

**Update report of the BIPM comparison BIPM.RI(II)-K1.Na-22 of
activity measurements of the radionuclide ^{22}Na to include
the CIEMAT, PTB and the NMISA**

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Abstract

Since 1976, twelve national metrology institutes (NMIs) have submitted 29 samples of known activity of ^{22}Na to the International Reference System (SIR) for activity comparison at the Bureau International des Poids et Mesures (BIPM). The activities ranged from about 300 kBq to 20 MBq. The degrees of equivalence between each equivalent activity measured in the SIR and the key comparison reference value (KCRV) have been calculated and the results are given in the form of a matrix for nine NMIs. A graphical presentation is also given of this BIPM.RI(II)-K1.Na-22 comparison.

1. Introduction

The SIR for activity measurements of γ -ray-emitting radionuclides was established in 1976. Each NMI may request a standard ampoule from the BIPM that is then filled (3.6 g) with the radionuclide in liquid form. For radioactive gases, a different standard ampoule is used. The NMI completes a submission form that details the standardization method used to determine the absolute activity of the radionuclide and the full uncertainty budget for the evaluation. The ampoules are sent to the BIPM where they are compared with standard sources of ^{226}Ra using pressurized ionization chambers. Details of the SIR method, experimental set-up and the determination of the equivalent activity, A_e , are all given in [1].

From its inception until 31 December 2008, the SIR has measured 914 ampoules to give 670 independent results for 63 different radionuclides. The SIR makes it possible for national laboratories to check the reliability of their activity measurements at any time. This is achieved by the determination of the equivalent activity of the radionuclide and by comparison of the result with the key comparison reference value determined from the results of primary standardizations. These comparisons are described as BIPM ongoing comparisons and the results form the basis of the BIPM key comparison database (KCDB) of the CIPM Mutual Recognition Arrangement (CIPM MRA) [2]. The report updates the comparison results previously published for the BIPM.RI(II)-K1.Na-22 key comparison [3, 4].

2. Participants

Twelve NMIs have submitted 29 ampoules for the comparison of ^{22}Na activity measurements since 1976. Another laboratory participated in 1980 but withdrew its result. The laboratory 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.Na-22

Original acronym	NMI	Full name	Country	Regional metrology organization	Date of measurement at the BIPM
ETL	NMIJ	National Metrology Institute of Japan	Japan	APMP	1976-11-23 1993-11-25
–	NPL	National Physical Laboratory	United Kingdom	EURAMET	1977-01-04
UVVVR	CMI-IIR	Český Metrologický Institut/Czech Metrological Institute, Inspectorate for Ionizing Radiation	Czech Republic	EURAMET	1977-05-13 1979-05-15
OMH	MKEH	Magyar Kereskedelmi Engedélyezési Hivatal	Hungary	EURAMET	1977-05-25 1985-07-10
ASMW*	PTB	Physikalisch-Technische Bundesanstalt	Germany	EURAMET	1977-11-24 1980-07-21 2006-05-22
LMRI LPRI	LNE-LNHB	Laboratoire national de métrologie et d'essais - Laboratoire national Henri Becquerel	France	EURAMET	1980-02-06 1994-06-09
NAC* CSIR- NML	NMISA	National Metrology Institute of South Africa	South Africa	AFRIMETS	1980-04-10 1984-11-05 2007-02-09

* another laboratory in the country

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

Original acronym	NMI	Full name	Country	Regional metrology organization	Date of measurement at the BIPM
AAEC	ANSTO	Australian Nuclear Science and Technology Organisation	Australia	APMP	1981-09-10 1993-12-16
NBS	NIST	National Institute of Standards and Technology	United States	SIM	1983-07-19
–	BEV	Bundesamt für Eich- und Vermessungswesen	Austria	EURAMET	2001-10-01
–	BARC	Bhabha Atomic Research Centre	India	APMP	2004-07-13
–	CIEMAT	Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas	Spain	EURAMET	2006-05-12

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. Details on the determination of the β^+ branching ratio and the activity standardization at PTB were published recently [5]. The list of acronyms used to summarize the methods is given in Appendix 2. The uncertainty budgets of the latest submissions from the CIEMAT, PTB and the NMISA are given in Appendix 1. The uncertainty budgets for the BARC, published in the Appendix 1 of the report in 2005 [4] contained an error but only in the unit indicated for the relative standard uncertainty, which should have been 10^2 not 10^4 as quoted.

The half-life given in Table 2 is the value (with its uncertainty) as used by the participant. The half-life used by the BIPM since 2005 is 950.8 (9) d [6] as published by the IAEA. The half-life used for the earlier results is 950.4 (1.5) d [7]. This difference does not affect the SIR results significantly.

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

NMI	Method used and acronym (see Appendix 2)	Half-life	Activity A_i / kBq	Reference date YY-MM-DD	Relative standard uncertainty $\times 100$ by method of evaluation	
					A	B
NMIJ	4 $\pi\beta$ - γ coincidence 4P-PC-PO-NA-GR-CO	–	1 897.4 1 908.5 ^b	76-11-01 12 h UT	0.02	0.28
			1 813	93-11-01 0 h UT	0.4	0.3
NPL	Pressurized IC ^c 4P-IC-GR-00-00-00	–	591.6 592.8 ^b	76-12-20 0 h UT	0.15	1.98
CMI-IIR	4 $\pi\beta$ - γ coincidence 4P-PC-PO-NA-GR-CO	–	3 993	77-04-14 13 h UT	0.06	0.40
		2.6 a	4 198	79-03-19 11 h UT	0.2	0.4
MKEH	4 $\pi\beta$ - γ coincidence 4P-PC-PO-NA-GR-CO	950.4 (1.5) d [7]	1 384.3 1 384.3 ^b	77-04-30 12 h UT	0.2	0.6
		2.602 (1) a [8]	3 626	85-07-01 12 h UT	0.04	0.36
PTB	4 $\pi\beta$ - γ coincidence 4P-PC-PO-NA-GR-CO	–	2 575.4 2 602.4 ^b	77-10-21 12 h UT	0.15	0.15
			3 622.1	80-05-01 0 h UT	0.04	0.10
	4 $\pi\beta$ - γ coincidence ^d 4P-PC-PO-NA-GR-CO and CIEMAT-NIST [5] 4P-LS-MX-00-00-CN	950.5 (4) d	6 779 ^f	06-01-01 0 h UT	0.08 ^f	0.18 ^f
LNE-LNHB	4 $\pi(\text{NaI})\gamma$ 4P-NA-GR-00-00-00	2.602 (1) a [8]	1765.8 1747.5 ^b	79-11-27 12 h UT	0.01	0.20
	4 $\pi\beta$ - γ coincidence 4P-PC-PO-GH-GR-CO	2.602 7 (9) a	653.7 652.3 ^b	94-05-18 12 h UT	0.14	0.19
NMISA	4 $\pi(\text{LS})\beta$ - γ [9] 4P-LS-PO-NA-GR-CO	950.4 d	10 803 12 087 ^b	80-03-18 10 h UT	0.04	0.23
			19 830	84-10-24 12 h UT	0.11	0.16
		2.602 7 (10) a [10]	604.9 ^e	06-08-16 6 h UT	0.05	0.16

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

NMI	Method used and acronym (see Appendix 2)	Half-life	Activity A_i / kBq	Reference date YY-MM-DD	Relative standard uncertainty $\times 100$ by method of evaluation	
					A	B
ANSTO	4 $\pi\beta$ - γ coincidence 4P-PC-PO-NA-GR-CO	–	404.8	81-08-15 0 h UT	0.10	0.36
			592.8	91-03-17 23 h UT	0.22	0.06
NIST	Pressurized IC calib. in 1969 by 4 $\pi\beta$ - γ coincidence 4P-PP-MX-NA-GR-CO and annihilation- γ coincidence 4P-NA-GR-NA-GR-CO	–	3 206	83-06-06 14 h UT	0.04	0.53
BEV	Pressurized IC traceable to NPL 4P-IC-GR-00-00-00	950.5 d	691.8	01-09-01 0 h UT	0.08	0.40
BARC	Pressurized IC ^a 4P-IC-GR-00-00-00	950.360 2 d	1 351	04-02-16 6 h 30 UT	0.1	1.1
	4 $\pi\beta$ - γ coincidence 4P-PC-BP-NA-GR-CO		1 364		0.30	0.22
CIEMAT	4 $\pi\beta$ - γ coincidence 4P-PP-PO-NA-GR-CO and 4 $\pi\gamma$ NaI(Tl) well-type counting 4P-NA-GR-00-00-00	2.602 7 (10) a [9]	342.4	06-01-01 0 h UT	0.37	

^a calibrated with a ^{22}Na source traceable to the NIST

^b two ampoules submitted

^c calibrated by primary measurements of ^{22}Na

^d with distance variation of the NaI detector

^e relying on the β^+ branching ratio of 89.892 %

^f weighted mean of the measurements using the two methods indicated taking into account the correlation due to weighing (same balance)

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 standard method for evaluating the activity of impurities using a calibrated Ge(Li) spectrometer is described in [11]. The CCRI(II) agreed in 1999 [12] that this method should be followed according to the protocol described in [13] when an NMI makes such a request or when there appear to be discrepancies. Consequently, no impurity measurements were made at the BIPM.

Table 3. Details of the solution of ^{22}Na submitted

NMI	Chemical composition	Solvent conc. / (mol dm^{-3})	Carrier: conc. / ($\mu\text{g g}^{-1}$)	Density / (g cm^{-3})	Relative activity of impurity ¹
NMIJ 1976 1993	NaCl in	0.1	NaCl: 50	–	–
	HCl			1.00	–
NPL 1977	NaCl in HCl	0.1	NaCl: 100	–	< 0.03 %
CMI-IIR 1977 1979	NaCl in water	–	NaCl: 50	1	< 0.1 %
	NaCl in HCl	0.08	NaCl : 50	–	< 0.1 %
MKEH 1977 1985	Na in HCl	0.1	Na : 25	–	< 0.03 %
				–	–
PTB 1977 1980 2006	NaCl in	0.1	NaCl: 20	–	< 0.1 %
	HCl		NaCl: 50	1.00	–
			NaCl: 50	1.00	–
LNE-LNHB 1980 1994	NaCl in	0.1	NaCl: 10	0.999	< 0.0001 %
	HCl	1	NaCl: 100	1.016	–
NMISA 1980 1984 2007	NaCl in	1.0	Na^+ : 395	1.036	–
	HCl		Na^+ : 224	1.0169	–
			Na^+ : 200	1.018	–
ANSTO 1981 1993	NaCl in HCl	0.1	NaCl: 200	1.00	< 0.05 %
	^{22}Na in HCl	0.1	–	–	–
NIST 1983	NaCl in HCl	1.0	NaCl: 81	1.014	–
BEV 2001	NaCl in HCl	0.1	NaCl : 50	1.0	–
BARC 2004	NaCl in HCl	0.1	NaCl: 25	1	–
CIEMAT 2006	NaCl in HCl	0.1	NaCl: 50	1	–

¹ the ratio of the activity of the impurity to the activity of ^{22}Na 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 activity measurements for ^{22}Na arise from twenty-nine ampoules and the SIR equivalent activity for each ampoule, A_{ei} , is given in Table 4 for each NMI, i .

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]. The dates of measurement in the SIR are given in Table 1 and are used in the KCDB and all references in this report.

The SIR measurement of the CIEMAT ampoule was repeated after about one year and gave a result in agreement within the combined standard uncertainty. This confirms the absence of significant impurities.

Apart from two earlier submissions that were withdrawn, no recent submission has been identified as a pilot study so the most recent result of each NMI is normally eligible for the KCDB of the CIPM MRA. However, the results of the NPL, CMI-IIR and the NIST are now over 25 years old and consequently no longer eligible for the KCDB [14].

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 ^{22}Na

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 $u_{c,i} / \text{kBq}$
NMIJ 1976	3.605 81	1 897.4	4	7518	4×10^{-4}	22
	3.626 86	1 908.5		7516		
1993	3.608 55	1 813	4	7543	5×10^{-4}	38
NPL 1977	3.549 0	591.6	3	7538	5×10^{-4}	150
	3.555 9	592.8		7542 ^a		
CMI-IIR 1977	3.530 96	3 993	4	7526	5×10^{-4}	31
	1979	3.662 81	4 198	4	7537	5×10^{-4}
MKEH 1977	3.605 8	1 384.3	3	7547	6×10^{-4}	44
	3.605 9	1 384.3		7542		
1985	3.603 9	3 626	5	7525	4×10^{-4}	27

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Table 4 continued. Results of SIR measurements of ^{22}Na

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 $u_{c,i} / \text{kBq}$
PTB	1977	3.502 01	4	7503	4×10^{-4}	16
		3.538 71		7501 ^a		16
	1980	3.673 2	4	7528	4×10^{-4}	9
	2006	3.600 44 (9)	5	7523	4×10^{-4}	15
LNE-LNHB	1980	3.610 99	4	7528	5×10^{-4}	16
		3.573 69		7530		
	1994	3.567 4	3	7534	6×10^{-4}	18
		3.559 4		7536 ^a		
NMISA	1980	3.594 ^d	5	7477	4×10^{-4}	18
		3.610		7475		
	1984	3.619 52 ^e	5	7527	4×10^{-4}	15
	2007	3.648 58	3	7568	6×10^{-4}	14
ANSTO	1981	3.596 0	3	7535	7×10^{-4}	28
	1993	3.728 27	2	7671	14×10^{-4c}	21
NIST	1983	3.725 58	4	7496	3×10^{-4}	40
BEV	2001	3.597 3	3	7490	6×10^{-4}	31
BARC	2004	3.635 34	3	7506	5×10^{-4}	80
		1 364 ^b		7579 ^b		29
CIEMAT	2006	3.645 8	2	7523	9×10^{-4}	29

^a the mean of the two A_e values shown for the same measurement date is used with an averaged uncertainty, as attributed to an individual entry [15]

^b for the KCDB, the weighted mean activity and standard uncertainty are used to calculate the final result $A_e = 7\,570\,(27)$ kBq (see [4])

^c large SIR uncertainty produced by a delay of 2.75 a between the SIR measurement and the reference date

^d masses prior to dilution were 94.17 mg and 105.36 mg respectively

^e mass prior to dilution was 198.954 mg.

The recent PTB result is in agreement within standard uncertainty with their previous result dating 1980.

For NMISA, the difference observed compared to their 1984 result is related to the change of value of the β^+ branching ratio. It would be helpful if the other participants

for which the result depends on this branching ratio were to re-submit a new ^{22}Na solution to the SIR in the near future.

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 included¹;
- b) each NMI or other laboratory has only one result (normally the most recent result or the mean if more than one ampoule is submitted);
- c) any outliers are identified using a reduced chi-squared test and, if necessary, excluded from the KCRV using the normalized error test with a test value of four;
- d) exclusions must be approved by the CCRI(II).

The reduced data set used for the evaluation of the KCRVs is known as the KCRV file and is the reduced data set from the SIR master-file. Although the KCRV may be modified when other NMIs participate, on the advice of the Key Comparison Working Group of the CCRI(II), such modifications are only made by the CCRI(II), normally during one of its biennial meetings.

As the ANSTO (1993) result does not pass the normalized error test (item c above) the CCRI(II) agreed to include the earlier ANSTO result (1981) in the KCRV.

Consequently, the KCRV for ^{22}Na has been identified as 7534 (7) kBq using the results from the NPL, ASMW, CMI-IIR (1979), ANSTO (1981), NIST, MKEH (1985), NMIJ (1993), LNE-LNHB (1994), BARC (coincidence result only), CIEMAT, PTB (2006) and the NMISA (2007).

4.2 Degrees of equivalence

Every NMI that has submitted an ampoule to the SIR within the last 25 years [14] is entitled to have one comparison result included in the KCDB as long as the NMI is a signatory or designated institute listed in the CIPM 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

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

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

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

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

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

taking correlations into account as appropriate [16].

4.2.2 Comparison of any two NMIs with each other

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

$$D_{ij} = D_i - D_j = A_{e_i} - A_{e_j} \quad (3)$$

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

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

where any obvious correlations between the NMIs (such as a traceable calibration for example between the BARC and the NIST) are subtracted using the covariance $u(A_{e_i}, A_{e_j})$, as are normally those correlations coming from the SIR.

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

Table 5 shows the matrix of all the degrees of equivalence as they will appear in the KCDB. It should be noted that for consistency within the KCDB, a simplified level of nomenclature is used with A_{e_i} 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. This 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. The results in black are more than 20 years old.

The data presented in the tables, while correct at the time of publication of the present report, may be replaced in the future when NMIs make new comparisons that result in

a new KCRV. The formal results under the CIPM MRA are those given in the KCDB and in the most recent comparison report for this radionuclide.

Conclusion

The BIPM ongoing key comparison for ^{22}Na , BIPM.RI(II)-K1.Na-22 currently comprises nine results. These have been analysed with respect to the re-evaluated 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 ^{22}Na activity measurements to this comparison.

Acknowledgements

The authors would like to thank the NMIs for their participation in this comparison and Dr P.J. Allisy-Roberts of the BIPM for editorial assistance.

References

- [1] Ratel G., The Système International de Référence and its application in key comparisons, *Metrologia*, 2007, **44**(4), [S7-S16](#)
- [2] CIPM MRA: *Mutual recognition of national measurement standards and of calibration and measurement certificates issued by national metrology institutes*, International Committee for Weights and Measures, 1999, 45 pp. <http://www.bipm.org/pdf/mra.pdf>.
- [3] Ratel G. and Michotte C., BIPM comparison BIPM.RI(II)-K1.Na-22 of activity measurements of the radionuclide ^{22}Na , *Metrologia*, 2003, **40**, *Tech. Suppl.*, [06035](#)
- [4] Ratel G. and Michotte C., BIPM comparison BIPM.RI(II)-K1.Na-22 of activity measurements of the radionuclide ^{22}Na , *Metrologia*, 2005, **42**, *Tech. Suppl.*, [06005](#)
- [5] Nähle O., Kossert K., Klein, R., Activity Standardization of ^{22}Na , *Appl. Radiat. and Isotop.* 2008, **66**, 865-871.
- [6] IAEA-TECDOC-619, X-ray and gamma-ray standards for detector calibration, Vienna, IAEA, 1991.
- [7] BNM-CEA, *Table de Radionucléides*, version 1974, BNM-LNHB, Gif-sur-Yvette.
- [8] BNM-CEA, *Table de Radionucléides*, version 1982, BNM-LNHB, Gif-sur-Yvette.
- [9] Simpson B.R.S., Meyer B.R., Standardization of ^{22}Na , *CSIR Research Report* **596**, 1985, 1 - 21.
- [10] BNM-CEA/DTA/DAMRI/LPRI, 1998, *Nucléide*, Nuclear and Atomic Decay Data Version : 1-98 19/12/98 CD ROM, BNM-LNHB, Gif-sur-Yvette.

- [11] Michotte C., Efficiency calibration of the Ge(Li) detector of the BIPM for SIR-type ampoules, [Rapport BIPM-1999/03](#), 15 pp.
- [12] *Comité Consultatif pour les Étalons de Mesures des Rayonnements Ionisants 16th meeting (1999)*, 2001, CCRI(II) 81-82.
- [13] Michotte C., Protocol on the use of the calibrated spectrometer of the BIPM for the measurement of impurities in ampoules submitted to the SIR, [CCRI\(II\)/01-01](#), 2001, 2pp.
- [14] Allisy P.J., Validity of Ionizing Radiation Comparisons under the auspices of the CIPM MRA, *Rapport BIPM-2010/XX*, in preparation.
- [15] Woods M.J., Reher D.F.G., Ratel G., Equivalence in radionuclide metrology, *Appl. Radiat. Isotop.*, 2000, **52**, 313-318.
- [16] Ratel G., Evaluation of the uncertainty of the degree of equivalence, 2005, [Metrologia 42, 140-144.](#)

**Table 5. Table of degrees of equivalence and introductory text for ²²Na
Key comparison BIPM.RI(II)-K1.Na-22**

MEASURAND : Equivalent activity of ²²Na

Key comparison reference value: the SIR reference value x_R for this radionuclide is 7534 kBq, with a standard uncertainty, $u_R = 7$ 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 $U_i = 2((1 - 2/n)u_i^2 + (1/n^2)\sum u_i^2)^{1/2}$ 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.

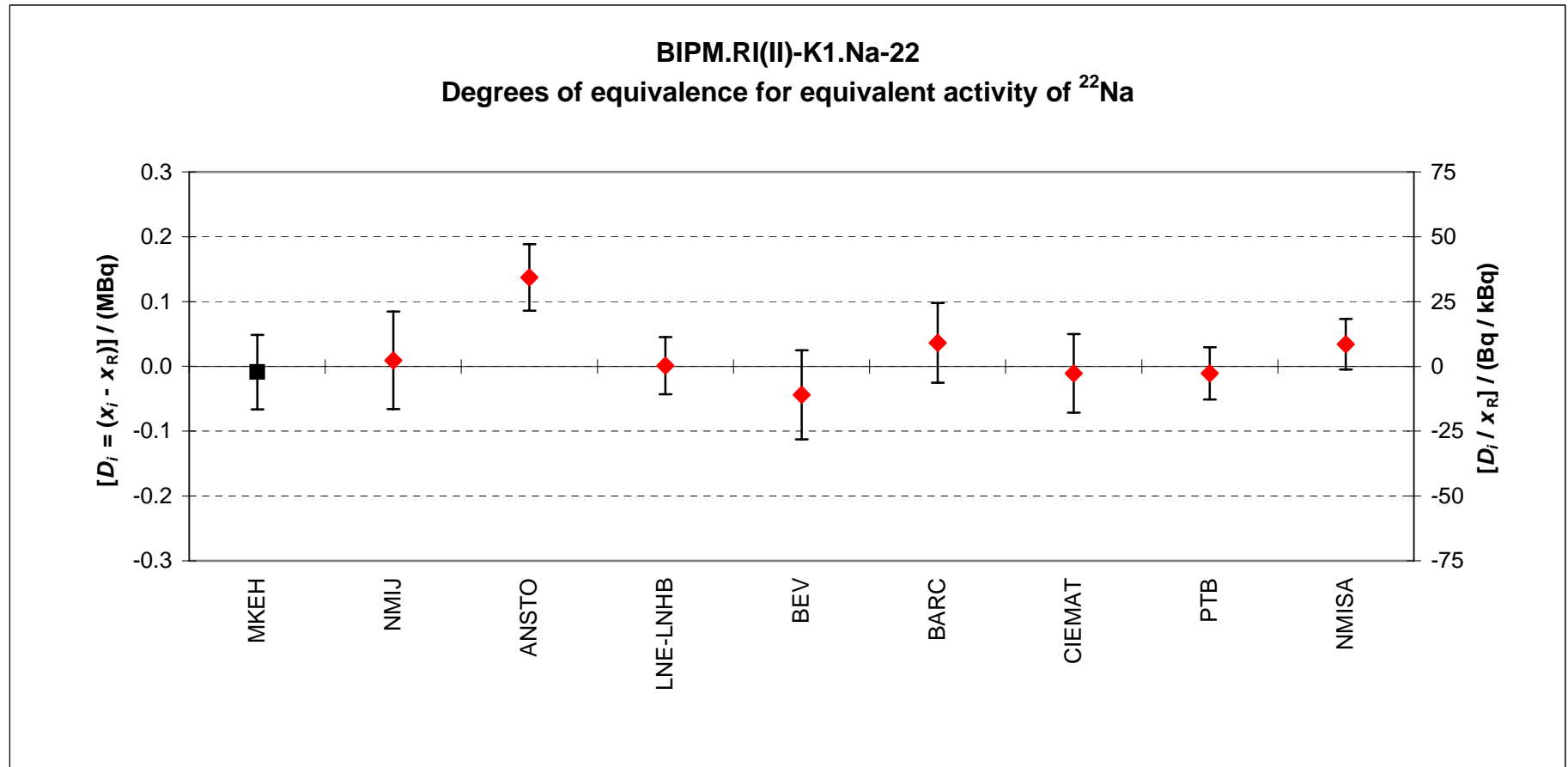
Lab j \longrightarrow

Lab i \downarrow	D_i U_i / MBq		MKEH		NMIJ		ANSTO		LNE-LNHB		BEV	
	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
MKEH	-0.01	0.06			-0.02	0.09	-0.15	0.07	-0.01	0.06	0.04	0.08
NMIJ	0.01	0.08	0.02	0.09			-0.13	0.09	0.01	0.08	0.05	0.10
ANSTO	0.14	0.05	0.15	0.07	0.13	0.09			0.14	0.06	0.18	0.07
LNE-LNHB	0.00	0.04	0.01	0.06	-0.01	0.08	-0.14	0.06			0.05	0.07
BEV	-0.04	0.07	-0.04	0.08	-0.05	0.10	-0.18	0.07	-0.05	0.07		
BARC	0.04	0.06	0.05	0.08	0.03	0.09	-0.10	0.07	0.04	0.06	0.08	0.08
CIEMAT	-0.01	0.06	0.00	0.08	-0.02	0.10	-0.15	0.07	-0.01	0.07	0.03	0.08
PTB	-0.01	0.04	0.00	0.06	-0.02	0.08	-0.15	0.05	-0.01	0.05	0.03	0.07
NMISA	0.03	0.04	0.04	0.06	0.03	0.08	-0.10	0.05	0.03	0.05	0.08	0.07

Lab i \downarrow

Lab i \downarrow	D_i U_i / MBq		BARC		CIEMAT		PTB		NMISA	
	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
MKEH	-0.01	0.06	-0.05	0.08	0.00	0.08	0.00	0.06	-0.04	0.06
NMIJ	0.01	0.08	-0.03	0.09	0.02	0.10	0.02	0.08	-0.03	0.08
ANSTO	0.14	0.05	0.10	0.07	0.15	0.07	0.15	0.05	0.10	0.05
LNE-LNHB	0.00	0.04	-0.04	0.06	0.01	0.07	0.01	0.05	-0.03	0.05
BEV	-0.04	0.07	-0.08	0.08	-0.03	0.08	-0.03	0.07	-0.08	0.07
BARC	0.04	0.06			0.05	0.08	0.05	0.06	0.00	0.06
CIEMAT	-0.01	0.06	-0.05	0.08			0.00	0.07	-0.05	0.06
PTB	-0.01	0.04	-0.05	0.06	0.00	0.07			-0.05	0.04
NMISA	0.03	0.04	0.00	0.06	0.05	0.06	0.05	0.04		

Figure 1. Graph of degrees of equivalence with the KCRV for ^{22}Na
(as it appears in Appendix B of the MRA)



N.B. The right-hand axis represents approximate values only
Result shown as black squares are more than 20 years old

Appendix 1. Uncertainty budgets for the activity of ^{22}Na submitted to the SIR**CIEMAT: coincidence method**

Relative standard uncertainties	$u_{\text{relative}} \times 10^4$ evaluated by method	
	A	B
Contributions due to		
counting statistics	20	–
weighing	–	10
dead time	–	20
resolving time	–	10
counting time	–	1
input parameters and statistical model	–	50
half life	–	1
background	20	–
Quadratic summation	28	56
Relative combined standard uncertainty, u_c	62	

CIEMAT: $4\pi\gamma$ NaI well type counting

Relative standard uncertainties	$u_{\text{relative}} \times 10^4$ evaluated by method	
	A	B
Contributions due to		
counting statistics	8	–
weighing	–	10
pile-up	1	–
counting time	–	1
input parameters and statistical model	–	43
decay scheme parameters	6	–
zero-energy extrapolation	–	11
half life	–	< 1
background	1	–
Quadratic summation	10	46
Relative combined standard uncertainty, u_c	47	

PTB: coincidence method

Relative standard uncertainties	$u_{\text{relative}} \times 10^4$ evaluated by method	
Contributions due to	A	B
counting statistics	19	–
weighing	–	24
dead time	–	< 1
resolving time	–	2
counting time and duration	–	< 1
Gandy effect	–	3
extrapolation of efficiency curve	–	2
half life	–	< 1
background	–	2
impurities (none)	–	1
Quadratic summation	19	24
Relative combined standard uncertainty, u_c	31	

PTB: CIEMAT/NIST method

Relative standard uncertainties	$u_{\text{relative}} \times 10^4$ evaluated by method	
Contributions due to	A	B
counting statistics	8	–
weighing	–	7
dilution factor by weighing	–	4
dead time	–	10
counting time and duration	–	< 1
tracer	–	< 1
decay data and model	–	11
quenching	–	3
half life	–	< 1
background	–	3
impurities (none)	–	5
Quadratic summation	8	18
Relative combined standard uncertainty, u_c	20	

NMISA (2007)

Relative standard uncertainties	$u_{\text{relative}} \times 10^4$ evaluated by method	
	A	B
Contributions due to		
counting statistics	5	–
weighing	–	2
dead time	–	1
resolving time	–	0.2
counting time	–	0.1
Input parameters:		
interaction probability for γ -ray with LS cocktail	–	2.5
relative photopeak efficiency		13
branching ratio	–	2
extrapolation of efficiency curve	–	7
satellite pulses	–	4
background	–	4
Quadratic summation	5	16
Relative combined standard uncertainty, u_c	17	

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
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	Nal(Tl)	NA
		Ge(HP)	GH
		Ge-Li	GL
		Si-Li	SL
		CsI	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
bremsstrahlung	BS	coincidence	CO
gamma ray	GR	anti-coincidence	AC
X - rays	XR	coincidence counting with efficiency tracing	CT
alpha - particle	AP	anti-coincidence counting with efficiency tracing	AT
mixture of various radiation e.g. X and gamma	MX	triple-to-double coincidence ratio counting	TD
		selective sampling	SS

Examples	method	acronym
4 π (PC) β - γ -coincidence counting		4P-PC-BP-NA-GR-CO
4 π (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
4 π (PPC)AX- γ (GeHP)-anticoincidence counting		4P-PP-MX-GH-GR-AC
4 π CsI- β ,AX, γ counting		4P-CS-MX-00-00-00
calibrated IC		4P-IC-GR-00-00-00
internal gas counting		4P-PC-BP-00-00-IG