APMP comparison of the activity measurements of Ba–133 (APMP.RI(II)-K2.Ba-133) and links to the SIR

A. Yunoki[1)], L. Mo[2)], V.V. Shaha[3)], Nazaroh[4)], W.M. van Wyngaardt[5)], M. C. Yuan[6)], D. D. Nhan[7)], T. S. Park[8)], Y. Yuandi[9)], T. Soodprasert[10)], C. Michotte[11)]

[1)]NMIJ, [2)]ANSTO, [3)]BARC, [4)]PTKMR, [5)]NMISA, [6)]INER, [7)]INST, [8)]KRISS, [9)]NIM, [10)]OAP, [11)]BIPM

Abstract

The international comparison of radioactivity measurements of ^{133}Ba (APMP.RI(II)-K2.Ba-133) was carried out within the framework of the Asia-Pacific Metrology Programme (APMP). In total, ten institutes took part in the comparison, and five institutes undertook absolute measurements. Nine of the results agreed with each other within their specified uncertainties. The source from the same radioactive solution that was used in the comparison was sent to the BIPM/SIR in order to link this regional comparison to the BIPM key comparison reference value (KCRV). The degrees of equivalence between the APMP comparison and the other measurements for ^{133}Ba are presented.

1. Introduction

The regional key comparison of ^{133}Ba was discussed at the 5th meeting of APMP/TCRI in Korea, and registered as the official RMO key comparison, APMP.RI(II)-K2.Ba-133. The coordinating laboratory was the NMIJ/AIST. Ten institutes took part in the comparison. The radioactive sources were sent in February to April 2006 to the all participants. All of the ten institutes measured with their own methods and reported to the coordinating laboratory. Nine of the ten results agreed with each other within their specified uncertainties. The source from the same radioactive solution was also sent to the BIPM/SIR [1] in order to link the results of this regional comparison to the BIPM key comparison reference value (KCRV).

2. Source preparation

The original solution of ^{133}Ba was provided by Ritverc GmbH, with the chemical form of $BaCl_2$, and approximate specific activity of 37 MBq/g. After a quick activity measurement and impurity check, the original solution was diluted to be approximately 1.8 MBq/g by adding 0.1 N HCl with 50 μg/g of $BaCl_2$ carrier. The diluted solution was then transferred into the NMIJ standard ampoules and also into the BIPM/NIST type ampoule. The solution in NMIJ type ampoules was sent to all the participants. The solution in BIPM/NIST type ampoule was sent to the BIPM/SIR. All these ampoules were measured in the NMIJ ionization chambers before shipping,

and the standard deviation of specific output current (pA/g) was within 0.015 %. Ampoule numbers, mass and the institutes where the solutions were sent are listed in table 1.

Table 1 Ampoule numbers, mass and the institutes

Ampoule No.	Mass of solution / g	Institutes
b0601	3.5994	BIPM
a0603	5.0100	KRISS
a0604	4.9940	INER
a0605	4.9984	PTKMR
a0606	5.0222	OAP
a0607	4.9880	BARC
a0608	4.9960	ANSTO
a0610	4.9966	NIM
a0611	5.1212	NMISA
a0612	4.9988	INST
j0614	5.0213	NMIJ

3. Participants and standardization methods

The details of participating institutes are listed in table 2. The NMISA is within the AFRIMETS and other nine institutes are within the APMP.

Table 2. List of the institutes participating in the APMP. RI(II)-K2. Ba-133

NMI	Full name	Country	Regional metrology organization
ANSTO	Australian Nuclear Science and Technology Organisation	Australia	APMP
BARC	Bhabha Atomic Research Centre	India	APMP
PTKMR	Pusat Teknologi Keselamatan Dan Metrologi Radiasi	Indonesia	APMP
NMISA	National Metrology Institute of South Africa	South Africa	AFRIMETS
INER	Institute of Nuclear Energy Research	Chinese Taipei	APMP
INST	Institute of Nuclear Science and Technology	Viet Nam	APMP
KRISS	Korea Research Institute of Standards and Science	Korea	APMP
NIM	National Institute of Metrology	China	APMP
NMIJ	National Metrology Institute of Japan	Japan	APMP
OAP	Office of Atoms for Peace	Thailand	APMP

4. Results

The standardization methods used by each institute, the activity value determined with the uncertainties associated with the activity value and E_n evaluations are listed in table 3. Figure 1 shows the activity values relative to the mean value for each institute listed in table 3. As shown in the Fig. 1 and table 3, the E_n values are less than 1 for most results. The present KCRV (x_R) of 43.932 (67) MBq [2] is indicated in Fig. 1, to which this data will be linked by using the A_e value of NMIJ (Pilot laboratory) of 44.030 (100) MBq [2]. The uncertainty budgets of each institute are listed in table 4.

The ANSTO, BARC and the OAP measured the activity using a 4π ionization chamber to detect gamma rays. The INST measurements used both a 4π ionization chamber for gamma rays and a liquid scintillation counter with the efficiency tracer technique. The PTKMR measured the activity using a Ge(HP) gamma-ray spectrometer. The NMISA used a two-phototube LS detector for an e,X-counter and made coincidence measurements with a NaI(Tl) scintillation γ-counter [3]. The INER, NIM and the NMIJ measured the activity using a proportional counter for an e,X-counter and made coincidence measurements with a NaI(Tl) scintillation γ-counter. The KRISS measured the activity using a pressurized proportional counter for an e,X-counter and made coincidence measurements with a NaI(Tl) scintillation γ-counter. The NIM also measured the activity using a liquid scintillation counter with the CIEMAT/NIST method (CN2003) with ^{54}Mn used as a tracer.

The NMISA identified, using gamma-ray spectroscopy with a NaI(Tl) detector, that Cs-134 was negligible as an impurity, if present at all. The INER reported that 4.5E-5 Bq/Bq (ratio to Ba-133) of Cs-134 was identified as an impurity by gamma-ray spectroscopy using a Ge(HP) detector. The NIM reported that less than 1E-6 Bq/Bq (ratio to Ba-133) of Ba-131 and Ba-134 was identified as an impurity by gamma-ray spectroscopy using a Ge(HP) detector. The reported concentrations were all negligible.

Table 3. Standardization methods of the participants and their results

NMI	Method used (see Appendix 1)	Activity / (kBq/g)*	Relative uncertainty / % (k = 2)	E_n value**	Date of measurement
ANSTO	4P-IC-GR-00-00-00	1835.9	0.82	-0.34	2006/05/01
BARC	4P-IC-GR-00-00-00	1772.4	2.8	-1.4	2006/06/30
PTKMR	SA-GH-GR-00-00-00	1891.6	3.2	0.83	2006/04/01
NMISA	4P-LS-MX-NA-GR-CO	1831.7	0.49	-0.82	2006/05/18
INER	4P-PC-MX-NA-GR-CO	1841.2	0.60	-0.036	2006/06/06
INST	4P-IC-GR-00-00-00 4P-LS-MX-00-00-ET	1932.8	5.0	0.94	2006/06/28
KRISS	4P-PP-MX-NA-GR-CO	1844.6	0.65	0.20	2006/11/23
NIM	4P-PC-MX-NA-GR-CO 4P-LS-MX-00-00-CN	1851	1.3	-0.37	2006/06/20
NMIJ	4P-PC-MX-NA-GR-CO	1841.7	0.44	–	2006/02/10
OAP	4P-IC-GR-00-00-00	1830	3.5	-0.18	2006/04/14
Average		1847.3	1.4		

* reference date = 0:00 h UTC of 1 April 2006

** E_n = (Each Result - Pilot Lab's result) / SQRT(U_{each}^2+U_{pilot}^2)

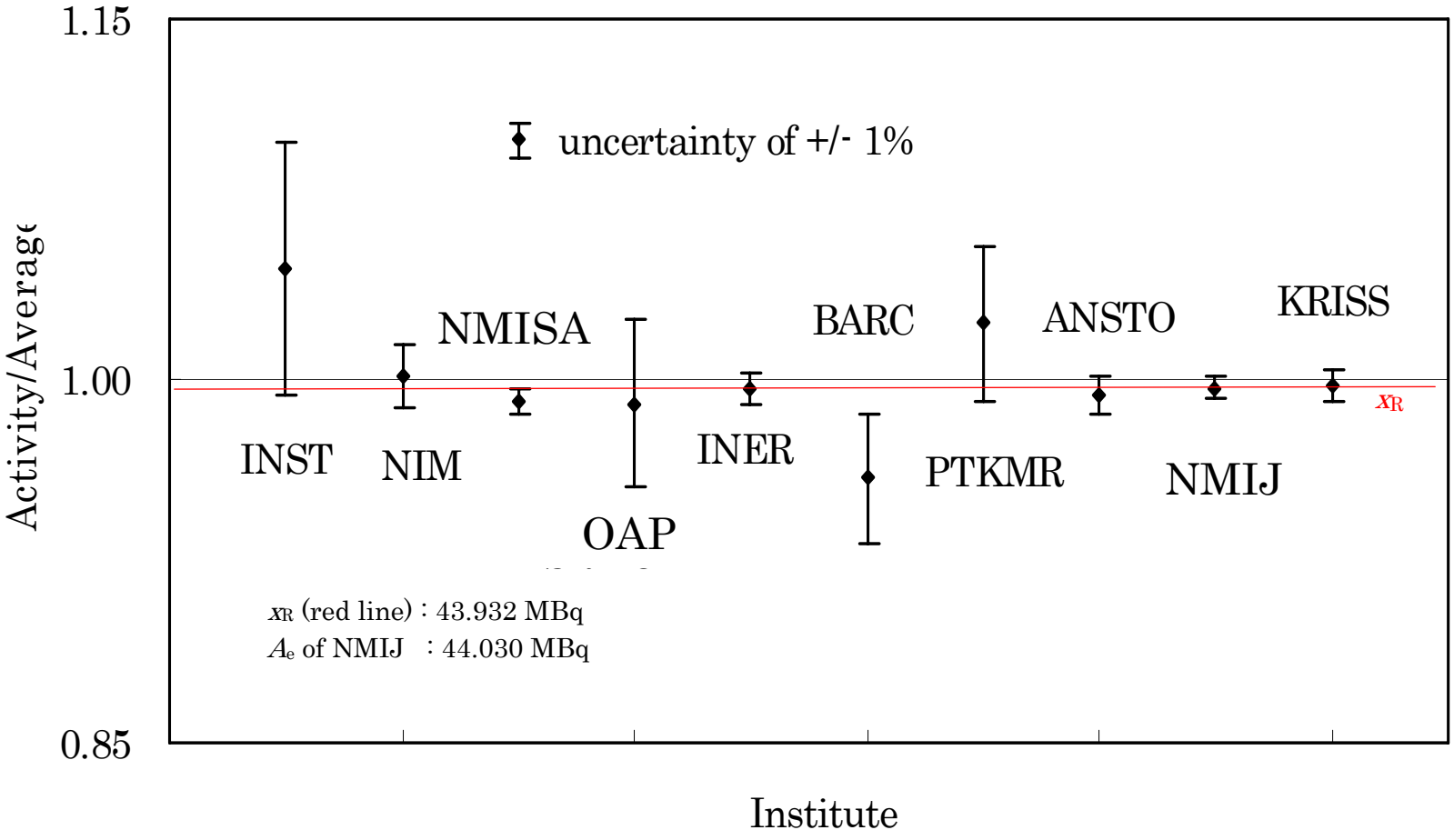


Figure 1 Results of APMP.RI(II)-K2.Ba-133 with $k = 2$ uncertainties

Table 4. Uncertainty components and estimated relative values / 10^{-2}.

Item No.	Function	ANSTO	BARC	PTKMR	NMISA	INER	INST[*1]
1	counting statistics	0.032 (current)	0.32	0.21	0.08	0.16	0.53
2	weighing	0.002	--	0.1	0.035	0.02	0.07
3	dead time	--	--	0.4	0.04	0.01	--
4	background	0.001	--	--	0.01	0.01	0.1
	pile up	--	--	--	--	--	--
5	resolving time	--	--	--	0.002	0.01	--
6	Gandy effect	--	--	--	--	--	--
7	counting time	--	--	0.1	0.001	0.01	0.1
8	adsorption	--	--	--	0.002	--	--
9	impurities	--	--	--	--	0.01	--
10	tracer	--	--	--	--	--	--
11	input parameters and statistical model	--	--	--	--	--	--
12	interpolation from calibration curve	--	--	--	--	--	0.70
13	quenching	--	--	--	--	--	--
14	decay-scheme parameters	--	--	--	--	--	--
15	half life $T_{1/2}$ = 10.54 a	--	--		0.001	0.01	
16	self absorption	--	--	--	--	--	
17	extrapolation of efficiency curve	--	--	--	0.20	0.23	0.30
18	other effects - ref source stability - electrometer accuracy - calibration factor - chamber linearity - source position - source volume - collection efficiency - wall thickness of source container - satellite pulses	 0.019 0.044 0.4 0.092	 0.5 0.1 1.2 0.2 0.2 0.1 0.15	1.5	 0.10	 -- 	 0.25 0.20 0.20
combined uncertainty (1σ)		0.41	1.4	1.57	0.244	0.30	1.01

*1 Uncertainty of measurement using the calibrated ionization chamber

Table 4. Uncertainty components and estimated relative values / 10^{-2} (continued).

Item No.	Function	INST[*2]	KRISS	NIM[*3]	NIM[*4]	NMIJ	OAP
1	counting statistics	0.40	0.20	0.1	0.1	0.1[(*5)]	--
2	weighing	0.10	0.15	0.10	0.1	0.05[(*5)]	0.02
3	dead time	0.04	0.03	0.05	0.01	<0.01	--
4	background	0.10	0.09	0.05	1.0E-5	0.01	--
	pile up	--	--		--	--	--
5	resolving time	--	0.06	0.08	--	0.01	--
6	Gandy effect	--	--	--	--	0.02	--
7	counting time	0.01	0.005	--	--	0.01	--
8	adsorption	--	--	--	1.0E-5	--	--
9	impurities	--	--	1.0E-5	1.0E-6	--	--
10	tracer	--	--	--	0.75	--	--
11	input parameters and statistical model	--	--	--	0.30	--	--
12	interpolation from calibration curve	--	--	--	0.02	--	0.5
13	quenching	2.20		--	0.35	--	--
14	decay-scheme parameters	--	--	--	0.10	--	--
15	half life $T_{1/2}$ = 10.54 a	--	0.06	9.2E-6	9.2E-6	<0.01	0.06
16	self absorption	--	--	--	--	--	--
17	extrapolation of efficiency curve	0.50	0.16	0.6	--	0.21	--
18	other effects - ref source stability - electrometer accuracy - calibration factor - chamber linearity - source position - source volume - collection efficiency - wall thickness of source container - satellite pulses	--	--	--	--	--	0.1 0.2 1.5
combined uncertainty (1σ)		2.30	0.32	0.626	0.897	0.22	1.75

[*2)] Uncertainty of measurement using the liquid scintillation counter
[*3)] Uncertainty of measurement using the coincidence counting method
[*4)] Uncertainty of measurement using the liquid scintillation counter
[*5)] Random components of counting and weighing are included in the extrapolation of efficiency.

5 Degrees of equivalence

The results $(A/m)_i$ for the laboratories that are participants in the CIPM MRA are linked to the SIR through the measurement in the SIR of an ampoule of the same solution standardized by the NMIJ. The link is made using a normalization ratio deduced from the NMIJ value in Table 4a of [2]:

$$A_{ei} = (A/m)_i \times \left(A_{e,\mathrm{NMIJ}} / (A/m)_{\mathrm{NMIJ}}\right) = (A/m)_i \times 23.908 \qquad (2)$$

The results of the links are given in Table 5 with the degrees of equivalence in Table 6. A graphical presentation of the degrees of equivalence with the KCRV is shown in Figure 2. The uncertainties for the regional comparison linked to the SIR are comprised of the original uncertainties together with the uncertainty in the link, 8×10^{-4}, given by the uncertainty of the SIR measurement of the NMIJ solution of the APMP.RI(II)-K2.Ba-133.

The results of the ANSTO and the NMISA agree within the standard uncertainties with their earlier results of 1984 in the CCRI(II)-K2.Ba-133 comparison. The result of the KRISS agrees within the standard uncertainty with their previous SIR result of 1995 in the BIPM.RI(II)-K1.Ba-133 comparison.

The SIR key comparison reference value for this radionuclide is x_R = 43.932 MBq with a standard uncertainty, u_R = 0.067 MBq [2].

Table 5 Results of the APMP comparison linked to the SIR through the NMIJ

NMI	Method acronym (see Appendix 1)	Activity * concentration measured $(A/m)_i$ / (kBq g^{-1})	Equivalent SIR activity A_{ei} / kBq	Combined standard uncertainty $u_{c\,i}$ / kBq
ANSTO	4P-IC-GR-00-00-00	1835.9	43 890	180
BARC	4P-IC-GR-00-00-00	1772.4	42 370	590
PTKMR*	SA-GH-GR-00-00-00	1891.6	45 220	720
NMISA	4P-LS-MX-NA-GR-CO	1831.7	43 790	110
INER	4P-PC-MX-NA-GR-CO	1841.2	44 020	140
INST*	4P-IC-GR-00-00-00 4P-LS-MX-00-00-ET	1932.8	46 210	1 200
KRISS	4P-PP-MX-NA-GR-CO	1844.6	44 100	150
NIM	4P-PC-MX-NA-GR-CO 4P-LS-MX -00-00-CN	1851	44 250	290
OAP	4P-IC-GR-00-00-00	1830	43 750	770

* Not eligible for the KCDB because not yet a designated institute of Indonesia and Viet Nam respectively.

Table 6 **Degrees of equivalence**

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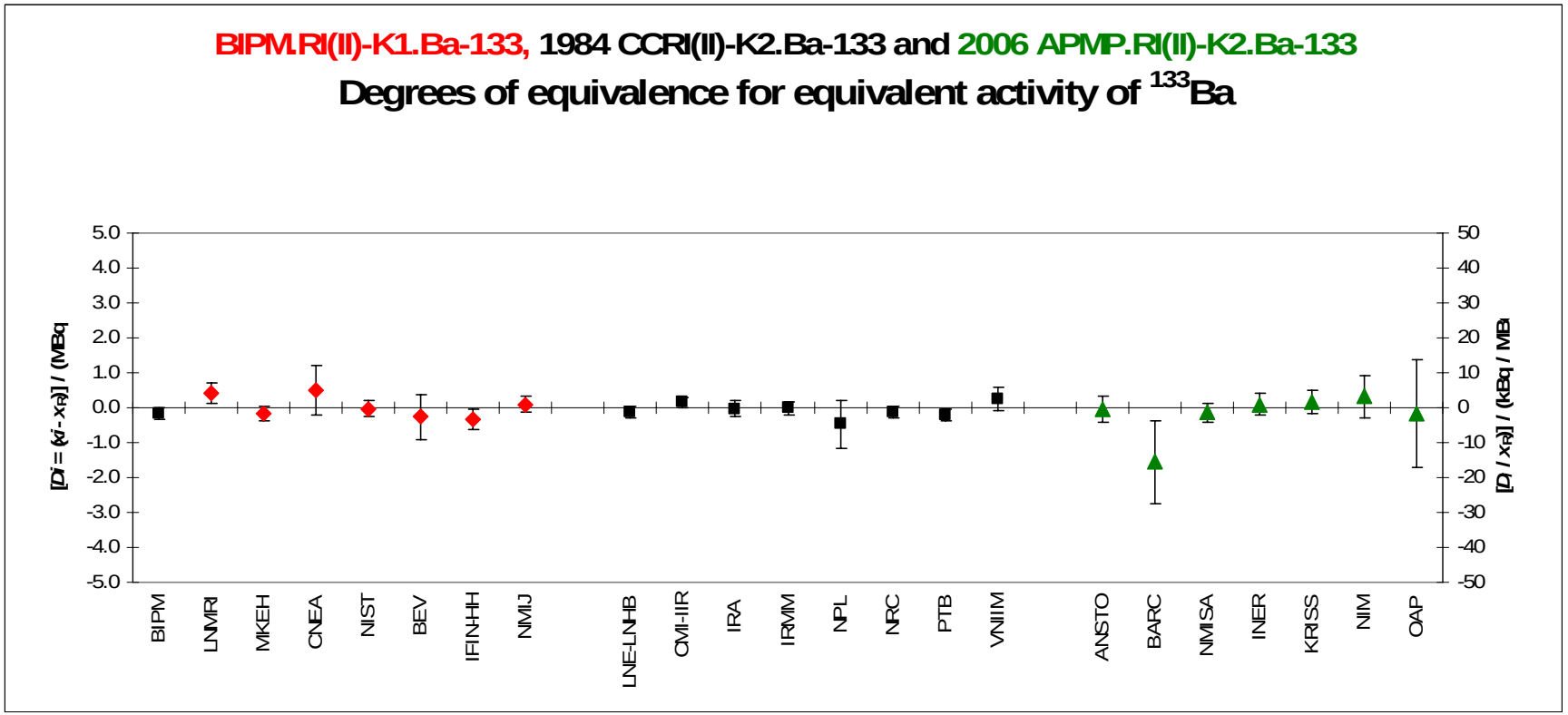
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	D_i / MBq	U_i / MBq	BIPM		LNMRI		MKEH		CNEA		NIST		BEV		IFIN-HH		NMIJ		LNE-LNHB		CMI-IIR		IRA		IRMM	
			D_{ij} / MBq	U_{ij} / MBq	D_{ij} / MBq	U_{ij} / MBq	D_{ij} / MBq	U_{ij} / MBq	D_{ij} / MBq	U_{ij} / MBq	D_{ij} / MBq	U_{ij} / MBq	D_{ij} / MBq	U_{ij} / MBq	D_{ij} / MBq	U_{ij} / MBq	D_{ij} / MBq	U_{ij} / MBq	D_{ij} / MBq	U_{ij} / MBq	D_{ij} / MBq	U_{ij} / MBq	D_{ij} / MBq	U_{ij} / MBq	D_{ij} / MBq	U_{ij} / MBq
BIPM	-0.16	0.15			-0.57	0.30	-0.01	0.23	-0.67	0.75	-0.14	0.27	0.10	0.65	0.18	0.30	-0.26	0.23	-0.04	0.11	-0.32	0.11	-0.14	0.18	-0.15	0.15
LNMRI	0.41	0.28	0.57	0.30			0.57	0.34	-0.10	0.79	0.43	0.37	0.67	0.70	0.75	0.40	0.31	0.34	0.53	0.29	0.26	0.29	0.43	0.33	0.42	0.31
MKEH	-0.16	0.21	0.01	0.23	-0.57	0.34			-0.67	0.77	-0.14	0.31	0.10	0.67	0.18	0.34	-0.26	0.28	-0.04	0.21	-0.31	0.21	-0.13	0.26	-0.15	0.24
CNEA	0.51	0.70	0.67	0.75	0.10	0.79	0.67	0.77			0.53	0.78	0.77	0.98	0.85	0.79	0.41	0.77	0.63	0.75	0.36	0.75	0.53	0.76	0.52	0.75
NIST	-0.02	0.25	0.14	0.27	-0.43	0.37	0.14	0.31	-0.53	0.78			0.24	0.68	0.32	0.37	-0.12	0.31	0.10	0.26	-0.17	0.26	0.00	0.30	-0.01	0.28
BEV	-0.26	0.65	-0.10	0.65	-0.67	0.70	-0.10	0.67	-0.77	0.98	-0.24	0.68			0.08	0.70	-0.36	0.67	-0.14	0.65	-0.41	0.65	-0.24	0.66	-0.25	0.65
IFIN-HH	-0.34	0.28	-0.18	0.30	-0.75	0.40	-0.18	0.34	-0.85	0.79	-0.32	0.37	-0.08	0.70			-0.44	0.34	-0.22	0.29	-0.49	0.29	-0.32	0.33	-0.33	0.31
NMIJ	0.10	0.21	0.26	0.23	-0.31	0.34	0.26	0.28	-0.41	0.77	0.12	0.31	0.36	0.67	0.44	0.34			0.22	0.22	-0.05	0.22	0.12	0.26	0.11	0.24
LNE-LNHB	-0.12	0.16	0.04	0.11	-0.53	0.29	0.04	0.21	-0.63	0.75	-0.10	0.26	0.14	0.65	0.22	0.29	-0.22	0.22			-0.28	0.08	-0.10	0.17	-0.11	0.13
CMI-IIR	0.15	0.16	0.32	0.11	-0.26	0.29	0.31	0.21	-0.36	0.75	0.17	0.26	0.41	0.65	0.49	0.29	0.05	0.22	0.28	0.08			0.18	0.17	0.16	0.13
IRA	-0.03	0.22	0.14	0.18	-0.43	0.33	0.13	0.26	-0.53	0.76	0.00	0.30	0.24	0.66	0.32	0.33	-0.12	0.26	0.10	0.17	-0.18	0.17			-0.02	0.20
IRMM	-0.01	0.19	0.15	0.15	-0.42	0.31	0.15	0.24	-0.52	0.75	0.01	0.28	0.25	0.65	0.33	0.31	-0.11	0.24	0.11	0.13	-0.16	0.13	0.02	0.20		
NPL	-0.47	0.69	-0.31	0.68	-0.88	0.74	-0.31	0.71	-0.98	1.00	-0.45	0.72	-0.21	0.46	-0.13	0.74	-0.57	0.71	-0.35	0.68	-0.62	0.68	-0.45	0.69	-0.46	0.69
NRC	-0.13	0.18	0.03	0.13	-0.54	0.30	0.03	0.23	-0.64	0.75	-0.11	0.27	0.13	0.65	0.21	0.30	-0.23	0.23	-0.01	0.11	-0.28	0.11	-0.11	0.18	-0.12	0.15
PTB	-0.21	0.17	-0.05	0.13	-0.62	0.30	-0.05	0.22	-0.72	0.75	-0.19	0.26	0.05	0.65	0.13	0.30	-0.31	0.23	-0.09	0.10	-0.37	0.10	-0.19	0.18	-0.20	0.15
VNIIM	0.25	0.33	0.41	0.31	-0.16	0.41	0.41	0.36	-0.26	0.80	0.27	0.38	0.51	0.71	0.59	0.41	0.15	0.36	0.37	0.30	0.10	0.30	0.27	0.33	0.26	0.31
ANSTO	-0.04	0.38	0.12	0.38	-0.45	0.46	0.12	0.41	-0.55	0.82	-0.02	0.43	0.22	0.73	0.30	0.46	-0.14	0.40	0.08	0.37	-0.19	0.37	-0.02	0.40	-0.03	0.39
BARC	-1.56	1.19	-1.40	1.19	-1.97	1.21	-1.40	1.20	-2.07	1.39	-1.54	1.20	-1.30	1.34	-1.22	1.21	-1.66	1.19	-1.44	1.18	-1.71	1.18	-1.54	1.19	-1.55	1.19
NMISA	-0.14	0.26	0.02	0.25	-0.55	0.36	0.02	0.29	-0.65	0.77	-0.12	0.33	0.12	0.68	0.20	0.36	-0.24	0.28	-0.02	0.24	-0.29	0.24	-0.12	0.28	-0.13	0.26
INER	0.09	0.31	0.25	0.30	-0.32	0.40	0.25	0.34	-0.42	0.79	0.11	0.37	0.35	0.70	0.43	0.40	-0.01	0.33	0.21	0.29	-0.06	0.29	0.11	0.33	0.10	0.31
KRISS	0.17	0.33	0.33	0.32	-0.24	0.41	0.33	0.36	-0.34	0.80	0.19	0.38	0.43	0.71	0.51	0.41	0.07	0.35	0.29	0.31	0.02	0.31	0.19	0.35	0.18	0.33
NIM	0.32	0.59	0.48	0.59	-0.09	0.64	0.48	0.61	-0.19	0.94	0.34	0.63	0.58	0.86	0.66	0.64	0.22	0.60	0.44	0.59	0.17	0.59	0.34	0.60	0.33	0.60
OAP	-0.18	1.55	-0.02	1.54	-0.59	1.57	-0.02	1.55	-0.69	1.71	-0.16	1.56	0.08	1.67	0.16	1.57	-0.28	1.55	-0.06	1.54	-0.33	1.54	-0.16	1.55	-0.17	1.55

Lab *j* ⟹

Lab *i* ⇩

	D_i / MBq	U_i / MBq	NPL		NRC		PTB		VNIIM		ANSTO		BARC		NMISA		INER		KRISS		NIM		OAP	
			D_{ij} / MBq	U_{ij} / MBq	D_{ij} / MBq	U_{ij} / MBq	D_{ij} / MBq	U_{ij} / MBq	D_{ij} / MBq	U_{ij} / MBq	D_{ij} / MBq	U_{ij} / MBq	D_{ij} / MBq	U_{ij} / MBq	D_{ij} / MBq	U_{ij} / MBq	D_{ij} / MBq	U_{ij} / MBq	D_{ij} / MBq	U_{ij} / MBq	D_{ij} / MBq	U_{ij} / MBq	D_{ij} / MBq	U_{ij} / MBq
BIPM	-0.16	0.15	0.31	0.68	-0.03	0.13	0.05	0.13	-0.41	0.31	-0.12	0.38	1.40	1.19	-0.02	0.25	-0.25	0.30	-0.33	0.32	-0.48	0.59	0.02	1.54
LNMRI	0.41	0.28	0.88	0.74	0.54	0.30	0.62	0.30	0.16	0.41	0.45	0.46	1.97	1.21	0.55	0.36	0.32	0.40	0.24	0.41	0.09	0.64	0.59	1.57
MKEH	-0.16	0.21	0.31	0.71	-0.03	0.23	0.05	0.22	-0.41	0.36	-0.12	0.41	1.40	1.20	-0.02	0.29	-0.25	0.34	-0.33	0.36	-0.48	0.61	0.02	1.55
CNEA	0.51	0.70	0.98	1.00	0.64	0.75	0.72	0.75	0.26	0.80	0.55	0.82	2.07	1.39	0.65	0.77	0.42	0.79	0.34	0.80	0.19	0.94	0.69	1.71
NIST	-0.02	0.25	0.45	0.72	0.11	0.27	0.19	0.26	-0.27	0.38	0.02	0.43	1.54	1.20	0.12	0.33	-0.11	0.37	-0.19	0.38	-0.34	0.63	0.16	1.56
BEV	-0.26	0.65	0.21	0.46	-0.13	0.65	-0.05	0.65	-0.51	0.71	-0.22	0.73	1.30	1.34	-0.12	0.68	-0.35	0.70	-0.43	0.71	-0.58	0.86	-0.08	1.67
IFIN-HH	-0.34	0.28	0.13	0.74	-0.21	0.30	-0.13	0.30	-0.59	0.41	-0.30	0.46	1.22	1.21	-0.20	0.36	-0.43	0.40	-0.51	0.41	-0.66	0.64	-0.16	1.57
NMIJ	0.10	0.21	0.57	0.71	0.23	0.23	0.31	0.23	-0.15	0.36	0.14	0.40	1.66	1.19	0.24	0.28	0.01	0.33	-0.07	0.35	-0.22	0.60	0.28	1.55
LNE-LNHB	-0.12	0.16	0.35	0.68	0.01	0.11	0.09	0.10	-0.37	0.30	-0.08	0.37	1.44	1.18	0.02	0.24	-0.21	0.29	-0.29	0.31	-0.44	0.59	0.06	1.54
CMI-IIR	0.15	0.16	0.62	0.68	0.28	0.11	0.37	0.10	-0.10	0.30	0.19	0.37	1.71	1.18	0.29	0.24	0.06	0.29	-0.02	0.31	-0.17	0.59	0.33	1.54
IRA	-0.03	0.22	0.45	0.69	0.11	0.18	0.19	0.18	-0.27	0.33	0.02	0.40	1.54	1.19	0.12	0.28	-0.11	0.33	-0.19	0.35	-0.34	0.60	0.16	1.55
IRMM	-0.01	0.19	0.46	0.69	0.12	0.15	0.20	0.15	-0.26	0.31	0.03	0.39	1.55	1.19	0.13	0.26	-0.10	0.31	-0.18	0.33	-0.33	0.60	0.17	1.55
NPL	-0.47	0.69	0.00	0.00	-0.34	0.68	-0.26	0.68	-0.72	0.74	-0.43	0.77	1.09	1.36	-0.33	0.71	-0.56	0.74	-0.64	0.74	-0.79	0.89	-0.29	1.68
NRC	-0.13	0.18	0.34	0.68			0.08	0.13	-0.38	0.31	-0.09	0.38	1.43	1.19	0.01	0.25	-0.22	0.30	-0.30	0.32	-0.45	0.59	0.05	1.54
PTB	-0.21	0.17	0.26	0.68	-0.08	0.13			-0.46	0.30	-0.17	0.38	1.35	1.19	-0.07	0.25	-0.30	0.30	-0.38	0.32	-0.53	0.59	-0.03	1.54
VNIIM	0.25	0.33	0.72	0.74	0.38	0.31	0.46	0.30			0.29	0.47	1.81	1.22	0.39	0.37	0.16	0.41	0.08	0.42	-0.07	0.65	0.43	1.57
ANSTO	-0.04	0.38	0.43	0.77	0.09	0.38	0.17	0.38	-0.29	0.47			1.52	1.23	0.10	0.41	-0.13	0.45	-0.21	0.46	-0.36	0.67	0.14	1.58
BARC	-1.56	1.19	-1.09	1.36	-1.43	1.19	-1.35	1.19	-1.81	1.22	-1.52	1.23			-1.42	1.20	-1.65	1.21	-1.73	1.21	-1.88	1.31	-1.38	1.94
NMISA	-0.14	0.26	0.33	0.71	-0.01	0.25	0.07	0.25	-0.39	0.37	-0.10	0.41	1.42	1.20			-0.23	0.34	-0.31	0.36	-0.46	0.61	0.04	1.55
INER	0.09	0.31	0.56	0.74	0.22	0.30	0.30	0.30	-0.16	0.41	0.13	0.45	1.65	1.21	0.23	0.34			-0.08	0.40	-0.23	0.64	0.27	1.56
KRISS	0.17	0.33	0.64	0.74	0.30	0.32	0.38	0.32	-0.08	0.42	0.21	0.46	1.73	1.21	0.31	0.36	0.08	0.40			-0.15	0.64	0.35	1.57
NIM	0.32	0.59	0.79	0.89	0.45	0.59	0.53	0.59	0.07	0.65	0.36	0.67	1.88	1.31	0.46	0.61	0.23	0.64	0.15	0.64			0.50	1.64
OAP	-0.18	1.55	0.29	1.68	-0.05	1.54	0.03	1.54	-0.43	1.57	-0.14	1.58	1.38	1.94	-0.04	1.55	-0.27	1.56	-0.35	1.57	-0.50	1.64		



Black squares indicate results that are more than 20 years old. The right hand axis is indicative only.

Figure 2 Graph of equivalence

6. Conclusion

In conclusion, the APMP key comparison of APMP.RI(II)-K2.Ba-133 radionuclide activity measurements was completed successfully. In total, ten institutes from two different regional metrology organizations participated, and most of the results agreed with each other within their specified uncertainties.

This regional comparison has enabled the ANSTO, KRISS and the NMISA to update their previous results for this radionuclide and four other NMIs to have a first measurement recorded in the KCDB. The degrees of equivalence between the APMP comparison and other measurements for ^{133}Ba are presented.

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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	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**
4π(PC)β–γ-coincidence counting	4P-PC-BP-NA-GR-CO
4π(PPC)β–γ-coincidence counting eff. tracing	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-00-00-00
calibrated IC	4P-IC-GR-00-00-00
internal gas counting	4P-PC-BP-00-00-IG