Results of the IFIN-HH (Romania), KRISS (Republic of Korea), CMI (Czech Republic) and the BEV (Austria) in the BIPM comparison BIPM.RI(II)-K1.I-131 of activity measurements of the radionuclide ^{131}I

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Abstract

Since 2005, five national metrology institutes (NMIs) have submitted four new samples of known activity of ^{131}I to the International Reference System (SIR) for activity comparison at the Bureau International des Poids et Mesures (BIPM). The latest activities ranged from about 2.8 MBq to 73 MBq. The submission of the CMI was to update an earlier submission. The key comparison reference value has been re-evaluated following the recommendations of the CCRI in May 2007. The degrees of equivalence between each equivalent activity measured in the SIR and the key comparison reference value (KCRV), and between each pair of participants have been calculated and the results are given in the form of a matrix for sixteen NMIs, including the previous participants. 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 (3.6 g) with the radionuclide in liquid form or a different standard ampoule for radioactive gases. 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 reference sources of ^{226}Ra using pressurized ionization chambers. Details of the SIR method, experimental set-up and the determination of the equivalent activity, A_e, are all given in [1].

From its inception until 31 December 2007, the SIR has measured 905 ampoules to give 662 independent results for 63 different radionuclides. The SIR makes it possible for national laboratories to check the reliability of their activity measurements at any time. This is achieved by the determination of the equivalent activity of the radionuclide and by comparison of the result with the key comparison reference value determined from the results of primary realizations. 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.I-131 key comparison and is an update of the previous results published in the KCDB [3, 4].

2. Participants

Eighteen NMIs and one other laboratory have submitted forty-two ampoules for the comparison of ^{131}I activity measurements since 1977. Some early results have been withdrawn. As the key comparison reference value has been re-evaluated for this comparison all the participants' details are given in Table 1. In cases where the laboratory has changed its name since the original submission, both the earlier and the current acronyms are given, as it is the latter that are used in the KCDB.

Table 1. Details of the participants in the BIPM.RI(II)-K1.I-131

Original acronym	**NMI**	**Full name**	**Country**	**Regional metrology organization**	**Date of measurement at the BIPM**
NBS	NIST	National Institute of Standards and Technology	United States	SIM	1977-05-24 1978-06-05 1979-09-03 1980-03-06 1981-03-06 1998-02-04
ASMW *	PTB	Physikalisch-Technische Bundesanstalt	Germany	EUROMET	1978-03-10 1989-10-31 1993-03-15 2004-04-30
–	BARC	Bhabha Atomic Research Centre	India	APMP	1979-07-17 1994-06-15
NAC*	NMISA	National Metrology Institute, South Africa	South Africa	SADCMET	1980-02-11
–	NPL	National Physical Laboratory	United Kingdom	EUROMET	1980-10-08 1999-03-18
OMH	MKEH	Magyar Kereskedelmi Engedéyezési Hivatal	Hungary	EUROMET	1983-03-04 1991-11-25 1998-10-28
IER	IRA	Institut de Radiophysique Appliquée	Switzerland	EUROMET	1984-05-24 1996-09-19

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Table 1 continued. Details of the participants in the BIPM.RI(II)-K1.I-131

Original acronym	NMI	Full name	Country	Regional metrology organization	Date of measurement at the BIPM
PDS	PTKMR	Pusat Teknologi Keselamatan dan Metrologi Radiasi	Indonesia	APMP	1985-06-17
ETL	NMIJ	National Metrology Institute of Japan	Japan	APMP	1986-02-05
UVVVR	CMI-IIR	Český Metrologický Institut - Inspectorate for Ionizing Radiation	Czech Republic	EUROMET	1986-10-02 2001-09-25 2006-08-22
LMRI	LNE-LNHB	Bureau national de métrologie-Laboratoire national Henri Becquerel	France	EUROMET	1987-06-22
NIRH	–	National Institute of Radiation Hygiene	Denmark	EUROMET	1991-03-27
–	ANSTO	Australian Nuclear Science and Technology Organisation	Australia	APMP	1994-06-02
–	LNMRI	Laboratorio Nacional de Metrologia das Radiaçoes Ionizantes	Brazil	SIM	1999-11-17
–	CIEMAT	Centro de Investigaciones Energéticas, Medioambientales y Tecnològicas	Spain	EUROMET	2002-06-26
–	IFIN-HH	Institutul de Fizica si Inginerie Nucleara-Horia Hulubei	Romania	EUROMET	2005-11-28 2008-01-03

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Table 1 continued. Details of the participants in the BIPM.RI(II)-K1.I-131

Original acronym	NMI	Full name	Country	Regional metrology organization	Date of measurement at the BIPM
–	KRISS	Korea Research Institute of Standards and Science	Republic of Korea	APMP	2005-12-23
–	BEV	Bundesamt für Eich- und Vermessungswesen	Austria	EUROMET	2007-05-23

* another laboratory in the country

3. NMI standardization methods

Each NMI that submits ampoules to the SIR has measured the activity either by a primary standardization method or by using a secondary method, for example a calibrated ionization chamber. In the latter case, the traceability of the calibration needs to be clearly identified to ensure that any correlations are taken into account.

A brief description of the standardization methods for each laboratory, the activities submitted and the relative standard uncertainties ($k = 1$) are given in Table 2. The uncertainty budgets for the four recent submissions are given in Appendix 1 attached to this report. The list of acronyms used to summarize the measurement methods is given in Appendix 2.

The half-life originally used by the BIPM was 8.021 (1) days [5] and all the earlier SIR results have been modified in accordance with the latest evaluation of 8.0233 (19) days [6]. The subsequent relative changes in the equivalent activity values are a maximum of 1.2×10^{-3}, for the NIST (1979). The half-life given in Table 2 is the value (with its uncertainty) as used by the participant.

Details of the standardization methods and results of all the earlier submissions are taken from [3] and [4].

Table 2. Standardization methods of the participants for ^{131}I

NMI	Method used and acronym (see Appendix 2)	Half-life / d	Activity A_i / kBq	Reference date	Relative standard uncertainty × 100 by method of evaluation	
				YY-MM-DD	A	B
NIST	Pressurized IC 4P-IC-GR-00-00-00 calibrated by 4πβ(PC) 4P-PC-BP-00-00-00	–	7 170 7 190 [a]	77-05-11 17 h UT	0.02	0.57
		8.02 (1)	4 648	78-05-24 12 h UT	0.01	0.63
	Pressurized IC 4P-IC-GR-00-00-00 calibrated in 1979 by 4πβ-γ coincidence 4P-PP-BP-NA-GR-CO	8.02 (1)	4 475	79-07-17 19 h UT	0.01	0.64
			4 395	80-02-21 7 h UT	0.01	0.61
			5 363 [b]	81-02-24 20 h UT	0.04	0.47
			19 850	98-01-27 22 h UT	0.02	0.35
PTB	Pressurized IC [d] 4P-IC-GR-00-00-00	–	32 160	78-03-08 0 h UT	0.01	0.15
	4πβ-γ coincidence 4P-PC-BP-NA-GR-CO	–	4 005	89-11-01 12 h UT	0.01	0.15
	Pressurized IC [d] 4P-IC-GR-00-00-00	–	3 719 3 708 [a]	93-03-12 0 h UT	0.03	0.20
	Pressurized IC 4P-IC-GR-00-00-00 calibrated in 2004 by 4πβ-γ coincidence 4P-PC-BP-NA-GR-CO and CIEMAT/NIST 4P-LS-MX-00-00-CN	8.0207 (9)	43 222 43 139 [a]	04-05-05 0 h UTC	0.04	0.18
BARC	4πβ-γ coincidence 4P-PC-BP-NA-GR-CO	–	1 901	79-07-05 6 h 30 UT	0.19	0.43
		–	259.2	94-06-01 6 h 30 UT	0.11	0.29
NMISA	4π(LS)β-γ coinc. 4P-LS-BP-NA-GR-CO	–	22 510 22 580 [a]	80-02-06 10 h UT	0.03	0.50

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Table 2 continued. Standardization methods of the participants for ^{131}I

NMI	Method used and acronym (see Appendix 2)	Half-life / d	Activity A_i / kBq	Reference date	Relative standard uncertainty × 100 by method of evaluation	
				YY-MM-DD	A	B
NPL	Pressurized IC[e] 4P-IC-GR-00-00-00	–	6 899	80-10-06 0 h UT	0.06	0.33
	4π(PPC)-γ coinc. 4P-PP-BP-NA-GR-CO	–	3 750 3 719[a]	99-03-02 12 h UT	0.09	0.27
MKEH	4πβ-γ coincidence 4P-PC-BP-NA-GR-CO	8.020 (2) [7]	3 702	83-03-08 12 h	0.02	0.63
		[5]	10 140	91-12-01 12 h UT	0.02	0.39
	4π(PC)-γ coinc. 4P-PC-BP-NA-GR-CO	[5]	9 398	98-10-27 0 h UT	0.02	0.31
IRA	4πβ-γ coincidence 4P-PC-BP-NA-GR-CO	–	3 634	84-05-16 0 h UT	0.04	0.49
	Pressurized IC[d] 4P-IC-GR-00-00-00	–	3 453	96-09-10 10 h UT	0.03	0.50
PTKMR	Pressurized IC 4P-IC-GR-00-00-00	–	2 360 2 360[a]	85-06-06 2 h UT	1.1	
NMIJ	4π(PC)β-γ coinc. 4P-PC-BP-NA-GR-CO	8.040	2 822 2 809[a]	86-02-04 12 h UT	0.08	0.26
CMI-IIR	4πβ-γ coincidence 4P-PC-BP-NA-GR-CO	8.02	20 290	86-10-01 12 h UT	0.04	0.27
	Pressurized IC[d] 4P-IC-GR-00-00-00	8.021 (1)	9 701	01-09-18 12 h UT	0.28	0.28
	4π(PC)β-γ coinc. 4P-PC-BP-NA-GR-CO	[6]	73 260	06-07-12 10h UT	0.10	0.26
LNE-LNHB	4πβ-γ coincidence 4P-PC-BP-NA-GR-CO	8.021 (1)	2 116 2 114[a]	87-06-24 12 h UT	0.10	0.13
NIRH	Pressurized IC 4P-IC-GR-00-00-00	–	67 200	91-03-20 23 h UT	0.5	2.5
ANSTO	Pressurized IC[c] 4P-IC-GR-00-00-00	–	6 491	94-05-17 23 h UT	0.02	0.88
LNMRI	Pressurized IC[f] 4P-IC-GR-00-00-00	[5]	11 610	99-11-01 0 h UT	0.18	0.43

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Table 2 continued. Standardization methods of the participants for ^{131}I

NMI	Method used and acronym (see Appendix 2)	Half-life / d	Activity A_i / kBq	Reference date YY-MM-DD	Relative standard uncertainty × 100 by method of evaluation	
					A	B
CIEMAT	4π(PC)β-γ (NaI) coincidence 4P-PC-BP-NA-GR-CO	8.021	35 940	02-06-05 10 h UT	0.45	0.10
IFIN-HH	4πβ-γ coincidence 4P-PC-BP-NA-GR-CO	8.021	2 845	05-11-14 12h UT	0.2	0.5
		8.0233 (19) [6]	3 057	07-11-29 12h UT	0.2	0.22
KRISS	4πβ-γ coincidence 4P-PC-BP-NA-GR-CO	[6]	17 366	05-12-15 0h UT	0.04	0.22
BEV	Pressurized IC [g] 4P-IC-GR-00-00-00	8.021	3 102	07-05-25 0h UT	0.07	0.37

[a] two ampoules submitted

[b] corrected for the growth of ^{131}Xe^{m} which was assumed to be zero at the time of sealing the ampoule

[c] calibrated by 4πβ-γ coincidence measurements of ^{131}I in1978

[d] traceable to 4πβ-γ coincidence measurements 4P-PC-BP-NA-GR-CO of ^{131}I (in 2001 for the CMI-IIR)

[e] calibrated by primary measurements of ^{131}I

[f] calibrated by 4πβ-γ coincidence measurements of ^{131}I in1993

[g] traceable to NPL.

Details regarding the solution submitted are shown in Table 3, including any impurities, when present, as identified by the laboratories. When given, the standard uncertainties on the evaluations are shown. The BIPM has 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. No impurities were identified in the latest KRISS, CMI-IIR and BEV submissions.

Table 3. Details of the solution of ^{131}I submitted

NMI		Chemical composition	Solubilization medium[11] conc.	Carrier conc. /(μg g^{-1})	Density /(g cm^{-3})	Relative activity of impurity†
NIST	1977	KI and Na_2SO_3 in diluted LiOH and NaOH	LiOH: 1.3×10^{-3} mol dm^{-3} NaOH: 0.05×10^{-3} mol dm^{-3} Na_2SO_3: 30 μg g^{-1}	KI: 60	0.999 (2)	^{125}I : 0.3 % *
	1978		LiOH: 0.1×10^{-3} mol dm^{-3} NaOH: 0.08×10^{-3} mol dm^{-3} Na_2SO_3: 3 μg g^{-1}	KI: 6	0.999 (2)	–
	1979				0.998 (2)	–
	1980	KI and Na_2SO_3 in diluted $LiOH.H_2O$ and NaOH	$LiOH.H_2O$: 0.05×10^{-3} mol dm^{-3} NaOH: 0.01×10^{-3} mol dm^{-3} Na_2SO_3: 2 μg g^{-1}	KI: 5	0.998 (2)	–
	1981		$LiOH.H_2O$: 0.07×10^{-3} mol dm^{-3} NaOH: 0.02×10^{-3} mol dm^{-3} Na_2SO_3: 3 μg g^{-1}	KI: 6	0.998 (2)	–
	1998	KI in LiOH	LiOH : 0.01 mol dm^{-3}	KI: 68	0.999	–
PTB	1978	NaI and $Na_2S_2O_3$ in water with 0.1 % Formalin	water with 0.1 % Formalin $Na_2S_2O_3$: 100 μg g^{-1}	NaI : 100	1.00	< 0.01 %
	1989	KI and $Na_2S_2O_3$ in water	$Na_2S_2O_3$: 50 μg g^{-1}	KI : 20	0.9982	< 0.03 %

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Table 3 continued. Details of the solution of ^{131}I submitted

NMI	Chemical composition	Solubilization medium[11] conc.	Carrier conc. /(µg g^{-1})	Density /(g cm^{-3})	Relative activity of impurity†
PTB 1993	NaI and $Na_2S_2O_3$ and 0.1 % Formalin in NaOH	NaOH: 1 mol dm^{-3} with 0.1 % Formalin $Na_2S_2O_3$: 45 µg g^{-1}	NaI : 60	1.0	–
2004	NaI and $Na_2S_2O_3$ in HCHO (formaldehyde)	HCHO: 0.04 mol dm^{-3} $Na_2S_2O_3$: 45 µg g^{-1}	NaI : 60	1.00	–
BARC 1979	KI and $Na_2S_2O_3$ in water	$Na_2S_2O_3$: 60 µg g^{-1}	KI: 200	–	–
1994	NaI and $Na_2S_2O_3$ in water		KI: 100	1	–
NMISA 1980	KI and Na_2SO_3 in diluted NaOH	NaOH: 0.2×10^{-3} mol dm^{-3} Na_2SO_3: 1600 µg g^{-1}	KI: 4800	1.007	–
NPL 1980	KI in NaOH	NaOH: 0.01 mol dm^{-3}	KI: 100	1.0004	–
1999	NaI and $Na_2S_2O_3$ in diluted NaOH	NaOH: 0.0025 mol dm^{-3} $Na_2S_2O_3$: 25 µg g^{-1}	NaI : 55	1	–
MKEH 1983	KI; KIO_3 and $Na_2S_2O_3$ in water	$Na_2S_2O_3$: 50 µg g^{-1}	KI : 50 KIO_3 : 50	–	< 0.01 %
1991			idem	–	–
1998	I in NaOH	NaOH: 0.01 mol dm^{-3}	–	–	–

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Table 3 continued. Details of the solution of ^{131}I submitted

NMI	Chemical composition	Solubilization medium[11] conc.	Carrier conc. /(µg g–1)	Density /(g cm–3)	Relative activity of impurity†
IRA 1984	KI and Na_2SO_3 in diluted LiOH	LiOH: 0.9×10^{-3} mol dm^{-3} Na_2SO_3 : 20 µg g^{-1}	KI : 50	1.00	–
1996			KI : 20	–	–
PTKMR1985	KI and Na_2SO_3 in diluted LiOH	LiOH: 0.9×10^{-3} mol dm^{-3} Na_2SO_3 : 20 µg g^{-1}	KI : 50	0.990 (1)	–
NMIJ 1986	NaI and Na_2SO_3 in diluted LiOH	LiOH: 0.9×10^{-3} mol dm^{-3} Na_2SO_3 : 30 µg g^{-1}	NaI: 50	0.9982	–
CMI-IIR1986	KI and $Na_2S_2O_3$ in $NaHCO_3$	$NaHCO_3$ 0.7×10^{-3} mol dm^{-3} $Na_2S_2O_3$: 50 µg g^{-1}	KI : 50	–	< 0.1 %
2001	KI and $Na_2S_2O_3$ in water	$Na_2S_2O_3$: 50 µg g^{-1}	KI : 50	–	< 0.1 %
2006	KI and $Na_2S_2O_3$ in $NaHCO_3$	$NaHCO_3$ 0.5×10^{-3} mol dm^{-3} $Na_2S_2O_3$: 50 µg g^{-1}	KI : 50	–	–
LNE-LNHB 1987	KI and $Na_2S_2O_3$ in diluted NaOH	NaOH 0.5×10^{-3} mol dm^{-3} $Na_2S_2O_3$: 50 µg g^{-1}	KI : 50	0.9983	$< 2\ 10^{-3}$ %
NIRH 1991	–	–	–	1	–

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Table 3 continued. Details of the solution of ^{131}I submitted

NMI	Chemical composition	Solubilization medium[11] conc.	Carrier conc. /(μg g–1)	Density /(g cm–3)	Relative activity of impurity†
ANSTO 1994	NaI	–	–	–	–
LNMRI 1999	NaCl in water	–	–	1.01	–
CIEMAT 2002	Na_2HPO_4 in water	Na_2HPO_4 : 6800 μg g^{-1}	–	–	–
IFIN-HH 2005	NaI and $Na_2S_2O_3$ in NaOH	NaOH: 0.01 mol dm^{-3} $Na_2S_2O_3$: 80 μg g^{-1}	NaI: 50	1	$^{131}Xe^m$: 2.69 (45) % *
2008	NaI and $Na_2S_2O_3$ in NaOH	NaOH: 0.01 mol dm^{-3} $Na_2S_2O_3$: 80 μg g^{-1}	NaI: 50	1	–
KRISS 2005	NaI in NaOH	NaOH: 0.1 mol dm^{-3}	NaI: 100	1.0012	–
BEV 2007	NaI and $Na_2S_2O_3$ in HCHO	HCHO: 0.04 mol dm^{-3} $Na_2S_2O_3$: 130 μg g^{-1}	NaI: 60	1.00	–

† the ratio of the activity of the impurity to the activity of ^{131}I at the reference date

* negligible effect on the SIR measurement.

4. Results

All the submissions to the SIR since its inception in 1976 are maintained in a database known as the "master-file". The activity measurements for ^{131}I arise from forty-two ampoules and the SIR equivalent activity for each ampoule, A_{ei}, is given in Table 4 for each NMI, i. The dates of measurement in the SIR are given in Table 1.

As the half-life of the daughter radionuclide ^{131}Xe^{m} ($T_{1/2}$ of 11.93 d [3]) is longer than that of the parent, no transient equilibrium can be reached. However, the contribution of ^{131}Xe^{m} to the SIR ionization current is negligible for a period of up to about 8 weeks after the source production, because of the low branching ratio and gamma-emission probability.

The relative standard uncertainties arising from the measurements in the SIR are also shown. This uncertainty is additional to that declared by the NMI for the activity measurement shown in Table 2. Although activities submitted are compared with a given source of ^{226}Ra, all the SIR results are normalized to the radium source number 5 [1].

Measurements repeated at the BIPM after periods of up to about three weeks produced the same comparison results for the MKEH (1991), KRISS and for the BEV. Measurements repeated at the BIPM after periods of up to about five weeks produced comparison results in agreement within the standard uncertainty for MKEH (1983), IRA(1984), NMIJ, CMI-IIR and for the NIST (1998).

The most recent value from the NIST contained a larger activity of ^{131}I than earlier submissions and also was measured at the BIPM closer to the reference date than had been possible previously. This results in a reduced SIR uncertainty that together with the smaller NIST uncertainty produces a much smaller combined uncertainty than the 1979 submission. Consequently, the1998 result is used in the KCRV.

The IFIN-HH result from 2005, for which an additional correction factor was identified after the result had been reported, has been updated with a new submission from a recent standardization, which contained no radionuclide impurities. There was a significant delay between sending the ampoule and its receipt at the BIPM. However, the SIR measurements were made immediately on arrival of the ampoule and on the following day. These two results agreed to within 10^{-4} in spite of the decayed activity. As this ampoule was submitted after the CCRI meeting in May 2007, its inclusion in the KCRV will be considered in May 2009.

No recent submission has been identified as a pilot study so the most recent result of each NMI is normally eligible for Appendix B of the MRA. However, the NIRH no longer undertakes the metrology of activity and Indonesia laboratory (PTKMR) has not yet been designated for radiation measurements by the Indonesian NMI, therefore none of these results is included in the KCDB.

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

Table 4. Results of SIR measurements of ^{131}I

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
NIST 1977	3.665 65	7 170	3	40 780	8×10^{-4}	240
	3.676 07	7 190		40 790		240
1978	3.671 13	4 648	2	40 700	9×10^{-4}	260
1979	3.620 48	4 475	1	40 160	24×10^{-4}	280
1980	3.611 43	4 395	2	40 380	10×10^{-4}	250
1981	3.580 17	5 363	3	40 340	7×10^{-4}	190
1998	3.596 14	19 850	4	40 510	7×10^{-4}	150
PTB 1978	3.682 7 (1)	32 160	5	40 392	6×10^{-4}	66
1989	3.511 6	4 005	3	40 533	7×10^{-4}	67
1993	3.641 8	3 719	3	40 416	7×10^{-4}	85
	3.631 0	3 708		40 352†		85
2004	3.6115 (9)	43 222	5	40 372	6×10^{-4}	77
	3.6045 (9)	43 139		40 342†		77
BARC 1979	3.599 7	1 901	1	40 450	13×10^{-4}	200
1994	3.585 2	259.2	1	40 380	23×10^{-4}	160
NMISA 1980	3.649	22 510	4	40 440	6×10^{-4}	200
	3.585 *	22 580		40 430†		200
NPL 1980	3.701 4	6 899	3	40 320	7×10^{-4}	140
1999	3.721 70	3 750	2	40 210	10×10^{-4}	120
	3.690 49	3 719		40 150†	9×10^{-4}	120
MKEH 1983	3.604 4	3 702	3	40 010	8 × 10–4	260
1991	3.610 8	10 140	4	40 420	6 × 10–4	160
1998	3.617 4	9 398	4	40 330	7 × 10–4	130
IRA 1984	3.584 7 (1)	3 634	3	40 320	7 × 10–4	200
1996	3.363 6 (1)	3 453	2	40 270	10 × 10–4	210
PTKMR 1985	3.575	2 360	2	40 260	9 × 10–4	440
	3.574	2 360		40 200†	10 × 10–4	440
NMIJ 1986	3.602 6	2 822	3	40 320	8 × 10–4	110
	3.586 5	2 809		40 320†	7 × 10–4	110

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Table 4 continued. Results of SIR measurements of ^{131}I

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
CMI-IIR 1986	3.588 0	20 290	3	40 330	6×10^{-4}	110
2001	3.610 4	9 701	3	40 640	7×10^{-4}	170
2006	3.596 6	73 260	2	40 370	13×10^{-4}	120
LNE-LNHB 1987	3.623 94 3.621 13	2 116 2 114	3	40 313 40 298[†]	7×10^{-4} 8×10^{-4}	72 72
NIRH 1991	3.316	67 200	5	40 200	6×10^{-4}	1000
ANSTO 1994	3.584	6 491	2	40 410	10×10^{-4}	360
LNMRI 1999	3.510 04	11 610	3	40 690	8×10^{-4}	190
CIEMAT 2002	3.546 3	35 940	3	40 150	8×10^{-4}	190
IFIN-HH 2005	3.604 29	2 845	2	39 814	12×10^{-4}	220
2008	3.293 00	3 057	1	40 371	18×10^{-4}	139
KRISS 2005	3.61344	17 366	4	39 962	7×10^{-4}	91
BEV 2007	3.603 7	3 102	3	40 540	7×10^{-4}	160

[†] the mean of the two A_e values is used with an averaged uncertainty, as attributed to an individual entry [12]

* mass of active solution before dilution: 1.188 28 g and 1.192 01 g respectively.

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];

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

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) any 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. This was the case in May 2007.

Consequently, the KCRV for ^{131}I has been re-evaluated as 40 400 (40) kBq using the most recent results from the NMISA, NMIJ, LNE-LNHB, PTB, ANSTO, BARC, NIST, MKEH, NPL, LNMRI and the CIEMAT and the earlier results from the IRA (1984), ASMW (1989) and the CMI-IIR (2001).

4.2 Degrees of equivalence

Every NMI that has submitted ampoules to the SIR is entitled to have one result included in Appendix B of the KCDB as long as the NMI is a signatory or designated institute listed in the MRA. Normally, the most recent result is the one included. Any NMI may withdraw its result only if all the participants agree.

The degree of equivalence of a given measurement standard is the degree to which this standard is consistent with the key comparison reference value [2]. The degree of equivalence is expressed quantitatively in terms of the deviation from the key comparison reference value and the expanded uncertainty of this deviation ($k = 2$). The degree of equivalence between any pair of national measurement standards is expressed in terms of their difference and the expanded uncertainty of this difference and is independent of the choice of key comparison reference value.

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

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

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

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

taking correlations into account as appropriate [13].

4.2.2 *Comparison of any two NMIs with each other*

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

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

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

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

where any obvious correlations between the NMIs (such as a traceable calibration) are subtracted using the covariance $u(A_{ei}, A_{ej})$, as are normally those correlations coming from the SIR.

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

Table 5 shows the matrix of all the degrees of equivalence as they will appear in the Key and Supplementary Comparisons section (Appendix B) of the CIPM MRA 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 the black squares indicate results obtained prior to 1987. 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 such as the correlation between BEV and NPL.

Conclusion

The BIPM ongoing key comparison for ^{131}I, BIPM.RI(II)-K1.I-131 currently comprises sixteen results. These have been analysed with respect to the revised KCRV determined for this radionuclide, and with respect to each other. The matrix of degrees of equivalence has been approved by the CCRI(II) and is published in the BIPM key comparison database. Other results may be added as and when other NMIs contribute ^{131}I activity measurements to this comparison.

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Table 5. Table of degrees of equivalence and introductory text for ^{131}I

Key comparison BIPM.RI(II)-K1.I-131

MEASURAND : **Equivalent activity of ^{131}I**

Key comparison reference value: the SIR reference value x_R for this radionuclide is 40 400 kBq, with a standard uncertainty, u_R = 40 kBq (see Section 4.1 of the Final Report). the value x_i is taken as the equivalent activity for laboratory *i*.

The degree of equivalence of each laboratory with respect to the reference value is given by a pair of terms: $D_i = (x_i - x_R)$ and U_i, its expanded uncertainty ($k = 2$), both expressed in MBq, and $U_i = 2((1 - 2/n)u_i^2 + (1/n^2)\Sigma u_i^2)^{1/2}$ when each laboratory has contributed to the calculation of x_R, with n the number of laboratories.

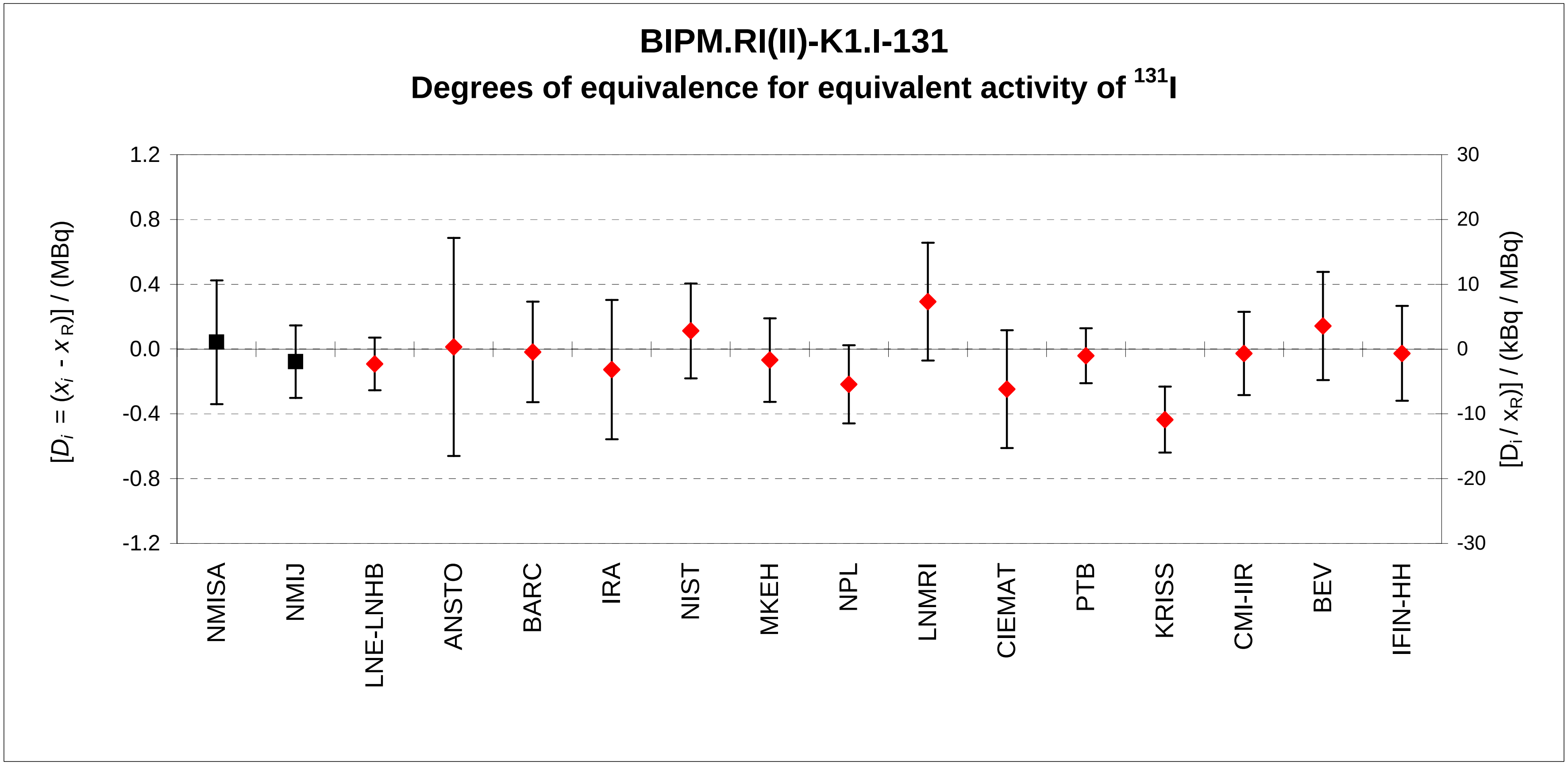
The degree of equivalence between two laboratories is given by a pair of numbers: $D_{ij} = D_i - D_j = (x_i - x_j)$ and U_{ij}, its expanded uncertainty ($k = 2$), both expressed in MBq. The approximation $U_{ij}^2 \sim 2^2(u_i^2 + u_j^2)$ is used in the following table.

Lab *j* ⇨

Lab *i* ⇩	D_i / MBq	U_i	**NMISA**		**NMIJ**		**LNE-LNHB**		**ANSTO**		**BARC**		**IRA**		**NIST**		**MKEH**	
			D_{ij} / MBq	U_{ij}	D_{ij} / MBq	U_{ij}	D_{ij} / MBq	U_{ij}	D_{ij} / MBq	U_{ij}	D_{ij} / MBq	U_{ij}	D_{ij} / MBq	U_{ij}	D_{ij} / MBq	U_{ij}	D_{ij} / MBq	U_{ij}
NMISA	**0.04**	0.38			**0.12**	0.46	**0.13**	0.43	**0.03**	0.82	**0.06**	0.51	**0.17**	0.58	**-0.07**	0.50	**0.11**	0.48
NMIJ	**-0.08**	0.22	**-0.12**	0.46			**0.01**	0.26	**-0.09**	0.75	**-0.06**	0.39	**0.05**	0.47	**-0.19**	0.37	**-0.01**	0.34
LNE-LNHB	**-0.09**	0.16	**-0.13**	0.43	**-0.01**	0.26			**-0.10**	0.73	**-0.07**	0.35	**0.04**	0.44	**-0.20**	0.33	**-0.02**	0.30
ANSTO	**0.01**	0.67	**-0.03**	0.82	**0.09**	0.75	**0.10**	0.73			**0.03**	0.79	**0.14**	0.83	**-0.10**	0.78	**0.08**	0.77
BARC	**-0.02**	0.31	**-0.06**	0.51	**0.06**	0.39	**0.07**	0.35	**-0.03**	0.79			**0.11**	0.53	**-0.13**	0.44	**0.05**	0.41
IRA	**-0.13**	0.43	**-0.17**	0.58	**-0.05**	0.47	**-0.04**	0.44	**-0.14**	0.83	**-0.11**	0.53			**-0.24**	0.52	**-0.06**	0.49
NIST	**0.11**	0.29	**0.07**	0.50	**0.19**	0.37	**0.20**	0.33	**0.10**	0.78	**0.13**	0.44	**0.24**	0.52			**0.18**	0.40
MKEH	**-0.07**	0.26	**-0.11**	0.48	**0.01**	0.34	**0.02**	0.30	**-0.08**	0.77	**-0.05**	0.41	**0.06**	0.49	**-0.18**	0.40		
NPL	**-0.22**	0.24	**-0.26**	0.47	**-0.14**	0.33	**-0.13**	0.28	**-0.23**	0.76	**-0.20**	0.40	**-0.09**	0.48	**-0.33**	0.38	**-0.15**	0.35
LNMRI	**0.29**	0.36	**0.25**	0.55	**0.37**	0.44	**0.38**	0.41	**0.28**	0.81	**0.31**	0.50	**0.42**	0.57	**0.18**	0.48	**0.36**	0.46
CIEMAT	**-0.25**	0.36	**-0.29**	0.55	**-0.17**	0.44	**-0.16**	0.41	**-0.26**	0.81	**-0.23**	0.50	**-0.12**	0.57	**-0.36**	0.48	**-0.18**	0.46
PTB	**-0.04**	0.17	**-0.08**	0.43	**0.04**	0.27	**0.05**	0.21	**-0.05**	0.74	**-0.02**	0.36	**0.09**	0.45	**-0.15**	0.34	**0.03**	0.30
KRISS	**-0.44**	0.20	**-0.48**	0.44	**-0.36**	0.29	**-0.34**	0.23	**-0.45**	0.74	**-0.42**	0.37	**-0.31**	0.46	**-0.55**	0.35	**-0.37**	0.32
CMI-IIR	**-0.03**	0.26	**-0.07**	0.47	**0.05**	0.33	**0.06**	0.28	**-0.04**	0.76	**-0.01**	0.40	**0.10**	0.48	**-0.14**	0.38	**0.04**	0.35
BEV	**0.14**	0.33	**0.10**	0.51	**0.22**	0.39	**0.23**	0.35	**0.13**	0.79	**0.16**	0.45	**0.27**	0.53	**0.03**	0.44	**0.21**	0.41
IFIN-HH	**-0.03**	0.29	**-0.07**	0.49	**0.05**	0.35	**0.07**	0.31	**-0.04**	0.77	**-0.01**	0.42	**0.10**	0.50	**-0.14**	0.41	**0.04**	0.38

Lab *i* ⇩	D_i / MBq	U_i	**NPL**		**LNMRI**		**CIEMAT**		**PTB**		**KRISS**		**CMI-IIR**		**BEV**		**IFIN-HH**	
			D_{ij} / MBq	U_{ij}	D_{ij} / MBq	U_{ij}	D_{ij} / MBq	U_{ij}	D_{ij} / MBq	U_{ij}	D_{ij} / MBq	U_{ij}	D_{ij} / MBq	U_{ij}	D_{ij} / MBq	U_{ij}	D_{ij} / MBq	U_{ij}
NMISA	**0.04**	0.38	**0.26**	0.47	**-0.25**	0.55	**0.29**	0.55	**0.08**	0.43	**0.48**	0.44	**0.07**	0.47	**-0.10**	0.51	**0.07**	0.49
NMIJ	**-0.08**	0.22	**0.14**	0.33	**-0.37**	0.44	**0.17**	0.44	**-0.04**	0.27	**0.36**	0.29	**-0.05**	0.33	**-0.22**	0.39	**-0.05**	0.35
LNE-LNHB	**-0.09**	0.16	**0.13**	0.28	**-0.38**	0.41	**0.16**	0.41	**-0.05**	0.21	**0.34**	0.23	**-0.06**	0.28	**-0.23**	0.35	**-0.07**	0.31
ANSTO	**0.01**	0.67	**0.23**	0.76	**-0.28**	0.81	**0.26**	0.81	**0.05**	0.74	**0.45**	0.74	**0.04**	0.76	**-0.13**	0.79	**0.04**	0.77
BARC	**-0.02**	0.31	**0.20**	0.40	**-0.31**	0.50	**0.23**	0.50	**0.02**	0.36	**0.42**	0.37	**0.01**	0.40	**-0.16**	0.45	**0.01**	0.42
IRA	**-0.13**	0.43	**0.09**	0.48	**-0.42**	0.57	**0.12**	0.57	**-0.09**	0.45	**0.31**	0.46	**-0.10**	0.48	**-0.27**	0.53	**-0.10**	0.50
NIST	**0.11**	0.29	**0.33**	0.38	**-0.18**	0.48	**0.36**	0.48	**0.15**	0.34	**0.55**	0.35	**0.14**	0.38	**-0.03**	0.44	**0.14**	0.41
MKEH	**-0.07**	0.26	**0.15**	0.35	**-0.36**	0.46	**0.18**	0.46	**-0.03**	0.30	**0.37**	0.32	**-0.04**	0.35	**-0.21**	0.41	**-0.04**	0.38
NPL	**-0.22**	0.24			**-0.51**	0.45	**0.03**	0.45	**-0.18**	0.29	**0.22**	0.30	**-0.19**	0.34	**-0.36**	0.25	**-0.19**	0.37
LNMRI	**0.29**	0.36	**0.51**	0.45			**0.54**	0.54	**0.33**	0.41	**0.73**	0.42	**0.32**	0.45	**0.15**	0.50	**0.32**	0.47
CIEMAT	**-0.25**	0.36	**-0.03**	0.45	**-0.54**	0.54			**-0.21**	0.41	**0.19**	0.42	**-0.22**	0.45	**-0.39**	0.50	**-0.22**	0.47
PTB	**-0.04**	0.17	**0.18**	0.29	**-0.33**	0.41	**0.21**	0.41			**0.40**	0.24	**-0.01**	0.29	**-0.18**	0.36	**-0.01**	0.32
KRISS	**-0.44**	0.20	**-0.22**	0.30	**-0.73**	0.42	**-0.19**	0.42	**-0.40**	0.24			**-0.41**	0.30	**-0.58**	0.37	**-0.41**	0.33
CMI-IIR	**-0.03**	0.26	**0.19**	0.34	**-0.32**	0.45	**0.22**	0.45	**0.01**	0.29	**0.41**	0.30			**-0.17**	0.40	**0.00**	0.37
BEV	**0.14**	0.33	**0.36**	0.25	**-0.15**	0.50	**0.39**	0.50	**0.18**	0.36	**0.58**	0.37	**0.17**	0.40			**0.17**	0.42
IFIN-HH	**-0.03**	0.29	**0.19**	0.37	**-0.32**	0.47	**0.22**	0.47	**0.01**	0.32	**0.41**	0.33	**0.00**	0.37	**-0.17**	0.42		

Figure 1. Graph of degrees of equivalence with the KCRV for ^{131}I
(as it appears in Appendix B of the MRA)



N.B. The right hand scale shows approximate relative values only

Appendix 1. Uncertainty budgets for the activity of ^{131}I submitted to the SIR

Uncertainty budget for the IFIN-HH (2005) [The 2007 budget is on page 22]

Relative standard uncertainties	$u_i \times 10^4$ evaluated by method	
Contributions due to	**A**	**B**
counting statistics	17	–
weighing	–	15
dead time	–	5
coincidence resolving time	–	15
background	–	2
half-life	–	6
extrapolation of efficiency curve	10	–
radionuclide impurities	–	45
Quadratic summation	**20**	**50**
Relative combined standard uncertainty, u_c	**54**	

KRISS Uncertainty budget for ^{131}I (2005)

Relative standard uncertainties	$u_i \times 10^4$ evaluated by method	
Contribution due to	**A**	**B**
counting statistics	4	–
weighing, dilution	–	15
dead time	–	2
resolving time	–	6
counting time	–	0.1
background	–	5
half-life	–	2
extrapolation of efficiency curve	–	13
Quadratic summation	**4**	**22**
Relative combined standard uncertainty, u_c	**22**	

Uncertainty budget for ^{131}I at the CMI-IIR (2006)

Relative standard uncertainties	$u_i \times 10^4$ evaluated by method	
Contribution due to	**A**	**B**
counting statistics	10	–
weighing	–	5
dead time	–	5
counting time	–	1
pile up	–	1
background	–	12
adsorption	–	5
radionuclide impurities	–	5
half-life	–	1
extrapolation of efficiency curve	–	21
ionization chamber	10	–
Quadratic summation	**10**	**26**
Relative combined standard uncertainty, u_c	**28**	

Uncertainty budget for the BEV (2007)

Relative standard uncertainties	$u_i \times 10^4$ evaluated by method	
Contributions due to	**A**	**B**
counting statistics	7.3	–
current measurement	–	10
weighing, dilution	–	5.0
background	0.1	–
half-life	–	1.1
calibration factor	–	33.3
ionization chamber calibration	–	10
Quadratic summation	**7**	**37**
Relative combined standard uncertainty, u_c	**38**	

Uncertainty budget for the IFIN-HH (2007)

Relative standard uncertainties	$u_i \times 10^4$ evaluated by method	
Contributions due to	**A**	**B**
counting statistics	17	–
weighing	–	15
dead time	–	5
coincidence resolving time	–	15
background	–	2
half-life	–	4
extrapolation of efficiency curve	10	–
radionuclide impurities	–	–
Quadratic summation	**20**	**22**
Relative combined standard uncertainty, u_c	**30**	

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