International comparison of activity measurements of a solution of tritiated water
CCRI(II)-K2.H-3

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Abstract:
An international comparison of activity measurements of a solution of tritiated water, CCRI(II)-K2.H-3, was organised in 2009 by the BIPM. Samples of this pure β emitter (provided by the LNE-LNHB) were measured using different techniques, but mostly with the TDCR method or methods relying on it. One result was identified as an outlier. Applying the PMM formalism a KCRV of 37.10(18) Bq/mg at 00:00 UTC on 31st May 2009 was obtained; degrees of equivalence for each participant have also been evaluated.

1. Introduction

An international comparison of activity measurements of a solution of tritiated water was organised under the auspices of the Comité Consultatif des Rayonnements Ionisants CCRI(II) in 2009, comparison CCRI(II)-K2.H-3. Samples were kindly made available to the participants by the LNE-LNHB. Tritium is a pure β emitter with the decay scheme shown in Figure 1. Nineteen laboratories participated in the exercise.

2. Relevant information about the comparison

The list of the participating institutions with information on the people who carried out the measurements is shown in Table 1. The tritiated water was prepared and dispatched to the participants by the LNE-LNHB. Table 2 gives some information about the main characteristics of the distributed ampoules. The laboratories who carried out appropriate tests reported no adsorption. No gamma-emitting impurities were detected in the samples (according to the results of measurements by ANSTO, NPL, PTB and RC). Table 3 provides the list of the methods used, together with the laboratories who applied these methods. Acronyms of the methods are also given, according to the CCRI(II) rules.

3. Results and evaluation of the KCRV and the Degrees of Equivalence

Nineteen laboratories took part in the exercise and reported a total of 22 independent results. Table 4 presents for each participant a detailed uncertainty budget as provided in their reporting forms. The reference time and date used was 00:00 UTC on 31st May 2009, and a half life of 4496.862(9.131) d was used [1]. Most of the reported uncertainties lie in the range between 0.5 % and 1.0 %.

A summary of the results is given in Table 5. Table 6 shows the final results using only one result per participating laboratory, as required by the CIPM MRA rules. The figures displayed are taking into account the wishes of the laboratories, which are collated in footnotes.

Following a recommendation of the KCWG(II), the Power-Moderated weighted Mean formalism (PMM) [2] has to be used to evaluate the Key Comparison Reference Value (KCRV). It should be emphasized that the results obtained using ^{3}H external standards were not included in the calculation of the KCRV. In addition, the MKEH value was identified as an outlier by the PMM procedure and was also excluded from the calculation of the KCRV. The KCRV calculated using the PMM method is thus 37.10(0.18) Bq/mg. An additional uncertainty of 0.539 Bq/mg was introduced in the evaluation of the KCRV applying the PMM with the empirical parameter $\alpha = 2\text{-}3/N$ that amounted to 1.77. The PMM is also used to evaluate degrees of equivalence for all participants in the comparison; these are shown in Table 7 and Figure 3.

4. Conclusion

The comparison of tritiated water was completed successfully. One outlier was identified but the rest of the laboratories obtained results in agreement with the key comparison reference value of 37.10(0.18) Bq/mg.

5. Acknowledgements

The authors are indebted to LNE-LNHB for supplying the samples of tritiated water, and to all the participants in the exercise. Thanks are also due to Steven Judge, BIPM, for editing the report.

References

[1] Monographie BIPM-5 (2006) *Table de Radionucléides*, BIPM, Pavillon de Breteuil, F-92310 Sèvres, pp. 1-4, Evaluation by V.P. Chechev.
[2] Pommé, S. & Keightley, J.D. 'Determination of a reference value and its uncertainty through a power-moderated mean' *Metrologia* 52 (2015) S200-S212

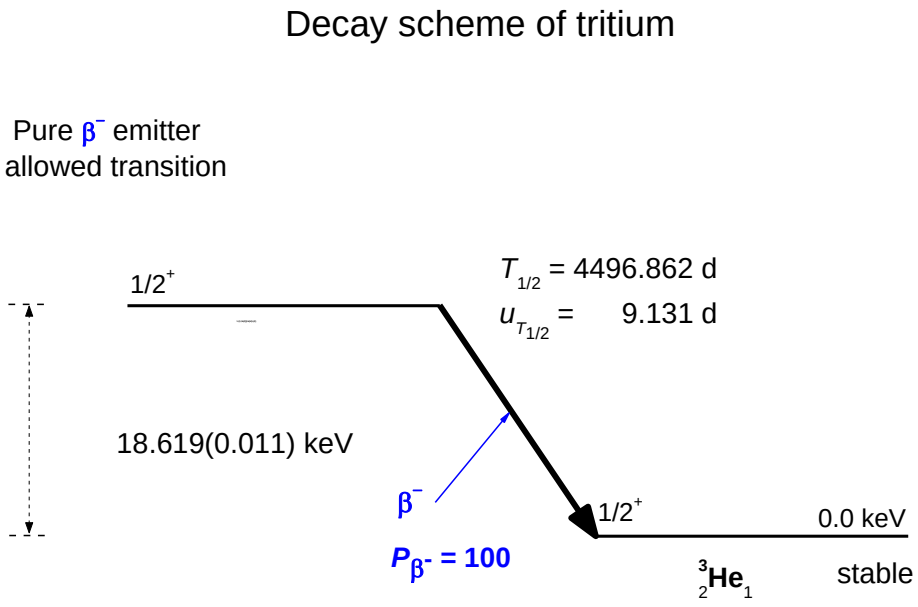

Figure 1 – Decay scheme of ^{3}H, taken from Monographie BIPM-5 (2006) *Table de Radionucléides*, BIPM, Pavillon de Breteuil, F-92310 Sèvres, pp. 1-4, Evaluation by V.P. Chechev.

Table 1 - List of participants

ANSTO	Australian Nuclear Science and Technology Organisation, Lucas Heights, Australia (Li Mo and Lindsey Bignell)
BARC	Bhabha Atomic Research Centre, Trombay, Mumbai, India (Leena Joseph, R. Anuradha and D.B. Kulkarni)
BIPM	Bureau International des Poids et Mesures, Sèvres, France (S. Courte and G. Ratel, source preparation; M. Nonis and G. Ratel, measurements)
ČMI-IIR	Czech Metrology Institute – Inspectorate for Ionizing Radiations, Prague, Czech Republic (P. Auerbach and J. Sochorová)
CNEA	Comisión Nacional de Energía Atómica, Laboratorio de Metrología de Radioisótopos, Buenos Aires, Argentina (Dario Rodrigues and Pablo Arenillas)
IFIN	National Institute of Research and Development for Physics and Nuclear Engineering - "Horia Hulubei" - IFIN-HH, Bucharest, Romania (Anamaria Cristina Wätjen, Andrei Antohe, Maria Sahagia)
IRMM	Institute for Reference Materials and Measurements, Geel, Belgium (T. Altzitzoglou)
KRISS	Korea Research Institute of Standards and Science, Yuseong, Daejon, Republic of Korea (K.B. Lee, Tae Soon Park, Jong Man Lee and Sang-Han Lee)
LNE-LNHB	Laboratoire National d'Essais – Laboratoire National Henri Becquerel, Gif-sur-Yvette, France (P. Cassette, C. Bobin and E. Verdeau)
MKEH	Magyar Kereskedelmi Engedélyezési Hivatal (Hungarian Trade Licensing Office) Budapest, Hungary (K. Rózsa, L. Szücs and A. Zsinka)
NIM	National Institute of Metrology, Beijing, Peoples Republic of China (Juncheng Liang and Jiacheng Liu, source preparation; Yang Yuandi, Juncheng Liang and Jiacheng Liu, measurements)
NMISA	National Metrology Institute of South Africa, Cape Town, South Africa (B.R.S. Simpson, M.J. van Staden, J. Lubbe and W.M. van Wyngaardt)
NPL	National Physical Laboratory, Teddington, United Kingdom (Hilary Phillips)
PTB	Physikalisch-Technische Bundesanstalt, Braunschweig, Germany (Ole Nähle and Karsten Kossert, TDCR; Karsten Kossert, CIEMAT/NIST; Oliver Ott, γ-spectrometry for impurity check)
RC	Institute of Atomic Energy, Radioisotope Centre POLATOM, Otwock-Świerk, Poland (R. Broda, T. Dziel and A. Muklanowicz)

Note: Since the comparison was carried out, the names and acronyms of some participating organizations have changed. These are: RC (now POLATOM) and IRMM (now JRC).

Table 2 – Characteristics of the distributed solutions

Laboratory	Ampoule number from the mother solution H3-LNHB-11-07	Adsorption	Impurity
ANSTO	N° 1	No adsorption found[1)]	No γ impurity [8)]
BARC			
BIPM	N° 23		
ČMI-IIR			
CNEA	N° 5		
IFIN	N° 6		
IRMM	N° 8	[2)]	
KRISS			
LNE-LNHB	N° 22 & N° 23		
MKEH	N° 3	[3)]	
NIM		No adsorption found[4)]	
NMISA	N° 15	No adsorption found [5)]	
NPL	N° 19		No γ impurity[9)]
PTB	N° 20	[6)]	No γ impurity [10)]
RC	N° 21	No significant adsorption found [7)]	No γ impurity [11)]

[1)] after measure of the original ampoule in the TDCR system after twice rinsing with Ultima Gold™ LLT.
[2)] 110 Bq after first rinsing, 3 Bq after the second rinsing and 0 Bq after the third rinsing. Only included in the uncertainty budget.
[3)] a mass of 5.0044 g of solution was found in the ampoule.
[4)] after three rinsings. A mass of 4.88896 g of solution was found in the ampoule.
[5)] after three rinsings. A mass of 5.02195 g of solution was found in the ampoule.
[6)] a mass of 5.00363 g of solution was found in the ampoule.
[7)] 164 Bq remaining in the original ampoule after two rinsings.
[8)] detection by γ spectrometry with HPGe detector.
[9)] detection by γ spectrometry with HPGe detector.
[10)] by γ spectrometry.
[11)] detection by γ spectrometry with HPGe detector, with a detection limit < 0.1 %.

Table 3 – List of the methods used

Method acronym Number of times used	Description of the method	Laboratories using this method
CIEMAT/NIST method 4P-LS-BP-00-00-CN (1 x)	4π liquid-scintillation counting using the CIEMAT/NIST method with ^{3}H as an external standard,	NIM
CIEMAT/NIST method 4P-LS-MX-00-00-CN (1 x)	4π liquid-scintillation counting using the CIEMAT/NIST method with ^{54}Mn as an external standard	PTB
TDCR method 4P-LS-BP-00-00-TD (13 x)	4π liquid-scintillation counting using the Triple-to-Double-Coincidence-Ratio method	ANSTO, BIPM, ČMI-IIR, CNEA, IFIN, IRMM, KRISS, LNE-LNHB, NIM, NMISA, NPL, PTB, RC
TDCR method 4P-LS-BP-00-00-TD (1 x)	4π liquid-scintillation counting using the Triple-to-Double-Coincidence-Ratio method and a digital MAC3[12)]	LNE-LNHB
TDCR method 4P-LS-BP-GH-GR-TT (1 x)	4π liquid-scintillation counting using the Triple-to-Double-Coincidence-Ratio method coupled to the Compton efficiency tracing using ^{241}Am	LNE-LNHB
4π(LS)β efficiency tracing 4P-LS-MX-00-00-ET (3 x)	4πβ liquid-scintillation secondary standardization against an ^{3}H standard	BARC, IRMM, NIM
4π(LS)β–γ efficiency tracing 4P-LS-MX-00-00-ET (1 x)	4πβ–γ efficiency tracing using the liquid-scintillation technique using ^{54}Mn as a tracer	MKEH
4π(PC) β 4P-PC-BP-00-00-IG	Differential proportional counting	LNE-LNHB, NPL

[12)] See http://www.nucleide.org/ICRM_LSCWG/icrmtdcr.htm#MAC3, accessed on 13th April 2018

Table 4 – Components of the standard uncertainties in % of the activity concentration

Uncertainty components	Laboratory Method					
	ANSTO 4π(LS)β TDCR			BARC 4π(LS)β secondary standardization		
	Relative value / (%)	Uncertainty evaluation type	Sensitivity factor	Relative value / (%)	Uncertainty evaluation type	Sensitivity factor
counting statistics	0.29	A		0.5[13)]	A	
weighing	0.30	B		0.06	B	
background	0.10	B		[14)]	A	
half-life	0.10	B		0.01	B	
kB	0.59	A				
standard deviation between liquid scintillators	0.15	A				
tracer				0.6	B	
extrapolation of efficiency curve				1.35	A	
quench indicator parameter				0.25	A	
combined uncertainty (as quadratic sum of all uncertainty components)	**0.75**			**1.58**		

[13)] including background
[14)] included in the counting statistics

Table 4 – Components of the standard uncertainties in % of the activity concentration (continued)

Uncertainty components	Laboratory Method					
	BIPM 4π(LS)β TDCR			ČMI-IIR 4π(LS)β TDCR		
	Relative value / (%)	Uncertainty evaluation type	Sensitivity factor	Relative value / (%)	Uncertainty evaluation type	Sensitivity factor
counting statistics	< 0.24	A		0.25		
weighing	< 0.015	B		0.01		
dead time				0.1		
background	[15)]	A		0.05		
adsorption				0.2		
counting time	negligible[16)]					
impurities	not determined					
input parameters and statistical model				0.6		
half-life	0.18[17)]	B	0.0092			
extrapolation of efficiency curve with respect to *kB*	< 0.35	B				
dispersion of individual source measurements	1.41	B				
combined uncertainty (as quadratic sum of all uncertainty components)	**1.48**			**0.68**		

[15)] included in the counting statistics
[16)] quartz precision better than 10^{-3}
[17)] for the 60 d of measurements (measurement to reference date uncertainty).

Table 4 – Components of the standard uncertainties in % of the activity concentration (continued)

Uncertainty components	Laboratory Method					
	CNEA 4π(LS)β TDCR			IFIN 4π(LS)β TDCR		
	Relative value / (%)	Uncertainty evaluation type	Sensitivity factor	Relative value / (%)	Uncertainty evaluation type	Sensitivity factor
counting statistics	0.10	A		0.63	A	
weighing	0.08	B		0.1	B	
background double coincidence				0.01	B	0.01
background triple coincidence				0.08	B	0.04
kB				0.6[18)]		
input parameters and statistical model	0.90	B				
decay-scheme parameters	0.02	B				
measurement variability	0.10					
combined uncertainty (as quadratic sum of all uncertainty components)	**0.91**			**0.88**		

[18)] difference between activities calculated using two successive *kB* values

Table 4 – Components of the standard uncertainties in % of the activity concentration (continued)

Uncertainty components	Laboratory Method					
	IRMM 4π(LS)β TDCR			IRMM 4π(LS)β efficiency tracing		
	Relative value / (%)	Uncertainty evaluation type	Sensitivity factor	Relative value / (%)	Uncertainty evaluation type	Sensitivity factor
counting statistics	0.3	A	1	0.1	A	1
weighing	0.2	A	1	0.2	A	1
dead time	0.2	A	1	0.1	A	1
background	0.1	A	1	0.05	A	1
counting time	0.01	A	1	0.05	A	1
adsorption	0.05	B	1	0.05	B	1
impurities	0.05	B	1	0.05	B	1
tracer				0.7	A	1
Interpolation from calibration curve				0.5	A	1
input parameters and statistical model	0.9	B	1			
half-life	0.01	B	1	0.01	B	1
photomultiplier asymmetry	0.1	A	1			
combined uncertainty (as quadratic sum of all uncertainty components)	**1.0**			**0.9**		

Table 4 – Components of the standard uncertainties in % of the activity concentration (continued)

Uncertainty components	Laboratory Method					
	KRISS 4π(LS)β TDCR			LNE-LNHB Differential proportional counter		
	Relative value / (%)	Uncertainty evaluation type	Sensitivity factor	Relative value / (%)	Uncertainty evaluation type	Sensitivity factor
counting statistics	0.17[19)]	A	1	0.05	A	
weighing	0.05[20)]	B	1			
background				0.3	A	
volume				0.5	B	
input parameters and statistical model	0.50[21)]	B	1			
quenching	0.32[22)]	B	1			
half-life				0.001	B	
kB ionization quenching factor	1.78[23)]	B	1			
photomultiplier asymmetry	0.14[24)]	B	1			
extrapolation of efficiency curve threshold				0.1[25)]	B	
correction due to the non-ionising particles				0.07	B	
combined uncertainty (as quadratic sum of all uncertainty components)	**1.89**			**0.6**		

[19)] standard deviation of the counting of 9 samples
[20)] 10 mg mass sampling uncertainty due to the systematic effects of the micro-balance used
[21)] dependence on the Poisson and Pólya statistics and on the end point energy of the ^{3}H β-spectrum
[22)] dependence on the liquid scintillators used (Ultima Gold® and Hionic Fluor®)
[23)] standard uncertainty for the ^{3}H efficiency difference for $kB = 0.005$ through $kB = 0.018$
[24)] difference between the TDCR models with unequal or equal photomultiplier gains
[25)] correction due to the low-level threshold

Table 4 – Components of the standard uncertainties in % of the activity concentration (continued)

Uncertainty components	Laboratory Method					
	LNE-LNHB 4π(LS)β TDCR CET (Compton Efficiency Tracing)			LNE-LNHB 4π(LS)β TDCR		
	Relative value / (%)	Uncertainty evaluation type	Sensitivity factor	Relative value / (%)	Uncertainty evaluation type	Sensitivity factor
counting statistics	0.2	A	1	0.16	A	
weighing	0.1	B	1	0.01	B	
dead time	0.01	B	1	< 0.01	B	
background	0.03	A	1	0.03	A	
pile-up	0.02	B	1	0.02	B	
counting time	0.0001	B	1	0.0001	B	
input parameters and statistical model	0.3	B	1			
Quenching (*kB* factor)	0.13	B	1	0.64	B	
half-life	0.01	B	1	0.01	B	
influence of the scintillator	0.1	B	1			
counter effect				0.31[26)]	B	
combined uncertainty (as quadratic sum of all uncertainty components)	**0.41**			**0.73**		

[26)] variability observed between 2 different TDCR counters

Table 4 – Components of the standard uncertainties in % of the activity concentration (continued)

Uncertainty components	Laboratory Method					
	LNE-LNHB 4π(LS)β TDCR coupled with a digital MAC3 unit			MKEH 4π(LS)β efficiency tracing with ^{54}Mn as a tracer		
	Relative value / (%)	Uncertainty evaluation type	Sensitivity factor	Relative value / (%)	Uncertainty evaluation type	Sensitivity factor
counting statistics	0.1	B	1	0.16	A	1
weighing	0.05	B	1	0.01	B	1
dead time	0.01[27)]	B	1			
background	0.05	A	1	0.003	B	1
input parameters and statistical model	0.1	B	1			
quenching (*kB* factor)	1.1	B	1			
half-life	0.01	B	1	0.19	B	1
accidental coincidences	0.1[28)]	B	1			
counter effect	0.31[29)]	B	1			
activity concentration of the MKEH standard				2.31[30)]	B	1
reproducibility of the TriCarb 2910TR spectrometer[31)]				0.73	B	
combined uncertainty (as quadratic sum of all uncertainty components)	**1.1**			**2.4**		

[27)] live-time
[28)] photomultipliers self-coincidences
[29)] variability observed between 2 different TDCR counters
[30)] uncertainty for the standardization of ^{54}Mn given on next page
[31)] due to geometry, vial dimensions, etc.

Table 4 – Components of the standard uncertainties in % of the activity concentration (continued)

Uncertainty components	Laboratory Method		
	MKEH 4π(NaI(Tl))γ coincidence counting standardization of the ^{54}Mn solution used as external standard		
	Relative value / (%)	Uncertainty evaluation type	Sensitivity factor
counting statistics	1.5	A	1
weighing	0.01	B	1
dead time	0.006	B	1
background	0.01	B	1
counting time	0.006	B	1
tracer	0.031	B	1
decay-scheme parameters	0.005	B	1
half-life	< 0.001	B	1
extrapolation of efficiency curve	1.75	B	1
coincidence resolving time	0.017	B	1
delay mismatch	0.05	B	1
combined uncertainty (as quadratic sum of all uncertainty components)	**2.31**		

Table 4 – Components of the standard uncertainties in % of the activity concentration (continued)

Uncertainty components	Laboratory Method					
	NIM 4π(LS)β CIEMAT/NIST			NIM 4π(LS) β TDCR		
	Relative value / (%)	Uncertainty evaluation type	Sensitivity factor	Relative value / (%)	Uncertainty evaluation type	Sensitivity factor
counting statistics	0.10	A	1	0.10	A	1
weighing	0.05	B	1	0.05	B	1
dead time	0.01	B	1	< 0.01[32)]	B	1
background				0.2	A	1
tracer	0.20	B	1			
input parameters and statistical model	0.86	B	1	0.65[33)]	B	1
quenching	0.02	B	1			
decay-scheme parameters	0.10	B	1			
half-life	< 0.01	B	1	< 0.01	B	1
extrapolation of efficiency curve with respect to *kB*						
dispersion of individual source measurements						
combined uncertainty (as quadratic sum of all uncertainty components)	**0.90**			**0.69**		

[32)] live-time clock
[33)] including TDCR and *kB* values

Table 4 – Components of the standard uncertainties in % of the activity concentration (continued)

Uncertainty components	Laboratory Method					
	NMISA 4π(LS)β TDCR			NPL 4π(LS)β TDCR		
	Relative value / (%)	Uncertainty evaluation type	Relative sensitivity factor	Relative value / (%)	Uncertainty evaluation type	Sensitivity factor
counting statistics	0.10	A	0.5112	0.08		
weighing	0.05	B	1.0000	0.03		
dead time	0.05	B	0.0050	0.02		
background	0.10	A	0.0352	0.02		
pile-up				0.03		
counting time	0.001	B	1.0000	0.001		
adsorption	0.05	B	0.5000	0.001		
impurities				0.1		
input parameters and statistical model	0.47	B	0.0423	0.94		
half-life	0.01	B	0.0492	0.001		
afterpulsing	0.5	B	0.0087			
combined uncertainty (as quadratic sum of all uncertainty components)	**0.71**			**0.95**		

Table 4 – Components of the standard uncertainties in % of the activity concentration (continued)

Uncertainty components	Laboratory Method					
	NPL Differential proportional counter			PTB 4π(LS)β CIEMAT/NIST		
	Relative value / (%)	Uncertainty evaluation type	Sensitivity factor	Relative value / (%)	Uncertainty evaluation type	Sensitivity factor
counting statistics	0.52			0.48	A	
weighing				0.02	B	
dead time	0.1			0.10	B	
background	0.5			0.05	A	
counting time	< 0.001			0.01	B	
adsorption				0.05	B	
impurities	< 0.001			0.20[34)]	B	
dilution	1.56					
conversion to gas	0.6					
half-life	0.04			< 0.01	B	
extrapolation	0.4[35)]					
input parameters and statistical model				0.70	B	
interpolation from calibration curve				[36)]		
decay-scheme parameters				[37)]		
combined uncertainty (as quadratic sum of all uncertainty components)	**1.87**					

[34)] contains also contribution due to the purity of ^{54}Mn
[35)] losses below threshold
[36)] included in tracer uncertainty
[37)] combined with input parameters

Table 4 – Components of the standard uncertainties in % of the activity concentration (continued)

Uncertainty components	Laboratory Method					
	PTB 4π(LS)β TDCR			RC 4π(LS)β TDCR		
	Relative value / (%)	Uncertainty evaluation type	Sensitivity factor	Relative value / (%)	Uncertainty evaluation type	Sensitivity factor
counting statistics	0.20	A		0.05		
weighing	0.02	B		0.02		
dead time	0.03	B				
background	0.05	A		0.04		
counting time	0.01	B		0.001		
adsorption	0.05	B		0.07		
impurities	0.05[38)]	B				
input parameters and statistical model	0.90[39)]	B		0.4		
decay-scheme parameters	[40)]			0.001		
half-life	< 0.01	B		0.003		
measurement of TDCR and asymmetry correction	0.08	B				
combined uncertainty (as quadratic sum of all uncertainty components)	**0.93**			**0.41**		

[38)] no impurity detected
[39)] including uncertainty of the model for $Q(E)$ and kB
[40)] combined with input parameters

Table 5 – Results

Laboratory Method	Activity concentration ($kBq\ g^{-1}$)	Combined standard uncertainty ($kBq\ g^{-1}$)	Relative standard uncertainty / %
ANSTO			
4π(LS)β TDCR	37.46[41)]	0.28	0.75
BARC			
4π(LS)β efficiency tracing (with ^{3}H as a tracer)	36.46	0.58	1.6
BIPM			
4π(LS)β TDCR	35.66[42)]	0.53	1.5
ČMI-IIR			
4π(LS)β TDCR	36.40	0.25	0.68
CNEA			
4π(LS)β TDCR	37.65	0.34	0.91
IFIN			
4π(LS)β TDCR	36.49	0.32	0.88
IRMM			
4π(LS)β TDCR	37.55	0.38	1.0
4π(LS)β efficiency tracing (with ^{3}H as a tracer)	37.7	0.3	0.9
KRISS			
4π(LS)β TDCR	37.60	0.71	1.9
LNE-LNHB			
Differential proportional counting	36.65	0.22	0.60
4π(LS)β TDCR with CET	36.40	0.15	0.41
4π(LS)β TDCR	36.75	0.27	0.73
4π(LS)β TDCR with a digital MAC3	36.60	0.41	1.1

[41)] arithmetic mean of the individual results
[42)] arithmetic mean of the individual results for five different sources

Table 5 – Results (continued)

Laboratory Method	Activity concentration ($kBq\ g^{-1}$)	Combined standard uncertainty ($kBq\ g^{-1}$)	Relative standard uncertainty / %
MKEH			
4π(LS)β efficiency tracing (with ^{54}Mn as a tracer)	31.15	0.76	2.5
NIM			
4π(LS)β CIEMAT/NIST	37.30	0.33	0.90
4π(LS)β TDCR	37.03	0.26	0.70
NMISA			
4π(LS)β TDCR	37.56	0.27	0.71
NPL			
Differential proportional counting	37.29[43)]	0.70	1.9
4π(LS)β TDCR	37.51	0.36	0.95
PTB			
4π(LS)β CIEMAT/NIST	36.69	0.37	1.0
4π(LS)β TDCR	36.69	0.34	0.93
RC			
4π(LS)β TDCR	37.90	0.16	0.41

[43)] mean of eight measurements

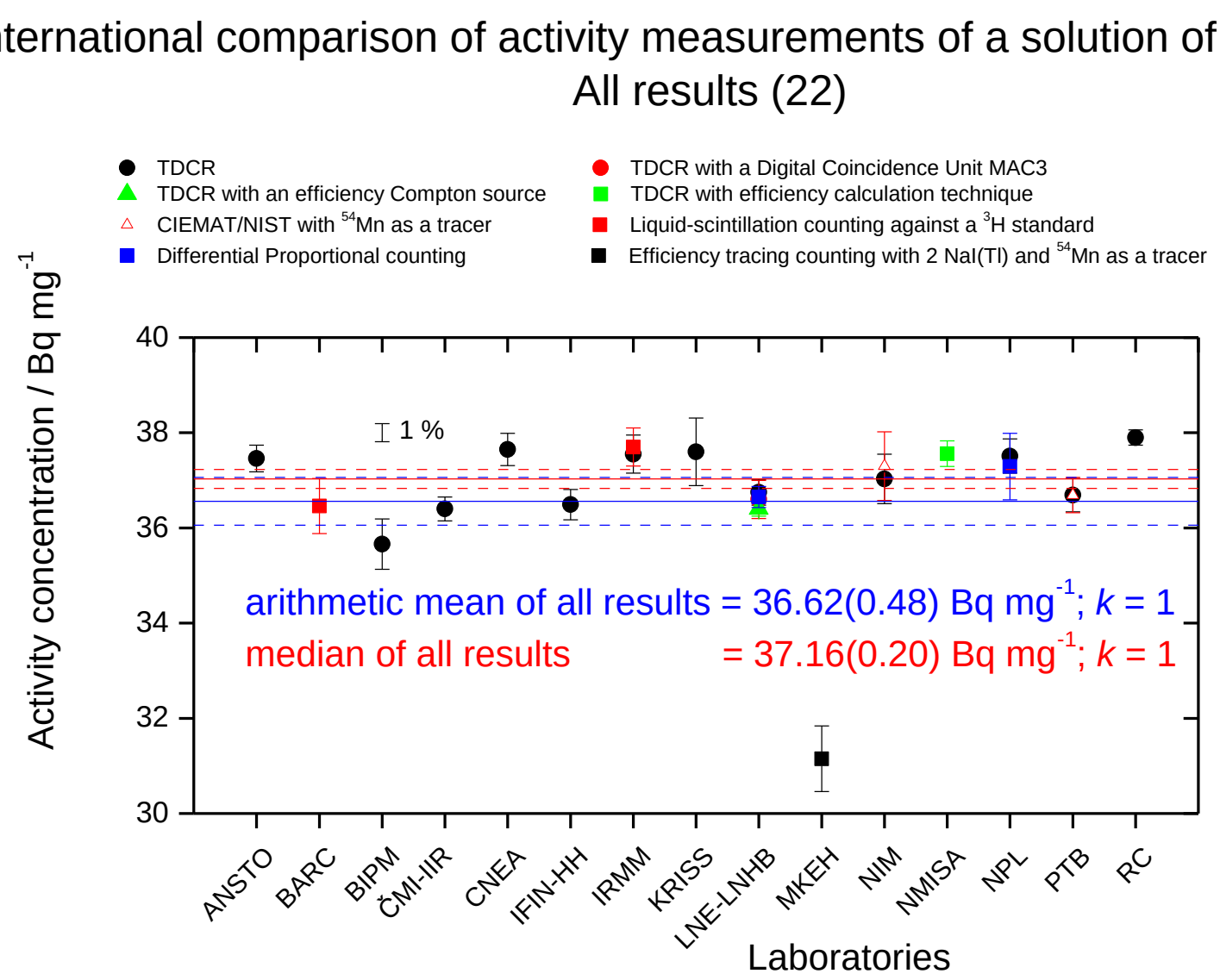

Figure 2 – Individual results of the international comparison of activity concentration of a solution of ^{3}H (22 individual results).

Table 6 – Results: one value per participating institute

Laboratory	Activity concentration (kBq g^{-1})	Combined standard uncertainty (kBq g^{-1})	Relative standard uncertainty / %	Result used for the KCRV (kBq g^{-1})
ANSTO	37.46	0.28	0.75	37.46(28)
BARC	36.46	0.58	1.58	–
BIPM	35.66	0.53	1.48	35.66(53)
ČMI-IIR	36.40	0.25	0.68	36.40(25)
CNEA	37.65	0.34	0.91	37.65(34)
IFIN	36.49	0.32	0.88	36.49(32)
IRMM	37.63[44)]	0.34[49)]	0.9	37.55(38) [TDCR]
KRISS	37.60	0.71	1.89	37.60(71)
LNE-LNHB	36.62[45)]	0.22[50)]	0.6	36.62(22)
MKEH	31.15	0.76	2.45	–
NIM	37.03[46)]	0.26[51)]	0.70	37.03(26)
NMISA	37.56	0.27	0.71	37.56(27)
NPL	37.51[47)]	0.36[52)]	0.95	37.51(36)
PTB	36.69[48)]	0.26[53)]	0.69	36.69(26)
RC	37.90	0.16	0.41	37.90(16)

Notes: The result from BARC was omitted from the calculation of the KCRV as the method used a ^{3}H tracer. The result from MKEH was identified as an outlier by the PMM method.

[44)] weighted mean of the values obtained for the two methods
[45)] final result taken as the mean of the value obtained by the gas counting method and the mean of the three liquid-scintillation determinations, i.e. 36.65(0.22) kBqq^{-1} and 36.58(0.18) kBq g^{-1} respectively
[46)] TDCR value
[47)] TDCR value
[48)] weighted mean of the two results
[49)] uncertainty of the most precise determination (efficiency tracing)
[50)] uncertainty taken as the largest uncertainty of the two results quoted in note [45)]
[51)] TDCR value; originally given for $k = 2$
[52)] TDCR value
[53)] uncertainty taken as the largest individual uncertainty 0.37 kBqq^{-1} (obtained for the CIEMAT/NIST method) divided by $\sqrt{2}$

Table 7. Table of degrees of equivalence and introductory text for ^{3}H

Key comparison CCRI(II)-K2.H-3

MEASURAND : **Activity concentration of ^{3}H**

Key comparison reference value: the power moderated weighted mean of the results x_R = 37.10 kBq.g^{-1}
with a standard uncertainty, u_R = 0.18 kBq.g^{-1}
The value x_i is the activity concentration 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 kBq.g^{-1}, and
$U_i = 2((1 - 2w_i)u_i^2 + u_R^2)^{1/2}$, where w_i is the weight of laboratory *i* contributing to the calculation of x_R.

Lab *i*	D_i / kBq.g^{-1}	U_i / kBq.g^{-1}
ANSTO	0.4	0.6
BARC	-0.6	1.2
BIPM	-1.4	1.1
CMI-IIR	-0.7	0.6
CNEA	0.6	0.7
IFIN	-0.6	0.7
IRMM	0.5	0.8
KRISS	0.5	1.4
LNE-LNHB	-0.5	0.5
MKEH	-5.9	1.6
NIM	-0.1	0.6
NMISA	0.5	0.6
NPL	0.4	0.8
PTB	-0.4	0.6
RC	0.8	0.5

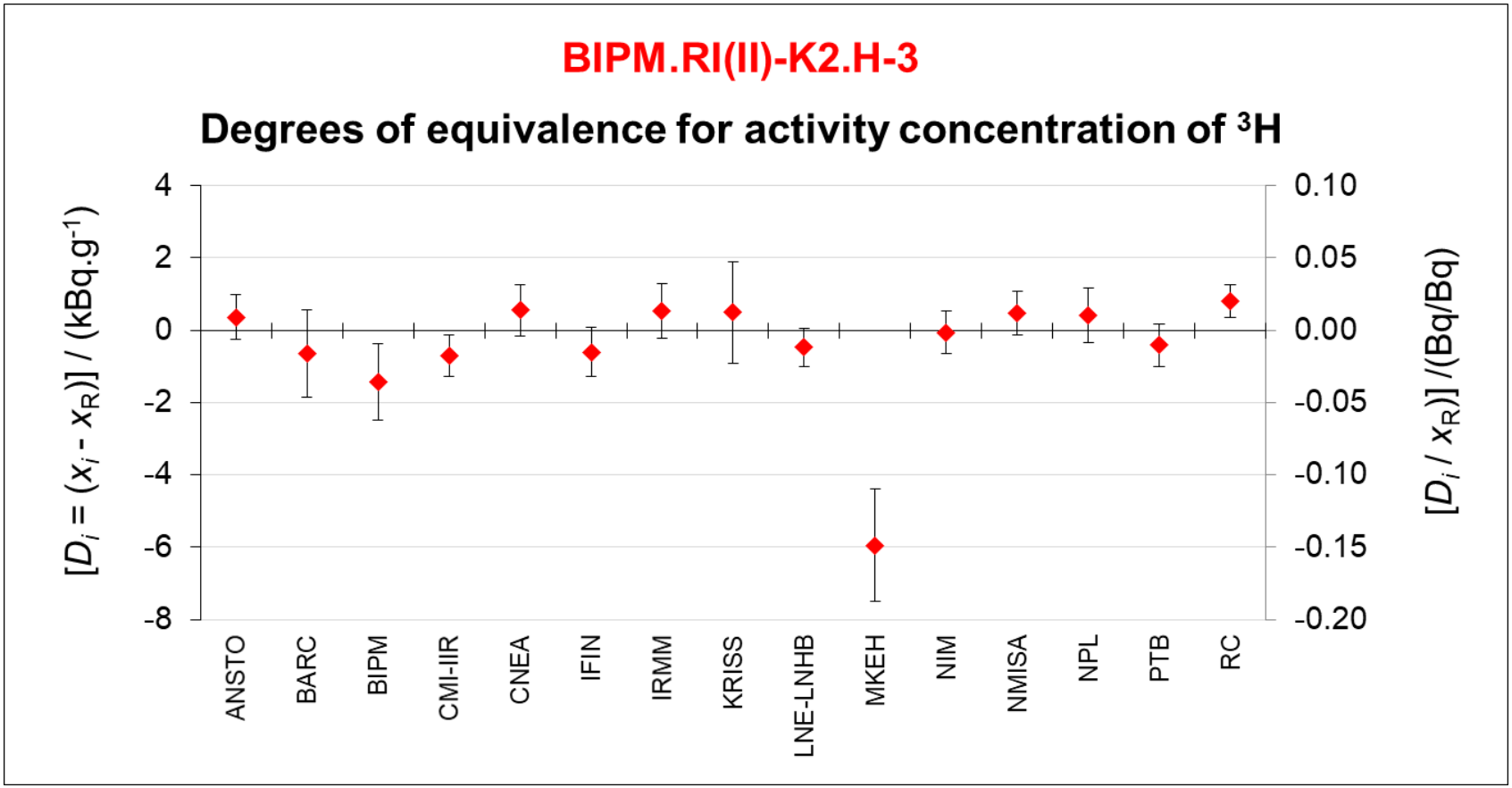

Figure 3: Graph of degrees of equivalence with the KCRV for ^{3}H (as it appears in Appendix B of the MRA).

The KCRV and the degrees of equivalence have been evaluated with the Power-Moderated weighted Mean (PMM) [2], k = 1. The result from BARC was omitted from the calculation of the KCRV as the method used a ^{3}H tracer. The result from MKEH was identified as an outlier by the PMM method.