Comparisons CCRI(II)-K3.F-18 and APMP.RI(II)-K3.F-18 of activity measurements of the radionuclide ^{18}F and links to the key comparison reference value of the BIPM.RI(II)-K1.F-18 comparison

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Abstract

In 2003, the CCRI(II) decided that an indirect comparison of ^{18}F measurements piloted by the National Physical Laboratory (NPL), UK in 2001 was sufficiently well constructed that it could be converted into a CCRI(II) comparison, with comparison identifier CCRI(II)-K3.F-18. At the same time, the pilot laboratory made a bilateral comparison with the institute in Chinese Taipei, comparison identifier APMP.RI(II)-K3.F-18. The results of the comparisons have been reported and the key comparison working group (KCWG) of the CCRI(II) has approved the mechanism to link all the results to the key comparison reference value (KCRV) of ^{18}F. The KCRV has been determined through the International Reference System (SIR) for activity comparison at the Bureau International des Poids et Mesures (BIPM), with comparison identifier BIPM.RI(II)-K1.F-18. These comparisons have enabled a further four results to be added to the matrix of degrees of equivalence for ^{18}F activity measurements.

1. Introduction

The requirement to establish equivalence for radioactivity standards for radionuclides used in nuclear medicine can be complicated by the short half-lives of many of the radionuclides of interest. Typically, half-lives of a few hours may be encountered and this prohibits the conduct of comparison exercises using the conventional techniques that are currently employed in this area. These conventional techniques either use travelling standards which are dispensed from a common stock solution with aliquots being despatched to individual national metrology institutes (NMIs) or entail individual NMIs despatching their own standardized solutions to the SIR. In both cases, geographical and transport complications prevent most NMIs from either receiving a sample from the pilot institute or despatching a sample to the SIR within an acceptable time frame when short half-lives are involved. The radionuclide ^{18}F, which has a half-life of approximately 2 hours, was chosen for this comparison as it is used increasingly in nuclear medicine for positron emission tomography.

An alternative approach to compare activity measurements for radionuclides with short half-lives is for NMIs to calibrate a transfer instrument at their own institute and to then compare the calibration figures. This requires the NMI transfer instrument to be of a common and reproducible type that allows normalized measurements to be conducted using long-lived reference samples that are themselves compared at the pilot institute. The link to the SIR is then completed by the submission of standardized solutions to the BIPM from one (or preferably two) NMIs that can ensure the despatch of samples to the BIPM within an acceptable time frame.

The SIR comparisons are described as BIPM ongoing comparisons [1] and the results provide the key comparison reference values (KCRV) and form the basis of the BIPM key comparison database (KCDB) of the CIPM Mutual Recognition Arrangement (MRA) [2]. The results of the BIPM.RI(II)-K1.F-18 comparison have been published in [3]. Five laboratories have been able to submit ^{18}F ampoules to the SIR, two of which can be used as the link for the current comparisons.

To extend the ^{18}F comparison to more distant laboratories, the transfer instrument used was the ionization chamber that forms the detector component of the NPL secondary standard radionuclide calibrator. These chambers are manufactured to tolerances that ensure a reasonable reproducibility of response across a defined gamma ray energy range (30 keV to 1500 keV). The number of NMIs that possess such ionization chambers is now sufficient to allow a meaningful comparison to be conducted. The protocol used a ^{68}Ge source for normalization purposes.

The results of this indirect comparison have been published [4] and only the summary details to enable the link to the KCRV and the degrees of equivalence to be evaluated are presented in this report.

The proposal to include this comparison exercise as a key comparison was adopted by the CCRI(II) in 2003 on the basis that the guidelines for a normal key comparison were followed. As this type of comparison, using calibration factors for a detector and a source for normalization purposes was a new concept, it has been identified as a K3 comparison with comparison identifier CCRI(II)-K3.F-18. At the same time the pilot laboratory conducted a bi-lateral comparison with a laboratory from the APMP. That comparison is identified as the APMP.RI(II)-K3.F18 comparison.

2. Participants

Eight NMIs participated in one of the two K3.F-18 comparisons and provided results in the agreed format. The laboratory details are given in Tables 1. The comparisons were piloted by the NPL.

3. Comparison method

A set of empty BIPM ampoules was sent to the NPL from the BIPM. These ampoules were compared for differences between their wall thickness using an ^{241}Am “point” sealed source and the NPL TPA Mk II high pressure ionization chamber (serial number PA782). The source is at the end of a thin rod that allows it to be located in the centre of each empty ampoule. The whole is then inserted into the well of the ionization chamber and the response measured. This procedure was repeated for all ampoules within the batch and a set of ampoules that showed the closest responses to each other was then chosen for this comparison. The purpose of this is to minimize the effect of the variations in wall thickness on the measurement results, which is actually not more than a few 10^{-4} for ^{18}F.

Table 1a. Details of the participants in the CCRI(II)-K3.F-18

NMI	Full name	Country	Regional metrology organization
ANSTO	Australian Nuclear Science and Technology Organisation	Australia	APMP
BNM⁺-LNHB	Bureau national de métrologie-Laboratoire national Henri Becquerel	France	EUROMET
CMI-IIR	Český Metrologický Institut/Czech Metrological Institute, Inspectorate for Ionizing Radiation	Czech Republic	EUROMET
IPEN-CNEN*	Comissão Nacional de Energia Nuclear	Brazil	SIM
NIRH*	National Institute of Radiation Hygiene	Denmark	EUROMET
NIST	National Institute of Standards and Technology	United States	SIM
NPL	National Physical Laboratory	United Kingdom	EUROMET

[+] New name from May 2005: Laboratoire national de métrologie et d'essais, LNE-LNHB
* as yet a non-designated laboratory in the country.

Table 1b. Details of the participants in the APMP.RI(II)-K3.F-18

NMI	Full name	Country	Regional metrology organization
INER	Institute of Nuclear Energy Research	Chinese Taipei	APMP
NPL	National Physical Laboratory	United Kingdom	EUROMET

3.1 <u>^{18}F standardization measurements and ionization chamber calibration</u>

Participants procured a stock solution of ^{18}F, dispensed about 3.6 g into the NPL-supplied SIR ampoule and assayed it in their ionization chamber. When the mass of solution was different from 3.6 g, the ionization current response was corrected by a factor determined experimentally at the NPL to normalize the result to that expected for 3.6 g [4]. Each participant prepared sources from its own same stock solution and most then performed absolute activity measurements, using the technique(s) of their choice.

As the NPL and the BNM-LNHB both have convenient access to the BIPM, an additional ^{18}F sample (the same sample for BNM-LNHB) was despatched to the BIPM for measurement in the SIR.

A brief description of the standardization methods for each laboratory, the activities used and the relative standard uncertainties (k = 1) are given in Table 2. The list of acronyms used to summarize the methods is given in Appendix 1. The uncertainty budgets for each participant are given in [3] or Appendix 2 for the NIRH.

Table 2. Standardization methods of the participants for ^{18}F

NMI	Method used and acronym (see Appendix 1)	Mass of solution / g	Activity per mass A_i / MBq g^{-1}	Reference date YY-MM-DD	Relative standard uncertainty × 100 by method of evaluation	
					A	B
ANSTO	4πPC-γ coinc. using ^{60}Co efficiency tracer 4P-PC-BP-NA-GR-CT	3.633 73	4.1599	01-03-15 1 h 00 UT	1.3	0.5
BNM-LNHB	liquid scintillation using TDCR 4P-LS-BP-00-00-TD	3.4995 (5)	1.941	02-04-10 12 h 00 UT	0.98	0.21
CMI-IIR	4πPC-γ coincidence 4P-PC-BP-NA-GR-CO	3.7279 3.6204	58.8 61.83	01-03-29 14 h 00 UT	0.08	0.43
IPEN	4πPC-γ coincidence 4P-PC-BP-NA-GR-CO	3.757 75	1.7120	01/04/11 19 h 49 UT	0.3	0.5
NIRH	IC measurement § 4P-IC-GR-00-00-00	3	835	01/01/16 14 h 05 UT	0.15	1.11
NIST	liquid scintillation using CIEMAT/NIST 4P-LS-BP-00-00-CN	3.650 078	62.49	01/03/21 0 h 00 UT	0.24	0.31
NPL	4πPC-γ coincidence 4P-PC-BP-NA-GR-CO	3.604 497	3.5102	01/03/22 12 h 00 UT	0.08	0.23
INER+	4πPC-γ coincidence 4P-PC-BP-NA-GR-CO	3.601 16	12.712	01/01/11 9 h 00 UT	0.43	0.27

§ traceable to the NPL

+ the APMP bi-lateral comparison.

Details regarding the solutions measured are summarized 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 the solutions of ^{18}F measured

NMI	Chemical composition	Solvent conc.	Carrier: conc. /(µg g^{-1})	Density /(g cm^{-3})	Relative activity of impurity†
ANSTO	FDG §	–	–	–	–
BNM-LNHB	FDG in HCl	0.1 mol dm^{-3}	–	0.97 (1)	–
CMI-IIR	KF in $Na_2S_2O_3$ and Na_2CO_3	–	KF : 200 $Na_2S_2O_3$: 100 Na_2CO_3 : 100	1	–
IPEN	FDG in water	–	–	1	–
NIRH	FDG	–	–	–	–
NIST	F in NaCl solution	0.4 %	–	1.05	^{48}V : 0.17 %
NPL	FDG	–	–	1	–
NRC	FDG in water	–	FDG: 500	1	–
PTB	–	–	–	–	–
INER*	FDG in NaCl solution	0.05 %	–	–	–

§ Fluoro-deoxy-glucose

† the ratio of the activity of the impurity to the activity of ^{18}F at the reference date

* the APMP bi-lateral comparison.

The starting date for the comparison was May 2000.

The half-life used by the BIPM is 1.8290 (5) h [5]. Such a short half-life requires a correction for the decay during the SIR measurement. The half-life recommended by the NPL for use in the current comparisons was 1.828 (2) h [6].

3.2 Normalizing the ^{18}F measurements

A stock solution of ^{68}Ge was dispensed at the NPL into a subset of the selected BIPM ampoules. Each ampoule contained approximately 3.6 g of solution and was assayed in the NPL PA782 ionization chamber and then sent to each participant along with two empty ampoules. The solution contained 0.05 mg g^{-1} Ge and 0.05 mg g^{-1} Ga in

0.5 M HCl. These ^{68}Ge sources were for normalization purposes. The choice of ^{68}Ge (a pure electron capture nuclide) was made because it is the long-lived parent of ^{68}Ga which is a positron emitter (effectively similar to ^{18}F since the electron capture emissions from ^{18}F and from ^{68}Ge will not be observed by the ionization chamber). NPL conducted purity and long-term stability measurements using ionization chambers and gamma spectrometry on the ^{68}Ge solution. The ^{68}Ge half-life value recommended by the NPL for the present comparisons is 270.8 (3) days [4].

Participants measured the ionization current from the ^{68}Ge ampoule in their ionization chamber generally at the time of their fluorine measurements. The NIST, NPL and BNM-LNHB measured their ^{18}F solution after a delay of about 2.5 months, 4 months and 16 months, respectively.

4. Results

The results of these comparisons are derived from the normalized calibration coefficients C_{ni} published in [4]. The normalizing factor is obtained from the NMI measurement of the ^{68}Ge check source in their ionization chamber compared with that obtained at the NPL. The normalized calibration coefficient is then the ratio of the calibrator response to the activity measured by the NMI at the reference time, divided by the normalization factor.[1]

As the quantities to be compared and linked to the SIR are the ^{18}F activities measured by each participant, the inverse of the normalized calibration coefficients are used as given in Table 4.

The equivalent activity measurements, A_e, of the BNM-LNHB and the NPL in the SIR for ^{18}F that are used to link the results of the present comparisons are also given in Table 4.

The CCRI(II) results are linked using the ratios A_{el} / C_{nl}^{-1} from Table 4 for the NPL and the BNM-LNHB as the linking laboratories l. Although these two ratios each have a 1.6×10^{-3} relative standard uncertainty, they differ by about 1.5×10^{-2} in relative value. In consequence the link is calculated as the mean of the two ratios and the relative standard uncertainty of the link is obtained as 6×10^{-3} assuming a rectangular probability distribution. The linked SIR equivalent activity for each participant, A_{ei}, is given in Table 4 for each NMI, i and is calculated from

$$A_{ei} = C_{ni}^{-1} \times \frac{1}{2} \sum_{l=1}^{2} A_{el} / C_{nl}^{-1} = 157.44 / C_{ni} \text{ kBq} \qquad (1)$$

All the results are eligible for Appendix B of the CIPM MRA except for the IPEN-CNEN and the NIRH which are not designated institutes for Brazil and Denmark respectively.

[1] In [4] the headings of columns 2 and 4 in Table 11 should read “Activity per mass at reference time / MBq g^{-1}” and “Calibrator response (volume corrected) per mass/ pA g^{-1}” respectively.

Table 4. Results of SIR measurements of ^{18}F

NMI	Activity per mass at each ref. date / MBq g^{-1}	Rel. uncert. × 100	Calibrator response per mass* / pA g^{-1}	Rel. uncert. × 100	Normalizing factor	Rel. uncert. × 100	C_n^{-1} / kBq pA^{-1}	Combined uncertainty $u_{c,i}$ / kBq pA^{-1}	Linked A_e / kBq	Uncertainty / kBq
ANSTO	4.1599	1.4	43.525	0.42	1.00687	0.19	96.228	1.4	15 150	240
BNM-LNHB	1.941	1.0	20.369	0.07	1.01855	0.11	97.059	0.98	15 170 [a]	150 [a]
CMI-IIR	58.8 61.83	0.4	618.99 650.87	0.21 0.21	1.00353	0.25	95.329 95.329	0.52 0.52	15 010	120
IPEN	1.7120	0.6	17.5987	1.2	0.97757	0.43	95.102	1.4	14 970	230
NIRH	835	1.1	8672.6	0.22	1.00549	1.1	96.809	1.6	15 240	260
NIST	62.49	0.4	678.069	0.32	1.01127	0.8	93.197	0.88	14 670	160
NPL	3.5102	0.25	36.4279	0.11	1.00000	n/a	96.358	0.81	15 281 [a]	39 [a]
INER+	12.712	0.5	131.961 132.621 #	0.22 0.49 #	1.00086 0.99007	0.27 0.48	96.413 94.904	0.98 0.59	15 130 [b]	150 [b]

* at each laboratory's reference date, corrected for the volume effect
[a] SIR result already published [3]
[b] weighted mean, taking into account the correlation
two calibrators were used
+ the APMP bi-lateral participant.

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, or ionization chamber measurements that are directly traceable to a primary measurement in the laboratory;
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 mother-file. The key comparison reference value for ^{18}F is 15 245 (32) kBq using the results from the IRA, BNM-LNHB, NPL and the CIEMAT as given in [3].

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

$$D_i = A_{ei} - \text{KCRV} \qquad (2)$$

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

$$U_i = 2u_{D_i}, \qquad (3)$$

taking correlations into account as appropriate [7].

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

$$D_{ij} = D_i - D_j = A_{e\,i} - A_{e\,j} \qquad (4)$$

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

$$u_{D_{ij}}^{\ 2} = u_i^{\ 2} + u_j^{\ 2} - 2u(A_{e,i}, A_{e,j}) \qquad (5)$$

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 appear in Appendix B of the KCDB. It should be noted that for consistency within the KCDB, a simplified level of nomenclature is used with A_{ei} replaced by x_i. The introductory text is that agreed for the comparison. The graph of the first column of results in Table 5, corresponding to the degrees of equivalence with respect to the KCRV (identified as x_R in the KCDB), is shown in Figure 1. 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. Figure 1 also shows values for the degrees of equivalence in relative terms, on the right-hand axis.

Conclusion

The BIPM ongoing key comparison for ^{18}F, BIPM.RI(II)-K1.F-18 currently comprises five results. Their analysis with respect to the KCRV determined for this radionuclide, and with respect to each other have been published in the BIPM key comparison database.

The CCRI(II)-K3.F-18 and APMP.RI(II)-K3.F-18 comparisons have been linked to the KCRV for ^{18}F through the measurements of the NPL and the BNM-LNHB submissions to the SIR. This has enabled another four NMIs to be linked to the KCRV and have degrees of equivalence published in the KCDB.

Further results for activity measurements of F-18 will be added to the KCDB as submissions are made to the SIR or another international comparison is held.

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References

[1] Ratel G. The international reference system for activity measurements of γ-emitting radionuclides (SIR), 2005, *BIPM Monograph XX*, (in preparation).

[2] 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., Michotte C., García-Toraňo E., Los Arcos J.-M., Update of the BIPM comparison BIPM.RI(II)-K1.F-18 of activity measurements of the radionuclide ^{18}F to include the CIEMAT, 2004, *Metrologia*, **41**, *Tech. Suppl.*, 06016

[4] Woods M.J., Baker M., Key comparison of ^{18}F using the NPL secondary standard radionuclide calibrator, 2004, *NPL Report* DQL RN(RES)001, 32 pp.

[5] BNM-CEA/DTA/DAMRI/LPRI, *Nucléide*, Nuclear and Atomic Decay Data Version : 1-98 19/12/98 CD ROM, BNM-LNHB, Gif-sur-Yvette.

[6] Nordberg C., Salvatores M., Status of the JEF Evaluated Data Library, 1994 *Proc.Nucl. Data for Science and Technology*, Ed. Dickens, J.K., Am. Nucl. Soc. Inc., La Grange Park, 680-684.

[7] Ratel G., Evaluation of the uncertainty of the degree of equivalence, 2005, *Metrologia* **42**, 140-144.

Table 5. Introductory text and table of degrees of equivalence for ^{18}F

Key comparison BIPM.RI(II)-K1.F-18

MEASURAND : **Equivalent activity of ^{18}F**

Key comparison reference value: the SIR reference value for this radionuclide is x_R = 15.25 MBq, with a standard uncertainty u_R = 0.03 MBq.
x_R is computed as the mean of the results obtained by primary methods.

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

The degree of equivalence between two laboratories is given by a pair of terms: $D_{ij} = D_i - D_j = (x_i - x_j)$ and U_{ij}, its expanded uncertainty (k = 2), both expressed in MBq. The approximation $U_{ij} \sim 2(u_i^2 + u_j^2)^{1/2}$ is used in the following table.

Linking CCRI(II)-K3.F-18 to BIPM.RI(II)-K1.F-18

The value x_i is the equivalent activity for laboratory i participant in CCRI(II)-K3.F-18 having been normalized to the value of the NPL and the BNM-LNHB combined as the link.

The degree of equivalence of laboratory i participant in CCRI(II)-K3. with respect to the key comparison 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. The approximation $U_i = 2(u_i^2 + u_R^2)^{1/2}$ is used in the following table as none of these laboratories contributed to the KCRV.

The degree of equivalence between two laboratories i and j, one participant in BIPM.RI(II)-K1.F-18 and one in CCRI(II)-K3.F-18, or both participants in CCRI(II)-K3.F-18, is given by a pair of terms expressed in MBq: $D_{ij} = D_i - D_j$ and U_{ij}, its expanded uncertainty (k = 2), approximated by $U_{ij} = 2(u_i^2 + u_j^2 - 2fu_l^2)^{1/2}$ with l referring to the link when each laboratory is from the CCRI or one of the linking laboratories and f is the correlation coefficient.

Linking APMP.RI(II)-K3.F-18 to BIPM.RI(II)-K1.F-18

The value x_i is the equivalent activity for laboratory i participant in APMP.RI(II)-K3.F-18 having been normalized to the value of the NPL and the BNM-LNHB combined as the link.

The degree of equivalence of laboratory i participant in APMP.RI(II)-K3. with respect to the key comparison 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. The approximation $U_i = 2(u_i^2 + u_R^2)^{1/2}$ is used in the following table as this laboratory did not contribute to the KCRV.

The degree of equivalence between two laboratories i and j, one participant in BIPM.RI(II)-K1.F-18 or in CCRI(II)-K3.F-18 and one in APMP.RI(II)-K3.F-18, is given by a pair of terms expressed in MBq: $D_{ij} = D_i - D_j$ and U_{ij}, its expanded uncertainty (k = 2), approximated by $U_{ij} = 2(u_i^2 + u_j^2 - 2fu_l^2)^{1/2}$ with l referring to the link when the other laboratory is from the CCRI or is one of the linking laboratories and f is the correlation coefficient.

These statements make it possible to extend the BIPM.RI(II)-K1.F-18 matrices of equivalence to all participants in the CCRI(II)-K3.F-18 and the APMP.RI(II)-K3.F-18 comparisons.

Table 5 continued. Degrees of equivalence for ^{18}F

Lab *j* ⇒

Lab *i* ⇓

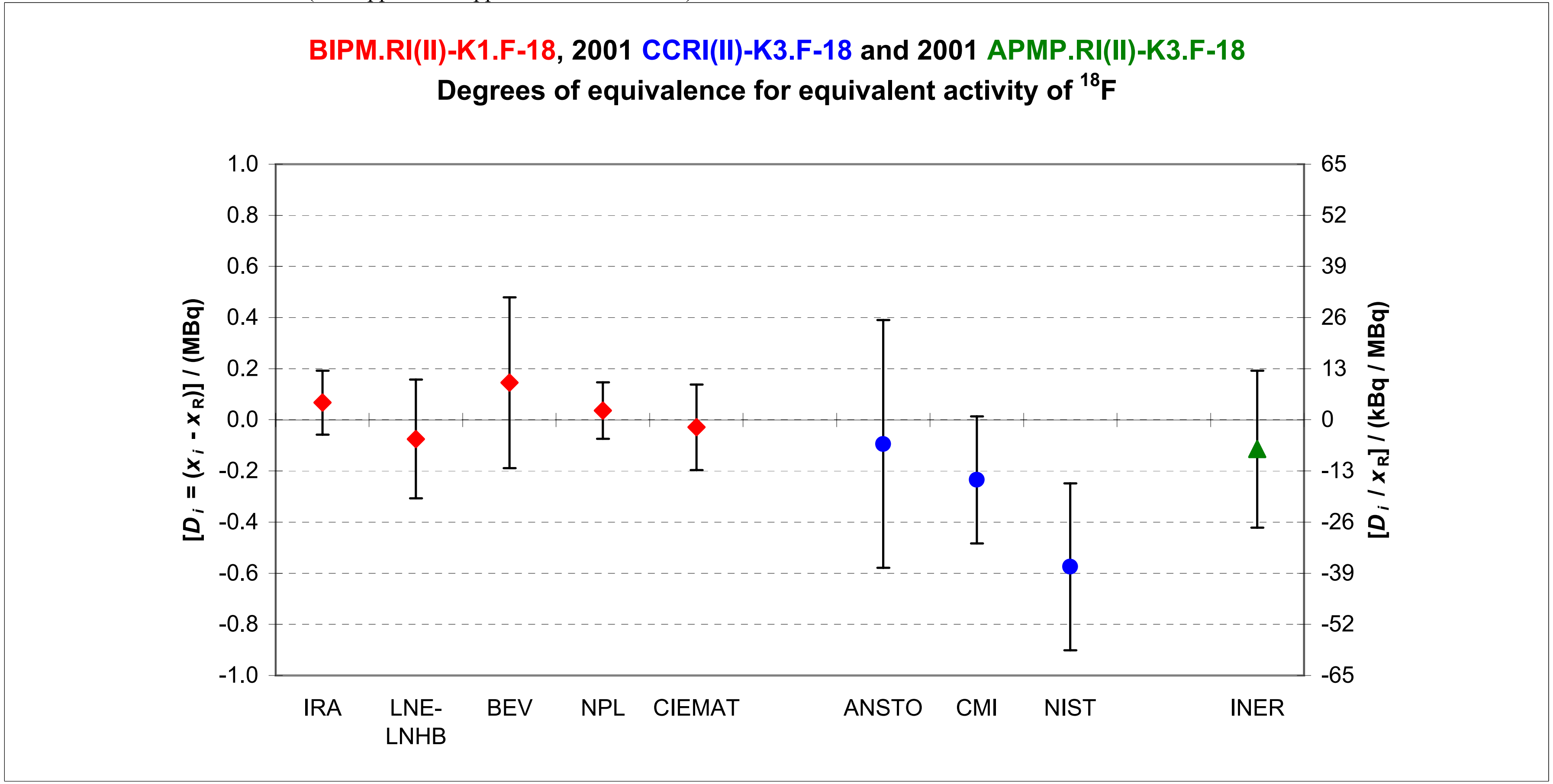
	D_i / MBq	U_i	IRA D_{ij} / MBq	IRA U_{ij}	BNM-LNHB D_{ij} / MBq	BNM-LNHB U_{ij}	BEV D_{ij} / MBq	BEV U_{ij}	NPL D_{ij} / MBq	NPL U_{ij}	CIEMAT D_{ij} / MBq	CIEMAT U_{ij}
IRA	**0.07**	0.13			**0.14**	0.32	**-0.08**	0.34	**0.03**	0.14	**0.10**	0.23
BNM-LNHB	**-0.07**	0.23	**-0.14**	0.32			**-0.22**	0.44	**-0.11**	0.31	**-0.05**	0.36
BEV	**0.15**	0.33	**0.08**	0.34	**0.22**	0.44			**0.11**	0.31	**0.17**	0.37
NPL	**0.04**	0.11	**-0.03**	0.14	**0.11**	0.31	**-0.11**	0.31			**0.07**	0.21
CIEMAT	**-0.03**	0.17	**-0.10**	0.23	**0.05**	0.36	**-0.17**	0.36	**-0.07**	0.21		
ANSTO	**-0.09**	0.48	**-0.16**	0.49	**-0.02**	0.56	**-0.24**	0.58	**-0.13**	0.47	**-0.07**	0.52
CMI	**-0.23**	0.25	**-0.30**	0.27	**-0.16**	0.37	**-0.38**	0.40	**-0.27**	0.23	**-0.21**	0.31
NIST	**-0.57**	0.33	**-0.64**	0.34	**-0.50**	0.43	**-0.72**	0.45	**-0.61**	0.31	**-0.55**	0.37
INER	**-0.11**	0.31	**-0.18**	0.32	**-0.04**	0.41	**-0.26**	0.44	**-0.15**	0.29	**-0.09**	0.36

Lab *i* ⇓

	D_i / MBq	U_i	ANSTO D_{ij} / MBq	ANSTO U_{ij}	CMI D_{ij} / MBq	CMI U_{ij}	NIST D_{ij} / MBq	NIST U_{ij}	INER D_{ij} / MBq	INER U_{ij}
IRA	**0.07**	0.13	**0.16**	0.49	**0.30**	0.27	**0.64**	0.34	**0.18**	0.32
BNM-LNHB	**-0.07**	0.23	**0.02**	0.56	**0.16**	0.37	**0.50**	0.43	**0.04**	0.41
BEV	**0.15**	0.33	**0.24**	0.58	**0.38**	0.40	**0.72**	0.45	**0.26**	0.44
NPL	**0.04**	0.11	**0.13**	0.47	**0.27**	0.23	**0.61**	0.31	**0.15**	0.29
CIEMAT	**-0.03**	0.17	**0.07**	0.52	**0.21**	0.31	**0.55**	0.37	**0.09**	0.36
ANSTO	**-0.09**	0.48			**0.14**	0.47	**0.48**	0.52	**0.02**	0.50
CMI	**-0.23**	0.25	**-0.14**	0.47			**0.34**	0.31	**-0.12**	0.29
NIST	**-0.57**	0.33	**-0.48**	0.52	**-0.34**	0.31			**-0.46**	0.36
INER	**-0.11**	0.31	**-0.02**	0.50	**0.12**	0.29	**0.46**	0.36		

Figure 1. Graph of degrees of equivalence with the KCRV for ^{18}F

(as it appears in Appendix B of the MRA)



N.B. one interval of 0.2 MBq on the y axis represents approximately1.3 % of the KCRV, right-hand axis shows approximate values only

Appendix 1. 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 radiation	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(GeHP)-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

Appendix 2. Uncertainty budget of the NIRH for the activity standardization of ^{18}F

Relative standard uncertainties	$u_i \times 10^4$ evaluated by method	
Contributions due to	**A**	**B**
current measurement, $\nu = 40^{\dagger}$	15	–
pA calibration of electrometer*	–	15
mass / volume	–	5
NPL calibration factor	–	110
Quadratic summation	**15**	**111**
Relative combined standard uncertainty, u_c	**112**	

† number of degrees of freedom
* rectangular distribution 0.52 %, divisor 2√3