Update of the BIPM comparison BIPM.RI(II)-K1.Na-22 of activity measurements of the radionuclide ^{22}Na to include the 2022 result of the NMISA (South Africa)

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Abstract Since 1976, 13 laboratories have submitted 30 samples of ^{22}Na 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.Na-22. Recently, the NMISA (South Africa) 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 representation is also given.

1. Introduction

The SIR for activity measurements of γ-ray-emitting radionuclides was established in 1976. Each national metrology institute (NMI) may request a standard ampoule from the BIPM that is then filled with 3.6 g of the radioactive solution. For radioactive gases, a different standard ampoule is used. Each NMI completes a 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 2022, the SIR has been used to measure 1045 ampoules to give 799 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.Na-22 key comparison. The results of earlier participations in this key comparison were published previously [3–6].

2. Participants

Laboratory details are given in Table 1, with the earlier submissions being taken from [3–6]. The dates of measurement in the SIR given in Table 1 are used in the KCDB and all references in this report.

Table 1: Details of the participants in the BIPM.RI(II)-K1.Na-22.

NMI or laboratory	**Previous acronyms or other institutes**	**Full name**	**Country**	**Regional Metrology Organization (RMO)**	**Date of SIR measurement** yyyy-mm-dd
ANSTO	AAEC	Australian Nuclear Science and Technology Organisation	Australia	APMP	1981-09-10 1993-12-16
ASMW	-	Amt für Standardisierung, Meßwesen und Warenprüfung	former East Germany	-	1977-11-24
BARC	-	Bhabha Atomic Research Centre	India	APMP	2004-07-13
BEV	IRK	Bundesamt fur Eich- und Vermessungswesen	Austria	EURAMET	2001-10-01
BKFH	OMH, MKEH	Government Office of the Capital City Budapest	Hungary	EURAMET	1977-05-25 1985-07-10
CIEMAT	-	Centro de Investigaciones Energéticas, Medioambientales y Tecnologicas	Spain	EURAMET	2006-05-12
CMI	UVVVR, CMI-IIR	Czech Metrological Institute	Czechia	EURAMET	1977-05-13 1979-05-15
LNE-LNHB	LMRI, LPRI, BNM-LNHB	Université Paris-Saclay, CEA, List, Laboratoire National Henri Becquerel	France	EURAMET	1980-02-06 1994-06-09 2014-07-03

... Continuation of Table 1.

NMI or laboratory	**Previous acronyms or other institutes**	**Full name**	**Country**	**RMO**	**Date of SIR measurement** yyyy-mm-dd
NIST	NBS	National Institute of Standards and Technology	United States	SIM	1983-07-19
NMIJ	ETL	National Metrology Institute of Japan	Japan	APMP	1976-11-23 1993-11-25
NMISA	NAC, CSIR-NML[a]	National Metrology Institute of South Africa	South Africa	AFRIMETS	1980-04-10 1984-11-05 2007-02-09 2022-11-25
NPL	-	National Physical Laboratory	United Kingdom	EURAMET	1977-01-04
PTB	-	Physikalisch-Technische Bundesanstalt	Germany	EURAMET	1980-07-21 2006-05-22

[a] NAC is another institute in the country now named iThemba LABS.

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 [3–6]. The list of acronyms used to summarize the methods is given in Appendix E.

Since 2004, the half-life used by the BIPM is 950.8(9) days as published in IAEA TECDOC-619 [7]. The half-life of 950.4(15) days [8] was used for the earlier results.

The standardization methods used by participating laboratories require that the branching ratio ^{22}Na β^+ be used to calculate activity. Usually taken into account in uncertainty budgets, the value used by laboratories could help in the evaluation and updating of the KCRV. It will be requested in future submissions to the BIPM.RI(II)-K1-Na-22 comparison. NMISA used a β^+ branching ratio of 89.892 % in its 2006 submission and a ratio equal to 90.355 % in 2022 [9].

Table 2: Standardization methods of the participants for ^{22}Na.

NMI or laboratory	Method used and the acronym	Activity A_i/kBq	Relative standard uncertainty /10^{-2} A	B	Reference date yyyy-mm-dd	Half-life /d
ANSTO	$4\pi\beta$-γ coincidence (4P-PC-PO-NA-GR-CO)	404.8	0.1	0.36	1981-08-15 00:00 UT	-
	$4\pi\beta$-γ coincidence (4P-PC-PO-NA-GR-CO)	592.8	0.22	0.06	1991-03-17 23:00 UT	
ASMW	$4\pi\beta$-γ coincidence (4P-PC-PO-NA-GR-CO)	2575.4[d]	0.15	0.15	1977-10-21 12:00 UT	
		2602.4	0.15	0.15		
BARC	Ionization chamber calibrated traceable to NIST (4P-IC-GR-00-00-00)	1351	0.1	1.1	2004-02-16 06:30 UT	950.3602
	$4\pi\beta$-γ coincidence (4P-PC-BP-NA-GR-CO)	1364	0.30	0.22		
BEV	Ionization chamber calibrated traceable to NPL (4P-IC-GR-00-00-00)	691.8	0.08	0.4	2001-09-01 00:00 UT	950.5
BKFH	$4\pi\beta$-γ coincidence (4P-PC-PO-NA-GR-CO)	1384.3[d]	0.2	0.6	1977-04-30 12:00 UT	950.4(15) [8]
		1384.3	0.2	0.6		
	$4\pi\beta$-γ coincidence (4P-PC-PO-NA-GR-CO)	3626	0.04	0.36	1985-07-01 12:00 UT	950.4(4) [12]
CIEMAT	$4\pi\beta$-γ coincidence and $4\pi\gamma$ NaI(Tl) well counter (4P-PP-PO-NA-GR-CO & 4P-NA-GR-00-00)	342.4	0.37		2006-01-01 00:00 UT	950.6(4) [13]
CMI	$4\pi\beta$-γ coincidence (4P-PC-PO-NA-GR-CO)	3993	0.06	0.4	1977-04-14 13:00 UT	-
	$4\pi\beta$-γ coincidence (4P-PC-PO-NA-GR-CO)	4198	0.2	0.4	1979-03-19 11:00 UT	949.7
LNE-LNHB	4π(NaI) γ counting (4P-NA-GR-00-00-00)	1765.8[d]	0.01	0.2	1979-11-27 12:00 UT	950.4(4) [12]
		1747.5	0.01	0.2		
	$4\pi\beta$-γ coincidence (4P-PC-PO-GH-GR-CO)	653.7[d]	0.14	0.19	1994-05-18 12:00 UT	950.6(3)
		652.3	0.14	0.19		
	Anti-coincidence counting (4P-PC-MX-NA-GR-AC)	1684.01	0.22	0.05	2014-06-16 12:00 UT	950.7(3)
	TDCR (4P-LS-MX-00-00-TD)	1684.01	0.13	0.27		
	$4\pi\gamma$ counting (4P-NA-GR-00-00-00)	1681.37	0.10	0.27		

... Continuation of Table 2.

NMI or laboratory	**Method used and the acronym**	**Activity** A_i/**kBq**	**Relative standard uncertainty /10^{-2}**		**Reference date**	**Half-life /d**
			A	**B**	**yyyy-mm-dd**	
NIST	Ionization chamber calibrated in 1969 using $4\pi\beta$-γ coincidence and annihilation-γ coincidence (4P-PP-MX-NA-GR-CO & 4P-NA-GR-NA-GR-CO)	3206	0.04	0.53	1983-06-06 14:00 UT	-
NMIJ	$4\pi\beta$-γ coincidence (4P-PC-PO-NA-GR-CO)	1897.4[d]	0.02	0.28	1976-11-01 12:00 UT	
		1908.5	0.02	0.28		
	$4\pi\beta$-γ coincidence (4P-PC-PO-NA-GR-CO)	1813	0.4	0.3	1993-11-01 00:00 UT	
NMISA	4π (liquid scintillation) β-γ coincidence (4P-LS-PO-NA-GR-CO)[a]	10 803[d]	0.04	0.23	1980-03-18 10:00 UT	950.4
		12 087	0.04	0.23		
	4π (liquid scintillation) β-γ coincidence (4P-LS-PO-NA-GR-CO)[a]	19 830	0.11	0.16	1984-10-24 12:00 UT	
	4π (liquid scintillation) β-γ coincidence (4P-LS-PO-NA-GR-CO)	604.9	0.05	0.16	2006-08-16 06:00 UT	950.6(4) [13]
	4π-positron-γ coincidence counting (4P-LS-PO-NA-GR-CO)	956.9	0.04	0.25	2022-10-11 10:00 UT	950.7(3) [9]
NPL	Ionization chamber calibrated using NPL primary standard (4P-IC-GR-00-00-00)	591.6[d]	0.15	1.98	1976-12-20 00:00 UT	-
		592.8	0.15	1.98		
PTB	$4\pi\beta$-γ coincidence (4P-PC-PO-NA-GR-CO)	3622.1	0.04	0.1	1980-05-01 00:00 UT	
	$4\pi\beta-\gamma$ coincidence[c] and CIEMAT-NIST (4P-PC-PO-NA-GR-CO & 4P-LS-MX-00-00-CN)[e]	6779.0[c2]	0.08	0.18	2006-01-01 00:00 UT	950.5(4)

[a] see details in [10]
[c] with distance variation of the NaI detector
[c2] weighted mean of the two measurements taking into account correlation due to weighing (same balance)
[d] Several samples submitted
[e] see details in [11]

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 ^{22}Na submitted.

NMI or laboratory / SIR year	**Chemical composition**	**Solvent conc.** /(mol dm^{-3})	**Carrier conc.** /(µg g^{-1})	**Density** /(g cm^{-3})	**Relative activity of any impurity**[a]
ANSTO 1981	NaCl in HCl	0.1	NaCl: 200	1	<0.05 %
1993	^{22}Na in HCl	0.1	-	-	-
ASMW 1977	NaCl in HCl	0.1	NaCl: 20	-	<0.1 %
BARC 2004	NaCl in HCl	0.1	NaCl: 25	1	-
BEV 2001	NaCl in HCl	0.1	NaCl: 50	1	-
BKFH 1977	Na in HCl	0.1	Na: 25	-	<0.03 %
1985	Na in HCl	0.1	Na: 25	-	-
CIEMAT 2006	NaCl in HCl	0.1	NaCl: 50	1	-
CMI 1977	NaCl in water	-	NaCl:50	1	<0.1 %
1979	NaCl in HCl	0.08	NaCl:50	-	<0.1 %
LNE-LNHB 1980	NaCl in HCl	0.1	NaCl: 10	0.999	<0.0001 %
1994	NaCl in HCl	1	NaCl: 100	1.016	-
2014	NaCl in HCl	0.1	NaCl:10	1.0001	None detected
NIST 1983	NaCl in HCl	1	NaCl: 81	1.014	-
NMIJ 1976	NaCl in HCl	0.1	NaCl:50	-	-
1993	NaCl in HCl	0.1	NaCl:50	1	-
NMISA 1980	NaCl in HCl	1	Na^+: 395	1.036	-
1984	NaCl in HCl	1	Na^+:224	1.0169	-
2007	NaCl in HCl	1	Na^+: 200	1.018	-
2022	NaCl in HCl	0.1	NaCl:?[b]	1	None detected
NPL 1977	NaCl in HCl	0.1	NaCl:100	-	<0.03 %
PTB 1980	NaCl in HCl	0.1	NaCl: 50	1	-
2006	NaCl in HCl	0.1	NaCl: 50	1	-

[a] The ratio of the activity of the impurity to the activity of ^{22}Na at the reference date
[b] The supplier could not inform of NaCl carrier concentration.

4. Results

All the submissions to the SIR since its inception in 1976 are maintained in a dedicated database [14]. The latest submission has added 1 ampoule for the activity measurements for ^{22}Na giving rise to 30 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 ^{226}Ra, all the SIR results are normalized to the radium source number 5 [1]. Table 4 also shows the comparison results selected for the KCRV as explained in section 4.1.

Table 4: Results of SIR measurement of ^{22}Na.

NMI or laboratory / SIR year	Mass m_i /g	A_i /kBq	^{226}**Ra source**	$A_{\mathbf{e}i}$ /kBq	**Relative uncert. from SIR** /10^{-4}	$u_{\mathbf{c}i}$ /kBq	$A_{\mathbf{e}i}$ **for KCRV** /kBq
ANSTO 1981	3.596	404.8	3	7535	7	28	7535(28)
1993	3.728 27	592.8	2	7671	14[a]	21	-
ASMW 1977	3.502 01	2575.4	4	7503	4	16	7502(16)[f]
	3.538 71	2602.4	4	7501	4	16	-
BARC 2004	3.635 34	1351	3	7506	5	80	7579(29)[g]
		1364		7579		29	-
BEV 2001	3.597 3	691.8	3	7490	6	31	-
BKFH 1977	3.605 8	1384.3	3	7547	6	44	-
	3.605 9	1384.3	3	7542	6	44	-
1985	3.603 9	3626	5	7525	4	27	7525(27)
CIEMAT 2006	3.645 8	342.4	2	7523	9	29	7523(29)
CMI 1977	3.530 96	3993	4	7526	5	31	-
1979	3.662 81	4198	4	7537	5	34	7537(34)
LNE-LNHB 1980	3.610 99	1765.8	4	7528	5	16	-
	3.573 69	1747.5	4	7530	5	16	-
1994	3.567 4	653.7	3	7534	6	18	-
	3.559 4	652.3	3	7536	6	18	-
2014	3.777 5	1684.01	4	7533[c]	5	17	7533(17)
		1684.01		7533		23	-
		1681.37		7521		22	-
NIST 1983	3.725 58	3206	4	7496	3	40	7496(40)
NMIJ 1976	3.605 81	1897.4	4	7518	4	22	-
	3.626 86	1908.5	4	7516	4	22	-
1993	3.608 55	1813	4	7543	5	38	7543(38)
NMISA 1980	3.594[d]	10 803	5	7477	4	18	-
	3.610	12 087	5	7475	4	18	-
1984	3.619 52[e]	19 830	5	7527	4	15	-
2007	3.648 58	604.9	3	7568	6	14	-
2022	3.716 22	956.9	3	7496	6	19	7496(19)
NPL 1977	3.549 0	591.6	3	7538	5	150	7540(150)[f]
	3.555 9	592.8	3	7542	5	150	-
PTB 1980	3.673 2	3622.1	4	7528	4	9	-
2006	3.600 44(9)	6779	5	7523	4	15	7523(15)

[a] large SIR uncertainty due to the delay between the SIR measurement and the reference date
[c] The result 7533(17) kBq from anti-coincidence counting is used in the KCDB.
[d] masses before dilution were 94.17 mg and 105.36 mg, respectively.
[e] mass before dilution was 198.954 mg.
[f] An average value and average uncertainty between all submitted samples is used for the KCDB [15].
[g] Primary result

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 [16] rather than an unweighted mean, as had been the policy. This type of weighted mean is similar to a Mandel-Paule mean in that the NMIs' uncertainties may be increased until the reduced chi-squared value is one. In addition, it allows for a power α smaller than two in the weighting factor. As proposed in [16], α is taken as $2 - 3/N$ where N is the number of results selected for the KCRV. Therefore, all SIR key comparison results can be selected for the KCRV with the following provisions:

(a) results for solutions standardized by only 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 use only one result (normally the most recent result or the mean if more than one ampoule is submitted);
(c) results more than 20 years old are included in the calculation of the KCRV but are not included in data shown in the KCDB or in the plots in this report, as they have expired;
(d) possible outliers can be identified on a mathematical basis and excluded from the KCRV using the normalized error test with a test value of 2.5 and using the modified uncertainties;
(e) results can also be excluded for technical reasons; and
(f) the CCRI(II) is always the final arbiter regarding excluding any data from the calculation of the KCRV.

Although the KCRV may be modified when other NMIs participate, on the advice of the Key Comparison Working Group of the CCRI(II), such modifications are made only by the CCRI(II) during one of its biennial meetings, or by consensus through electronic means (e.g., email) as discussed at the CCRI(II) meeting in 2013.

Consequently, using the recent result produces an updated KCRV for ^{22}Na in 2022 of **7522.4(69) kBq** with the power α =1.75 that has been calculated using the previously published results, selected as shown in Table 4, for the ASMW (1977), NPL (1977), CMI (1979), ANSTO (1981), NIST (1983), BKFH (1985), NMIJ (1993), BARC (2004, primary result only), CIEMAT (2006), PTB (2006), LNE-LNHB (2014), and the present NMISA (2022) result. This can be compared with the previous KCRV values of 7526(5) kBq published in 2003 [3] , 7534(7) kBq published in 2010 [5] and 7534.0(73) kBq published in 2020 [6].

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). 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]. An NMI may withdraw its result only if all other participants agree.

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

4.2.1. Comparison of a given NMI result with the KCRV

The degree of equivalence of the result of a particular NMI, i, with the key comparison reference value is expressed as the difference D_i between the values

$$D_i = A_{\mathrm{e}i} - \mathrm{KCRV} \tag{1}$$

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

$$U_i = 2u(D_i) \tag{2}$$

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

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

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

$$u^2(D_i) = u_i^2 + u^2(\mathrm{KCRV}) \tag{4}$$

The introductory text in Appendix A is the one agreed by the CCRI(II) for all the K1 comparisons.

4.2.2. Comparison between pairs of NMI results

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

$$D_{ij} = D_i - D_j = A_{\mathrm{e}i} - A_{\mathrm{e}j} \tag{5}$$

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

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

where any obvious correlations between the NMIs (such as a traceable calibration, 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 [17] 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 ^{22}Na, BIPM.RI(II)-K1.Na-22, currently comprises 5 results. The KCRV has been recalculated to include the latest result from the NMISA (South Africa). The results have been analyzed with respect to the updated KCRV, providing degrees of equivalence for 5 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 ^{22}Na activity measurements to this comparison or take part in other linked comparisons.

6. References

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Appendix A. Introductory text for ^{22}Na degrees of equivalence

Key comparison BIPM.RI(II)-K1.Na-22

MEASURAND: Equivalent activity of ^{22}Na

Key comparison reference value: the SIR reference value x_{R} for this radionuclide is 7522.4 kBq , with a standard uncertainty, u_{R} equal to 6.9 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: $D_i = (x_i - x_{\mathrm{R}})$ and U_i, its expanded uncertainty ($k = 2$), both expressed in kBq, and $U_i = 2((1 - 2w_i)u_i^2 + u_{\mathrm{R}}^2)^{1/2}$, where w_i is the weight of laboratory i contributing to the calculation of x_{R}.

Appendix B. Table of degrees of equivalence for BIPM.RI(II)-K1.Na-22

Table B1: The table of degrees of equivalence for BIPM.RI(II)-K1.Na-22

NMI i	D_i **/kBq**	U_i **/kBq**
BARC	48	56
CIEMAT	1	56
PTB	1	27
LNE-LNHB	11	32
NMISA	-26	36

Appendix C. Graph of degrees of equivalence with the KCRV for ^{22}Na (as it appears in Appendix B of the MRA)

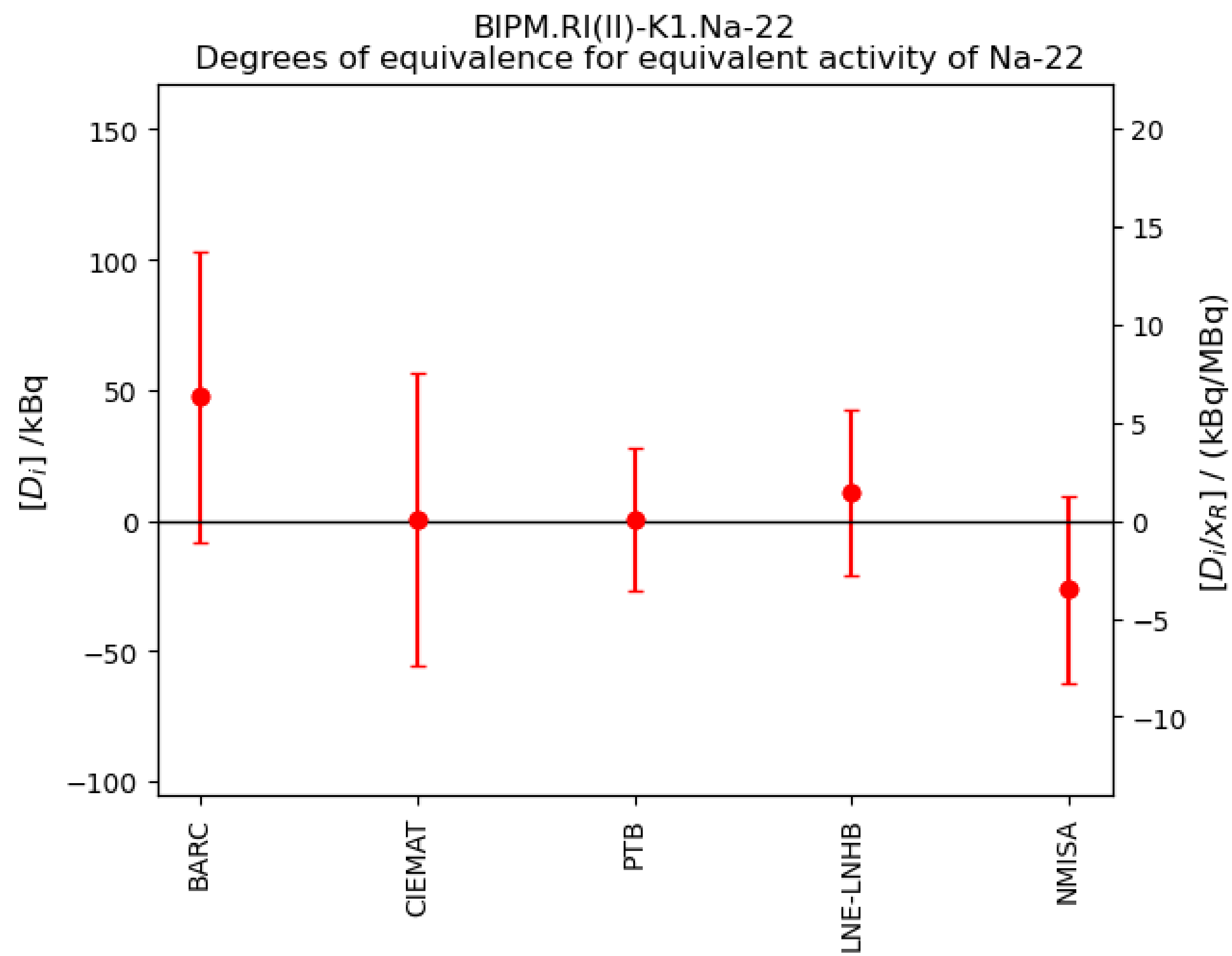

Figure C1. Degrees of equivalence for equivalent activity of ^{22}Na.

Appendix D. Uncertainty budgets for the activity of ^{22}Na submitted to the SIR

Uncertainty budget from the NMISA

SIR/SIRTI reporting form - radioactive solution

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

Measurement method	4pi-positron-gamma coincidence counting	
ACRONYM	4P-LS-PO-NA-GR-CO	**Comments:**
Activity concentration at reference date / kBq g^{-1}	257.48	
Relative standard uncertainty / 10^{-2}	0.26	
Date of measurement at the NMI (YYYY-MM-DD)	2022-10-11/12	

For relative methods:

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

Uncertainty budget

Uncertainty component	**Relative uncertainty / 10^{-2}**	**Evaluation type (A or B)**	**Comment**
Counting statistics	0.04	A	Standard deviation of the mean of 17 values
Background	0.05	B	BG square root statistics
Weighing	0.05	B	Mass from primary and ampoule preparation
Dilution			Added in weighing component
Dead time	0.01	B	From dead time uncertainty
Resolving time	0.03	B	From coincidence resolving time uncertainty
Pile-up, afterpulse	0.12	B	From afterpulse uncertainty
Adsorption	0.01	B	Count rates after multiple rinsings
Impurities	0		HPGe GS measurement
Decay correction	0.00001	B	From half-life uncertainty
Decay data	0.08	B	From unc in B+ branching ratio used
Extra-/Inter-polation of efficiency curve	0.19	B	Difference between 1st and 2nd order fits
Quenching, kB value			
Tracer			
Reproducibility			
Counting time	0.001	B	From timer calibration
Gamma-ray interaction prob	0.02	B	1275 keV gamma-ray interaction probability in LS
Combined standard uncertainty	**0.26**		

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.

Geometry	**acronym**	**Detector**	**acronym**
4 π	4P	proportional counter	PC
defined solid angle	SA	press. Prop. Counter	PP
2 π	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

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	anticoincidence	AC
gamma rays	GR	coincidence counting with efficiency tracing	CT
x-rays	XR	anticoincidence 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

Examples of methods	**acronym**
4π(PC)β-γ coincidence counting	4P-PC-BP-NA-GR-CO
4π(PPC)β-γ coincidence counting eff. trac	4P-PP-MX-NA-GR-CT
defined solid angle α-particle counting with a PIPS detector	SA-PS-AP-00-00-00
4π(PPC)AX-γ(GeHP)-anticoincidence counting	4P-PP-MX-GH-GR-AC
4πCsI-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