-CO)	189.4 <sup>j</sup>	0.14	0.04	1976-06-28 12:00 UT	-
		193.8	0.14	0.04		
	$4\pi\beta$ (PC)- $\gamma$ coincidence (4P-PC-BP-NA-GR-CO)	327.8 <sup>j</sup>	0.04	0.08	1984-10-17 12:00 UT	
		334.5	0.04	0.08		
NIM	$4\pi\beta$ (PC)- $\gamma$ coincidence (4P-PC-BP-NA-GR-CO)	1746.2 <sup>j</sup>	0.05	0.2	1978-08-31 04:00 UT	
		1746.4	0.05	0.2		
	$4\pi\beta$ (PC)- $\gamma$ coincidence (4P-PC-BP-NA-GR-CO)	1049.4	0.21	0.15	2014-06-07 00:00 UT	1925.2(3) [12]
NIST	$4\pi\beta$ - $\gamma$ coincidence and anti-coincidence (4P-PC-BP-NA-GR-CO, 4P-PC-BP-NA-GR-AC)	2038	0.06	0.15	1980-05-30 17:00 UT	-
		1402	0.03	0.23		
	Ionization chamber (4P-IC-GR-00-00-00) <sup>f</sup>	183	0.03	0.18	2007-01-01 17:00 UT	1925.2(3) [12]
NMIJ	$4\pi\beta$ (PC)- $\gamma$ coincidence (4P-PC-BP-NA-GR-CO)	1848 <sup>j</sup>	0.03	0.21	1976-11-01 12:00 UT	-
		1859	0.03	0.21		
	$4\pi\beta$ (PC)- $\gamma$ coincidence (4P-PC-BP-NA-GR-CO)	1435.7	0.05	0.09	2004-02-01 12:00 UT	1925.2
NMISA	$4\pi\beta$ (LS)- $\gamma$ coincidence (4P-LS-BP-NA-GR-CO)	4659 <sup>j</sup>	0.05	0.18	1981-06-19 10:00 UT	-
		5329	0.05	0.18		
	$4\pi\beta$ (LS)- $\gamma$ coincidence (4P-LS-BP-NA-GR-CO) <sup>g</sup>	7066 <sup>j</sup>	0.014	0.133	1992-09-10 12:00 UT	1925.4(2) [15]
	20 525	0.014	0.133			
$4\pi\beta$ (LS)- $\gamma$ coincidence (4P-LS-BP-NA-GR-CO) <sup>g</sup>	214	0.02	0.2 <sup>x</sup>	2002-03-28 12:00 UT		
NPL	Ionization chamber calibrated by $4\pi\beta$ (PC)- $\gamma$ coincidence (4P-IC-GR-00-00-00)	667 <sup>j</sup>	0.03	1.02	1976-12-20 12:00 UT	-
		644	0.03	1.02		

... Continuation of Table 2.

NMI or laboratory	Method used and the acronym	Activity $A_i$ /kBq	Relative standard uncertainty / $10^{-2}$		Reference date yyyy-mm-dd	Half-life /d
			A	B		
	$4\pi\beta$ (PPC)- $\gamma$ digital coincidence counting (4P-PP-BP-NA-GR-CO)	2290	0.1	0.27	2000-02-01 12:00 UT	
NRC	$4\pi\beta$ (PP)- $\gamma$ anti-coincidence (4P-PP-BP-NA-GR-AC)	298.15	0.03	0.1	2011-11-09 17:00 UT	1925.2(3) [12]
POLATOM	$4\pi\beta$ (LS)- $\gamma$ coincidence and anti-coincidence (4P-LS-BP-NA-GR-CO, 4P-LS-BP-NA-GR-AC) <sup>h</sup>	177.4	0.27	0.5	2003-04-03 12:00 UT	1925.3 [16]
PTB	$4\pi\beta$ (PC)- $\gamma$ coincidence (4P-PC-BP-NA-GR-CO)	3222.6 <sup>j</sup>	0.02	0.07	1977-01-01 12:00 UT	-
		3176.0	0.02	0.07		
	Ionization chamber calibrated by $4\pi\beta$ (PC)- $\gamma$ coincidence (4P-IC-GR-00-00-00)	100 020 <sup>j</sup>	0.02	0.07	1987-09-01 12:00 UT	
		18 272	0.02	0.06		
		2036	0.03	0.09		
Ionization chamber calibrated by $4\pi\beta$ - $\gamma$ coincidence (4P-IC-GR-00-00-00)	13 760	0.03	0.22	2001-01-01 12:00 UT	1925.3(4)	
$4\pi\beta$ (PC)- $\gamma$ coincidence (4P-PC-BP-NA-GR-CO) $4\pi\beta$ (LS)- $\gamma$ coincidence (4P-LS-BP-NA-GR-CO) CIEMAT/NIST (4P-LS-MX-00-00-CN) TDCR (4P-LS-MX-00-00-TD)	2068.7 <sup>i</sup>	0.05	0.2	2016-01-01 00:00 UT	1925.3(4)	
PTKMR	$4\pi\beta$ (PC)- $\gamma$ coincidence (4P-PC-BP-NA-GR-CO)	1014 <sup>j</sup>	0.4		1984-06-01 08:00 UT	-
		1019	0.4			
TAEK	Ionisation chamber calibrated at the PTB in 2012 (4P-IC-GR-00-00-00)	888.7	0.49	1.16	2016-04-01 12:00 UT	1925.3(3)
VNIIM	$4\pi\beta$ (PC)- $\gamma$ coincidence (4P-PC-BP-NA-GR-CO)	1521.4	0.065	0.052	2018-04-01 00:00 UT	1925.23(29)



... Continuation of Table 2.

NMI or laboratory	Method used and the acronym	Activity $A_i$ /kBq	Relative standard uncertainty / $10^{-2}$		Reference date yyyy-mm-dd	Half-life /d
			A	B		

<sup>a</sup> For the CIEMAT/NIST method, a  $^3\text{H}$  tracer from LNE-LNHB was used. The result is the weighted mean of the different methods.

<sup>b</sup> The activity concentrations measured are 175.6 kBq/g and 175.7 kBq/g respectively. The weighted mean result is used for the comparison.

<sup>c</sup> With the Radiochemical Centre, Amersham, UK

<sup>d</sup> With the UVVVR

<sup>e</sup> see details in [?]

<sup>f</sup> calibrated in 1980 by  $4\pi\beta\text{-}\gamma$  coincidence and anti-coincidence

<sup>g</sup> see details in [?]

<sup>h</sup> see details in [?]

<sup>i</sup> The final result is the weighted mean of the results of four methods. The relative combined uncertainty (0.20 %) of the TDCR result is adopted for the final result. This is larger than the internal and external relative uncertainties of the weighed mean. Correlations and anti-correlations between the results were not considered

<sup>j</sup> Several samples submitted

<sup>x</sup> The uncertainty of 0.08 % submitted originally has been increased to include the uncertainty of an additional correction (see section 4 of [4]).

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 each solution of  $^{60}\text{Co}$  submitted.

NMI or laboratory / SIR year	Chemical composition	Solvent conc. /(mol dm <sup>-3</sup> )	Carrier conc. /( $\mu\text{g g}^{-1}$ )	Density /(g cm <sup>-3</sup> )	Relative activity of any impurity <sup>c</sup>
AECL 1980 1993	CoCl <sub>2</sub> in HCl	0.3	Co <sup>++</sup> : 10	1	-
	CoCl <sub>2</sub> .6H <sub>2</sub> O in HCl	0.1	CoCl <sub>2</sub> .6H <sub>2</sub> O: 100	1	-
ANSTO 1992	CoCl <sub>2</sub> in HCl	0.1	Co: 47	1	-
ASMW 1976	CoCl <sub>2</sub> in HCl	0.1	CoCl <sub>2</sub> : 20	-	-
BARC 1981 1994 2001 2012	CoCl <sub>2</sub> in HCl	0.1	CoCl <sub>2</sub> : 55	-	-
	Co(NO <sub>3</sub> ) <sub>2</sub> in HNO <sub>3</sub>	0.1	Co(NO <sub>3</sub> ) <sub>2</sub> : 50	1	-
	CoCl <sub>2</sub> in HCl	0.1	CoCl <sub>2</sub> : 25	1	-
BEV 1998 2007	CoCl <sub>2</sub> in HCl	0.1	CoCl <sub>2</sub> : 20	1	-
	CoCl <sub>2</sub> in HCl	0.1	CoCl <sub>2</sub> : 50	1	-
BIPM 1976	CoCl <sub>2</sub> in HCl	0.1	CoCl <sub>2</sub> : 5	1	-
BKFH 1977 1979 1999	Co in HCl	0.1	Co: 25	-	-
	Co in HCl	0.1	Co: 25	-	-
	CoCl <sub>2</sub> in HCl	0.1	CoCl <sub>2</sub> : 25	-	-

... Continuation of Table 3.

NMI or laboratory / SIR year	Chemical composition	Solvent conc. /(mol dm <sup>-3</sup> )	Carrier conc. /(µg g <sup>-1</sup> )	Density /(g cm <sup>-3</sup> )	Relative activity of any impurity <sup>c</sup>
CIEMAT 1999	CoCl <sub>2</sub> in HCl	1	CoCl <sub>2</sub> : 413	1.019	<sup>63</sup> Ni: 0.012 %
CMI-IIR 1977 1978	CoCl <sub>2</sub> in HCl	0.1	CoCl <sub>2</sub> : 20	1	<0.1 %
	CoCl <sub>2</sub> in HCl	0.08	CoCl <sub>2</sub> : 20	-	<0.1 %
CNEA 1992  2003  2011	CoCl <sub>2</sub> .6H <sub>2</sub> O in HCl	0.1	CoCl <sub>2</sub> : 10	0.999	<0.1 %
	CoCl <sub>2</sub> .6H <sub>2</sub> O in HCl	1	CoCl <sub>2</sub> .6H <sub>2</sub> O: 150	1.015	<0.01 %
	CoCl <sub>2</sub> .6H <sub>2</sub> O in HCl	0.1	CoCl <sub>2</sub> .6H <sub>2</sub> O: 90	1	-
ENEA- INMRI 1991	CoCl <sub>2</sub> .6H <sub>2</sub> O in HCl	0.1	Co <sup>++</sup> : 100	0.999	<sup>137</sup> Cs: 0.003(1) %  <sup>63</sup> Ni:0.026(5) %
IAEA 1978 1978	Co in HCl	0.1	Co: 100	-	-
	CoCl <sub>2</sub> in HCl	0.08	CoCl <sub>2</sub> : 10	-	<0.1 %
IFIN-HH 1983 2007	CoCl <sub>2</sub> in HCl	0.1	Co: 50	1	-
	CoCl <sub>2</sub> in HCl	0.1	CoCl <sub>2</sub> : 100	1	<0.01 %
IRA 1979 2000	Co <sup>++</sup> in HCl	0.1	Co <sup>++</sup> : 30	-	-
	Co <sup>++</sup> in HCl	0.1	Co <sup>++</sup> : 25	1.000(7)	-
JRC 2005	CoCl <sub>2</sub> in HCl	0.1	Co: 50	-	- <sup>a</sup>
KRISS 1995	CoCl <sub>2</sub> .6H <sub>2</sub> O in HCl	0.5	CoCl <sub>2</sub> .6H <sub>2</sub> O: 46	1.0061	-
LNE-LNHB 1978 1986 1999	CoCl <sub>2</sub> in HCl	0.1	CoCl <sub>2</sub> : 10	0.999	<0.02 %
	CoCl <sub>2</sub> in HCl	0.1	CoCl <sub>2</sub> : 10	0.999	<0.01 %
	Co in HCl	0.1	Co <sup>++</sup> : 10	1.001	-
LNMRI-IRD 1976 1984	CoCl <sub>2</sub> in HCl	0.1	CoCl <sub>2</sub> : 17.1	-	-
	Co in HCl	0.2	Co: 0.02	1.003	-
NIM 1978 2014	CoCl <sub>2</sub> in HCl	0.1	CoCl <sub>2</sub> : 100	1.0004	-
	Co <sup>++</sup> in HCl	0.1	Co <sup>++</sup> : 10	1.006	-
NIST 1980 1997 2007	Co in HCl	1	Co: 50	1.015(2)	-
	CoCl <sub>2</sub> in HCl	0.1	CoCl <sub>2</sub> : 100	1	-
	CoCl <sub>2</sub> in HCl	1.1	CoCl <sub>2</sub> : 130	1.017	<sup>57</sup> Co: 1.5(2)x10 <sup>-5</sup>
NMIJ 1976 2004	CoCl <sub>2</sub> in HCl	0.1	CoCl <sub>2</sub> :50	-	-
	CoCl <sub>2</sub> in HCl	0.1	CoCl <sub>2</sub> : 100	1.002	-
NMISA 1981 1992  2002	CoCl <sub>2</sub> in HCl	1	CoCl <sub>2</sub> : 540	1.037	-
	CoCl <sub>2</sub> .6H <sub>2</sub> O in HCl	1	Co <sup>++</sup> : 110	1.0183	-
	CoCl <sub>2</sub> .6H <sub>2</sub> O in HCl	-	Co <sup>++</sup> : 110	1.0183	-
NPL 1977 2000	CoCl <sub>2</sub> in HCl	0.1	CoCl <sub>2</sub> : 50	-	-
	CoCl <sub>2</sub> in HCl	0.1	CoCl <sub>2</sub> : 25	1	-
NRC 2012	CoCl <sub>2</sub> in HCl	0.1	CoCl <sub>2</sub> : 230	1.000(3)	- <sup>b</sup>

... Continuation of Table 3.

NMI or laboratory / SIR year	Chemical composition	Solvent conc. /(mol dm <sup>-3</sup> )	Carrier conc. /( $\mu$ g g <sup>-1</sup> )	Density /(g cm <sup>-3</sup> )	Relative activity of any impurity <sup>c</sup>
POLATOM 2003	CoCl <sub>2</sub> in HCl	0.1	Co: 25	1	<0.1 %
PTB 1977 1988 2001 2017	CoCl <sub>2</sub> in HCl	0.1	CoCl <sub>2</sub> : 50	-	-
	CoCl <sub>2</sub> in HCl	0.1	CoCl <sub>2</sub> : 50	1	-
	CoCl <sub>2</sub> in HCl	0.1	CoCl <sub>2</sub> : 50	1	-
	CoCl <sub>2</sub> in HCl	0.1	CoCl <sub>2</sub> : 50	1	-
PTKMR 1984	CoCl <sub>2</sub> .6H <sub>2</sub> O in HCl	1	CoCl <sub>2</sub> .6H <sub>2</sub> O: 50.5	0.990(1)	-
TAEK 2018	CoCl <sub>2</sub> in HCl	0.1	CoCl <sub>2</sub> : 50	1	-
VNIIM 2019	HNO <sub>3</sub>	2	-	1.065	< 0.01 %

<sup>a</sup> Confirmed by measurements carried out at the BIPM<sup>b</sup> None detected<sup>c</sup> the ratio of the activity of the impurity to the activity of <sup>60</sup>Co 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 latest submission has added 1 ampoule for the activity measurements for <sup>60</sup>Co giving rise to 73 ampoules in total. The SIR equivalent activity,  $A_{ei}$ , for each ampoule received from each NMI,  $i$ , including both previous and new results, is given in Table 4.

The relative standard uncertainties arising from the measurements in the SIR are also shown. This uncertainty is additional to that declared by the NMI ( $u(A_i)$ ) for the activity measurement shown in Table 2. Although submitted activities are compared with a given source of <sup>226</sup>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 most recent result of each NMI is normally eligible for inclusion on the KCDB platform of the CIPM MRA [2].

Table 4: Results of SIR measurement of <sup>60</sup>Co.

NMI or laboratory / SIR year	$m_i$ /g	$A_i$ /kBq	<sup>226</sup> Ra source	$A_{ei}$ /kBq	Relative uncert. from SIR /10 <sup>-4</sup>	$u_{ci}$ /kBq	$A_{ei}$ for KCRV /kBq
AECL 1980	0.941 77 <sup>a</sup>	1183.4	3	7050	5	4	-
	0.946 42	1189.3	3	7051	5	4	-
1993	0.233 2 <sup>a</sup>	2069.9	4	7064	4	6	7064(6)
ANSTO 1992	3.557 1	1676	4	7056	4	10	7056(10)
ASMW 1976	3.601 0	1867.8	4	7063	4	8	7062(8) <sup>d</sup>
	3.605 2	1870.0	4	7061	4	8	-
BARC 1981	3.599 8	584.4	3	7078	6	19	-

... Continuation of Table 4.

NMI or laboratory	$m_i$	$A_i$	$^{226}\text{Ra}$ source	$A_{ei}$	Relative uncert. from SIR	$u_{c,i}$	$A_e$ for KCRV
/ SIR year	/g	/kBq		/kBq	$/10^{-4}$	/kBq	/kBq
1994	3.605 8	676.1	3	7076	5	9	-
2001	3.614 5	1072	3	7099	5	46	7099(46)
2012	3.603 23	1560	4	7184	5	33	-
BEV 1998	3.618	2980	4	7049	4	42	-
2007	3.606 9	3081	4	7057	4	17	-
BIPM 1976	3.757 9	2611.2	4	7066	4	4	7066(4)
BKFH 1977	3.600 7	1345	4	7048	5	23	-
	3.600 6	1345	4	7043	5	23	-
1979	3.602 1	1490	4	7045	4	20	-
1999	3.612 2	1808	4	7051	5	18	7051(18)
CIEMAT 1999	3.682 16	364.8	2	7090	7	11	7090(11)
CMI-IIR 1977	3.568 43	37 680	5	7051	4	56	-
1978	3.615 29	4190	4	7054	4	20	7054(20)
CNEA 1992	2.075 43	785.3	3	7126	5	10	-
2003	3.650 37	641.2	3	7050 <sup>b</sup>	5	15	-
2011	3.606 43	175.5	2	7079	9	38	7070(26) <sup>e</sup>
		174.1		7060		33	-
ENEA-INMRI 1991	3.57	1053	3	7065	6	26	7065(26)
IAEA 1978	3.699 3	1770	4	7052	5	11	-
1978	3.584 18	3600	4	7053	4	20	-
IFIN-HH 1983	3.533 9	1444	4	7066	4	8	-
	3.485 4	1424	4	7068	4	8	-
2007	3.617 39	2149	4	7101	4	24	7101(24)
IRA 1979	3.629 93	3007	4	7039	4	8	7041(8) <sup>d</sup>
	3.599 67	2982	4	7042	4	8	-
2000	3.598	2518	4	7037	4	8	-
JRC 2005	3.497 98	1412	4	7039	4	17	7039(17)
KRISS 1995	3.585 26	511.6	3	7047	7	22	7047(22)
LNE-LNHB 1978	3.626 37	3303.3	4	7053	4	4	-
	3.618 76	3296.3	4	7052	4	4	-
1986	3.592 43	1777.5	4	7065	4	5	-
	3.599 83	1781.2	4	7063	4	5	-
1999	3.583 06	2838.9	4	7060	4	4	7060(4)
LNMRI-IRD 1976	3.459 33	189.4	2	7062	9	12	-
	3.539 01	193.8	2	7065	8	12	-
1984	3.468 94	327.8	2	7081	6	8	7077(8) <sup>d</sup>
	3.540 29	334.5	2	7073	6	8	-
NIM 1978	3.605 25	1746.2	4	7046	4	15	-
	3.605 67	1746.4	4	7042	4	15	-
2014	3.611 28	1049.4	3	7052	5	19	7052(19)
NIST 1980	3.666 88	2038	4	7069	4	12	-
1997	3.608 47	1402	4	7085	4	17	-

... Continuation of Table 4.

NMI or laboratory	$m_i$	$A_i$	$^{226}\text{Ra}$ source	$A_{ei}$	Relative uncert. from SIR	$u_{c,i}$	$A_e$ for KCRV
/ SIR year	/g	/kBq		/kBq	$/10^{-4}$	/kBq	/kBq
2007	3.659 57	183	2	7083	8	14	7083(14)
NMIJ 1976	3.607 86	1848	4	7044	4	16	-
	3.628 78	1859	4	7044	4	16	-
2004	3.633 75	1435.7	4	7050	4	8	7050(8)
NMISA 1981	3.600	4659	5	7064	3	13	-
	3.613	5329	5	7067	3	13	-
1992	3.612	7066	5	7066	3	10	7066(10) <sup>d</sup>
	3.610	20 525	5	7065	3	10	-
2002	3.596	214	2	7098 <sup>c</sup>	10	16	-
NPL 1977	3.770 4	667	3	7059	5	72	-
	3.640 7	644	3	7057	5	72	-
2000	3.567 15	2290	4	7053	4	21	7053(21)
NRC 2012	3.605 6	298.15	2	7065	8	9	7065(9)
POLATOM 2003	3.699 87	177.4	2	7040	8	40	7040(40)
PTB 1977	3.670 0	3222.6	4	7062	5	6	-
	3.616 9	3176.0	4	7060		6	-
1988	3.599 2	100 020	5	7068	3	6	-
	3.603 3	18 272	5	7056	3	5	-
	3.644 5	2036	4	7056	4	7	-
2001	3.600 7(9)	13 760	5	7057	3	16	-
2017	3.600 56	2068.7	4	7057	4	15	7057(15)
PTKMR 1984	3.550	1014	3	7103	5	27	7104(27) <sup>d</sup>
	3.567	1019	3	7105	6	27	-
TAEK 2018	3.584	888.7	3	7048	5	89	-
VNIIM 2019	3.597 67	1521.4	4	7062	4	7	7062(7)

<sup>a</sup> mass of solution before dilution<sup>b</sup> solution contained in a CNEA-type ampoule (see section 4 of [4])<sup>c</sup> not representative of the activity presently disseminated by NMISA (see section 4 of [4])<sup>d</sup> An average value and average uncertainty between all submitted samples is used for the KCDB [17].<sup>e</sup> An average value between all methods has been done.

#### 4.1. The key comparison reference value

In May 2013, the CCRI(II) decided to calculate the key comparison reference value (KCRV) by using the power-moderated weighted mean [18] 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 chisquared value is one. In addition, it allows for a power  $\alpha$  smaller than two in the weighting factor. As proposed in [18],  $\alpha$  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 may only use 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.

The BARC (2012) result is considered as an outlier so that their earlier result in 2001 is eligible to be kept in the KCRV. Consequently, using the recent result produces an updated KCRV for  $^{60}\text{Co}$  in 2020 of **7062.6(25) kBq** with the power  $\alpha = 1.885$  that has been calculated using the previously published results, selected as shown in Table 4, for the ASMW (1976), BIPM (1976), CMI-IIR (1978), IRA (1979), PTKMR (1984), LNMRI-IRD (1984), ENEA-INMRI (1991), ANSTO (1992), NMISA (NAC, 1992), AECL (1993), KRISS (1995), BKFH (1999), CIEMAT (1999), LNE-LNHB (1999), NPL (2000), BARC (2001), POLATOM (2003), NMIIJ (2004), JRC (2005), IFIN-HH (2007), NIST (2007), CNEA (2011), NRC (2012), NIM (2014), PTB (2017), and the present VNIIM (2019) result. This can be compared with the previous KCRV values of 7064.6(38) kBq published in 2003 [3], 7061.3(35) kBq published in 2006 [6], 7063.3(40) kBq published in 2010 [7], 7062.7(27) kBq published in 2017 [8] and 7062.7(27) kBq published in 2020 [9].

#### 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

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

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

$$U_i = 2u(D_i) \quad (2)$$

When the result of the NMI  $i$  is included in the KCRV with a weight  $w_i$ , then

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

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

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

##### 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

$$D_{ij} = D_i - D_j = A_{ei} - A_{ej} \quad (5)$$

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

$$u^2(D_{ij}) = u_i^2 + u_j^2 - 2u(A_{ei}, A_{ej}) \quad (6)$$

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  $u(A_{ei}, A_{ej})$  (see [19] 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 B1 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 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 C1. 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.

## 5. Conclusion

The BIPM continuous key comparison for  $^{60}\text{Co}$ , BIPM.RI(II)-K1.Co-60, currently comprises 15 results. The KCRV has been recalculated to include the result from the VNIIM (Russian Federation). The results have been analyzed with respect to the updated KCRV, providing degrees of equivalence for 15 national metrology institutes. The degrees of equivalence have been approved by the CCRI(II) and are published in the BIPM key comparison database. Other results may be added when other NMIs contribute  $^{60}\text{Co}$  activity measurements to this comparison or take part in other linked comparisons.

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## Appendix A. Introductory text for $^{60}\text{Co}$ degrees of equivalence

### Key comparison BIPM.RI(II)-K1.Co-60

#### MEASURAND: Equivalent activity of $^{60}\text{Co}$

**Key comparison reference value:** the SIR reference value  $x_{\text{R}}$  for this radionuclide is 7062.6 kBq , with a standard uncertainty,  $u_{\text{R}}$  equal to 2.5 kBq (see Section 4.1 of the Final Report). The value  $x_i$  is taken as the equivalent activity for a laboratory  $i$ .

The degree of equivalence of each laboratory with respect to the reference value is given by a pair of terms:  $D_i = (x_i - x_{\text{R}})$  and  $U_i$ , its expanded uncertainty ( $k = 2$ ), both expressed in kBq, and  $U_i = 2((1 - 2w_i)u_i^2 + u_{\text{R}}^2)^{1/2}$ , where  $w_i$  is the weight of laboratory  $i$  contributing to the calculation of  $x_{\text{R}}$ .

**Appendix B. Table of degrees of equivalence for BIPM.RI(II)-K1.Co-60**

Table B1: The table of degrees of equivalence for BIPM.RI(II)-K1.Co-60

NMI $i$	$D_i$ /kBq	$U_i$ /kBq
IRA	-26	17
NMISA	35	32
POLATOM	-23	80
NMIJ	-13	16
JRC	-24	34
IFIN-HH	38	48
NIST	20	28
BEV	-6	34
CNEA	7	52
BARC	121	66
NRC	2	18
NIM	-11	38
PTB	-6	30
TAEK	-20	180
VNIM	-1	14

Appendix C. Graph of degrees of equivalence with the KCRV for  $^{60}\text{Co}$  (as it appears in Appendix B of the MRA)

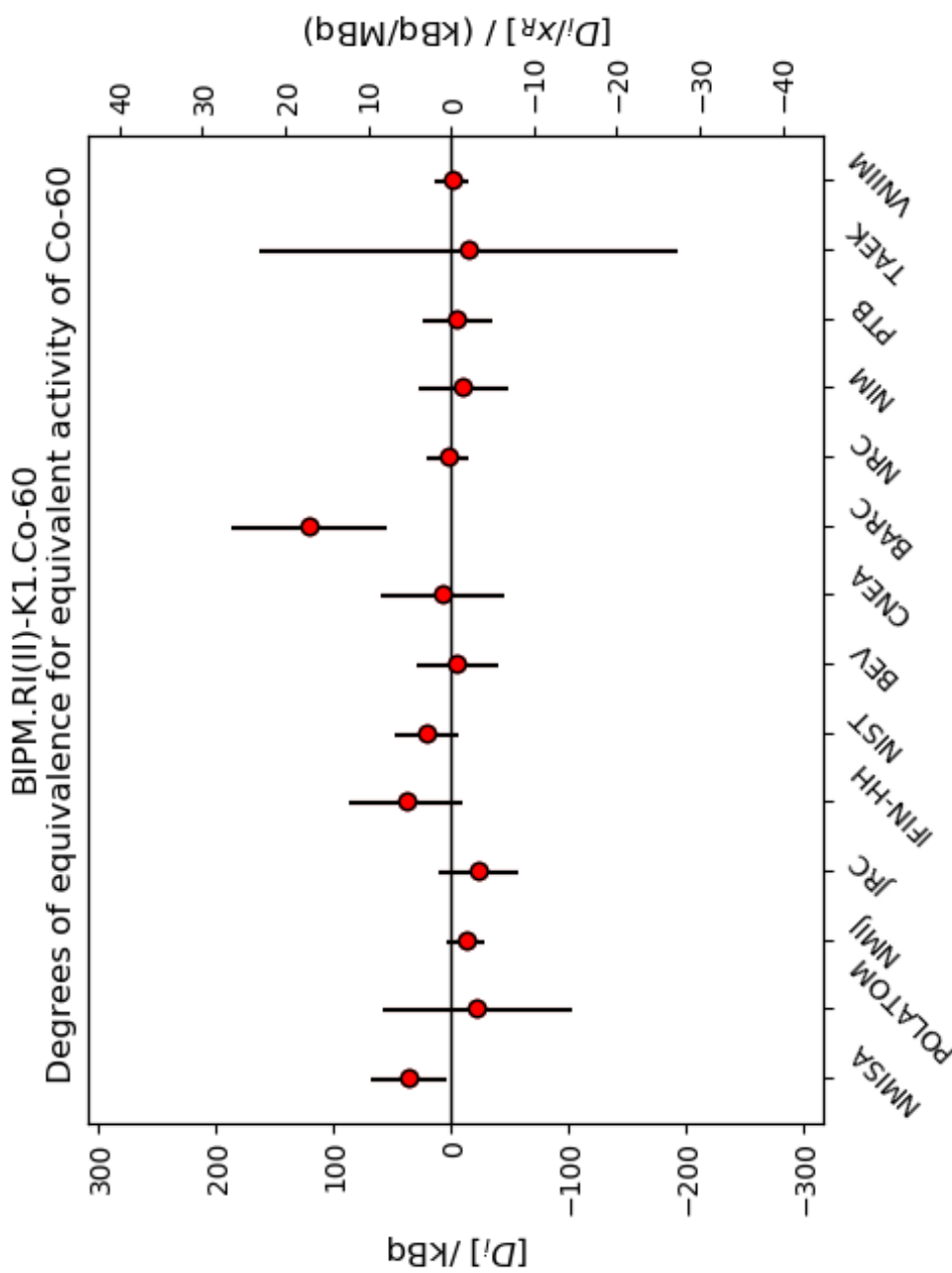


Figure C1. Degrees of equivalence for equivalent activity of  $^{60}\text{Co}$ .

**Appendix D. Uncertainty budgets for the activity of  $^{60}\text{Co}$  submitted to the SIR**

### Detailed Uncertainty Budget

Laboratory : VNIIM ; Radionuclide : <sup>60</sup>Co ; Ampoule number : 251 .

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

	Remarks	Evaluation type (A or B)
counting statistics	-----	----- <b>B</b> -----
weighing	-----	----- <b>A</b> -----
dead time	-----	----- <b>B</b> -----
background	-----	----- <b>A</b> -----
pile-up	-----	-----
counting time	-----	----- <b>B</b> -----
adsorption	-----	-----
impurities	-----	----- <b>B</b> -----
tracer	-----	-----
input parameters and statistical model	-----	-----
quenching	-----	-----
interpolation from calibration curve	-----	-----
decay-scheme parameters	-----	-----
half life ( $T_{1/2} = 1.92523 \times 10^3$ d; $u = 0.00029 \times 10^3$ d)	-----	----- <b>B</b> -----
self absorption	-----	-----
extrapolation of efficiency curve	-----	----- <b>A</b> -----
other effects (if relevant) (explain) <b>resolving time</b>	-----	----- <b>A</b> -----
combined uncertainty ( as quadratic sum of all uncertainty components)	-----	-----

\* 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).

**Appendix E. 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.

<b>Geometry</b>	<b>acronym</b>	<b>Detector</b>	<b>acronym</b>
$4\pi$	4P	proportional counter	PC
defined solid angle	SA	press. Prop. Counter	PP
$2\pi$	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
		CeBr3	CB

<b>Radiation</b>	<b>acronym</b>	<b>Mode</b>	<b>acronym</b>
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 ( $x + \gamma$ )	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

<b>Examples of methods</b>	<b>acronym</b>
$4\pi(\text{PC})\beta\text{-}\gamma$ coincidence counting	4P-PC-BP-NA-GR-CO
$4\pi(\text{PPC})\beta\text{-}\gamma$ coincidence counting eff. trac	4P-PP-MX-NA-GR-CT
defined solid angle $\alpha$ -particle counting with a PIPS detector	SA-PS-AP-00-00-00
$4\pi(\text{PPC})\text{AX-}\gamma(\text{GeHP})\text{-}$ anticoincidence counting	4P-PP-MX-GH-GR-AC
$4\pi\text{CsI-}\beta,\text{AX},\gamma$ counting	4P-CS-MX-00-00-HE
calibrated IC	4P-IC-GR-00-00-00
internal gas counting	4P-PC-BP-00-00-IG