APMP/TCRI Key Comparison Report of Measurement of Air Kerma for Medium-energy X-Rays (APMP.RI(I)-K3)

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Abstract

The APMP/TCRI Dosimetry Working Group performed the APMP.RI(I)-K3 key comparison of measurement of air kerma for medium-energy x-rays (100 kV to 250 kV) between 2000 and 2003. In total, 11 institutes took part in the comparison, among which 8 were APMP member laboratories. Two commercial cavity ionization chambers were used as transfer instruments and circulated among the participants. All the participants established the 100 kV, 135 kV, 180 kV and 250 kV x-ray beam qualities equivalent to those of the BIPM. The results showed that the maximum difference between the participants and the BIPM in the medium-energy x-ray range, evaluated using the comparison data of the linking laboratories ARPANSA and PTB, is less than 1.4 %. The degrees of equivalence between the participants are presented and this comparison confirms the calibration capabilities of the participating laboratories.

1. Preface

The Asia Pacific Metrology Programme (APMP) is one of the five Specialist Regional Bodies under the Asia-Pacific Economic Cooperation (APEC). The APMP was established in 1980 and is a regional forum organized by national metrology institutes in the Asia-Pacific region. The objective of the APMP is to promote cooperation in standards metrology among member laboratories by sharing information on special techniques and exchanging technical services.

Under the APMP, there are eleven technical committees. The technical committee dealing with ionization radiation is the TCRI (Technical Committee on Ionizing Radiation). The TCRI held its first Workshop and Meeting in November 2000 in Thailand and decided on this occasion to reorganize itself by replacing old working groups with four new ones: Dosimetry, Radioactivity, Neutron and CMC Review Group. The mission of each group is to conduct necessary key comparisons to promote the CIPM Mutual Recognition Arrangement and review intra- and inter-regional calibration and measurement capabilities.

At present, the Dosimetry Working Group has the following five key comparison projects:

- Measurement of air kerma for ^{60}Co (APMP.RI(I)-K1)
- Measurement of air kerma for low energy x-rays (10 kV to 50 kV) (APMP.RI(I)-K2)
- Measurement of air kerma for medium-energy x-rays (100 kV to 250 kV) (APMP.RI(I)-K3)
- Measurement of absorbed dose to water for ^{60}Co (APMP.RI(I)-K4)
- Measurement of air kerma for ^{137}Cs (APMP.RI(I)-K5)

2. Protocol for the APMP RI(I)-K3 key comparison

In 1999, the Institute of Nuclear Energy Research (INER) was invited by the TCRI chairperson to act as the coordinator of the APMP.RI(I)-K3 key comparison project and take the responsibilities of planning and organizing the comparison program for the measurement of air kerma for medium-energy x-rays. Thus, in July 1999, INER designed and delivered a questionnaire to each member laboratory to gauge their intentions with respect to this comparison. Table 1 gives information on the participating laboratories and contact persons for this APMP.RI(I)-K3 key comparison.

2.1 Comparison methodology

The methods used in international ionizing radiation comparisons can be divided into two types: direct comparisons (DC) and indirect comparisons (IC). In direct comparisons, each participating laboratory takes its primary standard to a single laboratory to participate in the measurement comparison. That is, each participating laboratory performs comparison measurements in the same radiation field and under the same environmental conditions. In indirect comparisons, the participating laboratories sequentially calibrate the same transfer chamber using similar radiation fields in their own laboratories. Considering that the typical primary standard for measuring medium-energy x-rays — a free air ionization chamber — is too unwieldy to be moved and positioned in a simple manner, it was considered that a direct comparison program would be unrealistic. Hence, it was decided to make this APMP.RI(I)-K3 key comparison indirectly by circulating transfer chambers.

2.2 Comparison conditions

Currently, international comparisons for medium-energy x-rays are made on the basis of beam qualities that have been approved by the CCRI and are used at the Bureau International des Poids et Mesures (BIPM). The four beam qualities are indicated in Table 2 [1]. The participating laboratories established equivalent beam qualities as indicated in Table 3. The traceability of the standard used at each laboratory and the transfer chamber calibration conditions are given in Table 4. All the chamber calibration coefficients were normalized to 20 °C and 101.325 kPa and were provided in units of Gy C^{-1}.

2.3 The transfer chambers used in the comparison

This comparison employed INER's two high-stability, 0.6 cm^3 PTW-30001 ionization chambers as transfer instruments. The chambers were circulated without an electrometer. The TCRI chose this type of chamber because it had been used by the VNIIM (Russia) in a medium-energy x-ray comparison with the BIPM and the measured calibration coefficients agreed to within 0.5 % [2] at all four x-ray beam qualities. The characteristics of the transfer chambers and the polarity of the voltage applied in the participating laboratories are given in Table 5.

2.4 Schedule for the comparison

After discussions with all eleven participating laboratories, the comparison was scheduled to begin in July 2000 and end in June 2003. Laboratories were requested to complete their calibrations within a month. In order to verify the stability and functioning of the PTW-30001 transfer chambers during the period of the comparison, each laboratory was required to send the chambers back to INER for stability tests in ^{60}Co as soon as it finished its calibrations [3]. An additional month was allowed for the round trip of these two transfer chambers between INER and a participating laboratory. The INER would pass the chambers to the next laboratory for calibration when stability tests were complete.

In order to control the progress and timing of the whole comparison, the INER agreed to take responsibility for the organization and costs of transportation.

2.5 Calibration certificates

It was expected that participating laboratories would submit calibration certificates in English within a month of the calibrations. The format of this certificate could be identical to that normally used by the participating laboratory. The content must include at least the air kerma calibration coefficients (Gy C^{-1}) of the ionization chambers, the air kerma rate of the radiation field (mGy s^{-1}), the calibration distance and the expanded uncertainty (with coverage factor $k = 2$) of the calibration coefficients. Furthermore, it was requested that the relative humidity conditions at the time of calibration be stated on the certificate. Ideally, the relative humidity of the participating laboratories at the time of measurement should be within the range from 30 % to 70 %.

2.6 Evaluation of measurement uncertainty

All the participating laboratories were required to evaluate the uncertainty of calibration coefficients as Type A and Type B according to the criteria of the “Guide to The Expression of Uncertainty in Measurement” issued by the International Organization for Standardization (ISO) in 1995 [4]. The Type A uncertainty is obtained by the statistical analysis of a series of observations; the Type B uncertainty is obtained by means other than the statistical analysis of series' of observations. In order to analyze the uncertainties and take correlations into account for degrees of equivalence entered in the BIPM key comparison database [5], the CIPM has recommended that the participating laboratories submit their detailed uncertainty budgets (preferably with the relative standard uncertainties, $k = 1$) to the pilot laboratory.

2.7 The comparison report

When the comparison was completed, the INER combined the measured calibration coefficients from all the participating laboratories to obtain mean values of the calibration coefficients for each beam quality. This allowed the production of a plot of the distribution of the measured calibration coefficients for each quality, and the production of a draft comparison report. The draft comparison report was sent to the participating laboratories for confirmation of results and any additional comments. When all participants had responded, the draft was further edited into a final report and submitted to the APMP/TCRI chairperson. This was accepted and the degrees of equivalence were then calculated as presented in the current report.

3. The linking of regional comparisons to international comparisons

To link the APMP/TCRI comparison (a regional comparison) with the BIPM (an international comparison), two participating laboratories (PTB and ARPANSA) that had made comparisons with the BIPM for the measurement of air kerma for medium-energy x-rays were used to play the role of "linking laboratories". Then, through the following equation, the measured calibration coefficients for each laboratory were converted to air kerma ratios relative to the BIPM;

$$R_{\mathrm{NMI,BIPM}} = R_{\mathrm{NMI,Link}} \times R_{\mathrm{Link,BIPM}} \quad . \qquad (1)$$

In this equation,

$R_{\mathrm{NMI,Link}}$ = the ratio of the measurement value from a participating NMI to that of the linking laboratory

$R_{\mathrm{Link,BIPM}}$ = the ratio of the linking laboratory and the BIPM obtained in the BIPM.RI(I)-K3 air kerma key comparison [5]

$R_{NMI,BIPM}$ = the derived air kerma ratio of the participating NMI and the BIPM.

Originally, the ARPANSA (Australia), which had made a comparison with the BIPM for medium-energy x-ray qualities in 1988 [5, 6], was the only laboratory in the Asia-Pacific region that was eligible to be a linking laboratory. To enhance the accuracy and confidence of the whole comparison linkage with the BIPM, the PTB (Germany) was invited to take part in this APMP/TCRI medium-energy x-ray comparison. The PTB had made a bilateral comparison with the BIPM in 1999, for which the measured values of the PTB and BIPM calibration coefficients agreed within 0.4 % [7] at each of the four x-ray beam qualities. The comparison results ARPANSA/BIPM and PTB/BIPM for medium-energy x-rays to be used as the links are given in Table 6.

4. Results and discussion

The results of the transfer chamber stability tests made at the pilot laboratory, the INER, are given in Figs. 1 and 2. An NE-2571 (S/N 3025) chamber and the PTW-30001 (S/N 2340) chamber were sent out together initially but then the NE (S/N 3025) chamber was damaged. Subsequently, the PTW-30001 (S/N 2251) chamber replaced the damaged chamber. The PTW (S/N 2251) and PTW (S/N 2340) chambers were sent out together to the remaining laboratories. After that, the PTW (S/N 2251) chamber was sent by itself to those laboratories that had previously calibrated the NE (S/N 3025) chamber. The figures confirm that the transfer chambers behaved normally during this comparison, with the standard uncertainty of the distribution being 0.15 % for the PTW (S/N2340) and 0.11 % for the PTW (S/N 2251).

The calibration coefficients for the transfer chambers are given in Tables 7 and 8. The detailed uncertainty budgets for all the participants are given in the Appendix. For each chamber at each beam quality, the mean value and the standard deviation of the distribution of the calibration coefficients are evaluated; the standard deviation is typically 0.6 %. Figs 3 and 4, produced using the data of Tables 7 and 8, show no unexpected behaviour, with most calibration coefficients falling within two standard deviations of the mean and no outliers identified. Figs. 5 and 6 show the combined results for each chamber relative to the mean values. All results are within 2 % of the relevant mean.

The results have been analysed following the guidance given in [8]. Unweighted mean values have been used to combine the data for the two transfer chambers and for the two linking laboratories. Table 9 gives the comparison result for each laboratory, evaluated using equation (1), for each of the linking laboratories ARPANSA and PTB. The ratios are unweighted means for the two chambers, the difference for each chamber being typically around 0.5 %. Comparing the values in Table 9, it is seen that regardless of whether the link is evaluated via the ARPANSA or the PTB, the results are consistent within 0.4 %. This consistency allows the mean ratio obtained from Table 9 to be the final comparison result $R_{\mathrm{NMI,BIPM}}$ for each laboratory relative to the BIPM, as given in Table 10 and Figure 7. The largest deviation from unity in Figure 7 for the medium-energy kilovoltage x-ray range is less than 1.4 %.

The combined standard uncertainty $\underline{u}_{\mathrm{NMI,BIPM}}$ of $R_{\mathrm{NMI,BIPM}}$ for each laboratory is also given in Table 10. The uncertainty has four components: (i) the laboratory calibration uncertainty as given in the appendix; (ii) the BIPM uncertainty (0.21 %); (iii) the uncertainty u_{stab} arising from the stability of the transfer chambers, where u_{stab} = 0.15 % for the PTW S/N 2340 and u_{stab} = 0.11 % for the PTW S/N 2251, giving the combined value u_{stab} = 0.09 %; and (iv) the procedural uncertainty $\underline{u}_{\mathrm{Link}}$ associated with two calibrations at the linking laboratory, that is, the uncertainty associated with chamber positioning, ionization current measurements and normalization to standard air density, as given for the ARPANSA and the PTB in the appendix, where for the ARPANSA u_{Link} = 0.24 % and for the PTB u_{Link} = 0.20 %, giving the combined value u_{Link} = 0.16 %. From this total must be removed any correlation in the laboratory and BIPM standards. For most standards, the only notable correlation is the uncertainty (0.15 %) of W, the mean energy required to create an ion pair in dry air. However, five laboratories, the AECS, IAEA, KRISS, NMISA and the Nuclear Malaysia (for chamber PTW S/N 2251), are traceable to the BIPM and this correlation is also removed.

As can be seen from Table 10 and Figure 7, there are no obvious outliers and only two results in 34 deviate from unity by more than two standard deviations, a distribution that one would expect statistically.

5. Degrees of equivalence

The analysis of the results of BIPM comparisons in medium-energy x-rays in terms of degrees of equivalence is described in [5]. Following a decision of the CCRI, the BIPM determination of the air kerma is taken as the key comparison reference value $x_{R,i}$, for each of the CCRI radiation qualities. It follows that for each NMI i having comparison result $R_{i,\text{BIPM}}$ (denoted in earlier sections as $R_{\text{NMI,BIPM}}$) with combined standard uncertainty $u_{i,\text{BIPM}}$, (as given in Table 10), the degree of equivalence with respect to the reference value is $D_i = R_{i,\text{BIPM}} - 1$ and its expanded uncertainty $U_i = 2\, u_{i,\text{BIPM}}$. The results for D_i and U_i, including those of the present comparison, are shown in Figure 8 and in Tables 11 to 14 for the four radiation qualities, expressed in mGy/Gy. It should be noted that for consistency within the KCDB, a simplified level of nomenclature is used in these tables with $R_{i,\text{BIPM}}$ equivalent to $x_i / x_{R,i}$.

The degree of equivalence of NMI i with respect to each NMI j is the difference $D_{ij} = D_i - D_j = R_{i,\text{BIPM}} - R_{j,\text{BIPM}}$ and its expanded uncertainty $U_{ij} = 2\, u_{ij}$. The combined standard uncertainty u_{ij}, for i and j within the region, is the combined uncertainty of the air-kerma calibration coefficients for i and j and the uncertainty arising from transfer chamber stability, that is, twice u_{stab} (as two calibrations are involved). For i within the region and j outside the region, u_{stab} is included only once, but the uncertainty u_{Link} must be included. In evaluating each u_{ij}, correlation between the standards of NMIs i and j is removed, notably that arising from the physical constants and, for NMIs holding secondary standards (the AECS, DMSC, IAEA, KRISS, Nuclear Malaysia, and the NMISA), that arising from traceability. Note that the uncertainty of the BIPM determination of air kerma does not enter in u_{ij}.

The results for D_i and U_i and those for D_{ij} and U_{ij} are given in Tables 11 to 14 for the four radiation qualities in the format in which they will appear in the key comparison database. Unfortunately, the results for the AECS cannot be included in the database as Syria is not a Member State of the BIPM, nor can those for the DMSC as it is not yet a designated institute of Thailand. Note that the data presented in the tables, while correct at the time of publication of the present report, will become out-of-date as NMIs make new comparisons. The formal results under the CIPM MRA are those available in the key comparison database.

6. Conclusion

This comparison of air kerma measurement standards is the first to be conducted in the Asia-Pacific region using the BIPM medium-energy x-ray beam qualities. The results show the calibration capabilities of all participating laboratories to be in general agreement within the stated uncertainties. As a result, each participating laboratory has not only verified its own measurement capabilities but also strengthened technical cooperation and the exchange of ideas with other laboratories in the process of achieving a comparison link with the BIPM.

References

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Tables and Figures

Table 1. Participating laboratories and their contact persons for the APMP.RI(I)-K3 key comparison

Participating Laboratory	Acronym or Abbreviation, Economy	Contact Person
Atomic Energy Commission of Syria	AECS, Syria	M. Takeyeddin
Australian Radiation Protection and Nuclear Safety Agency	ARPANSA, Australia	Lew Kotler*, David Webb
Bhabha Atomic Research Centre	BARC, India	V. V. Shaha
Department of Medical Sciences	DMSC, Thailand	Siri Srimanoroth
International Atomic Energy Agency	IAEA	A. Meghzifene
Institute of Nuclear Energy Research	INER, Taiwan	Jeng-Hung Lee
Korea Research Institute of Standards and Science	KRISS, Korea	Suck Ho Hah
Malaysian Nuclear Agency (previously MINT)	Nuclear Malaysia	Taiman Bin Kadni
National Metrology Institute of South Africa (previously CSIR-NML)	NMISA, South Africa	Zakithi Msimang
National Metrology Institute of Japan	NMIJ, Japan	Nobuhisa Takata
Physikalisch-Technische Bundesanstalt	PTB, Germany	Ludwig Büermann

* Retired in March 2004

Table 2. Conditions of measurement at the BIPM (100 kV to 250 kV)

Distance between focal spot and reference plane: 120 cm
Beam diameter in the reference plane: 10.5 cm
Inherent filtration: 2.3 mm Al

X-ray tube voltage / kV	100	135	180	250
Additional filtration				
mm Al	1.204	N.A.	N.A.	N.A.
mm Cu	N.A.	0.232	0.484	1.570
Half-value layer				
mm Al	4.027	N.A.	N.A.	N.A.
mm Cu	0.148	0.494	0.990	2.500
Air-attenuation coefficient μ/ρ (cm^2/g)	0.299	0.198	0.167	0.145
Air kerma rate (mGy s^{-1})	0.21	0.20	0.29	0.38

Table 3. HVL values for the APMP.RI(I)-K3 key comparison for all participants as stated on the respective calibration certificate

Participant	HVL (mm Al)	HVL (mm Cu)		
	100 kV	135 kV	180 kV	250 kV
AECS, Syria	3.91	0.51	1.05	2.50
ARPANSA, Australia	3.94	0.51	0.99	2.52
BARC, India	4.026	N.A.	N.A.	2.496
DMSC, Thailand	0.15 (mm Cu)	0.50	1.00	2.50
IAEA	3.91	0.50	1.03	2.49
INER, Taiwan	4.047	0.491	0.980	2.500
KRISS, Korea	4.025	0.479	0.974	2.467
Nuclear Malaysia	4.05	0.52	1.01	2.51
NMIJ, Japan	4.014	0.496	0.990	2.498
NMISA, South Africa	4.00	0.50	1.00	2.50
PTB, Germany	3.978	0.482	1.018	2.526

Table 4. Standard traceability and transfer chamber calibration conditions for each participant

Participant	Standard traceability	Calibration distance (cm)	Field size	Air kerma rate ($mGy\ s^{-1}$)			
				100 kV	135 kV	180 kV	250 kV
AECS, Syria	IAEA	100	10 cm × 10 cm square	1.93	1.48	1.65	1.57
ARPANSA, Australia	ARPANSA, Australia	140	10 cm in diameter	0.83	0.78	1.14	1.11
BARC, India	BARC, India	120	10.5 cm in diameter	1.05	N.A.	N.A.	1.50
DMSC, Thailand	NPL, UK	120	10 cm in diameter	0.20	0.20	0.32	0.27
IAEA	BIPM	100	10 cm in diameter	1.80	1.55	1.85	1.42
INER, Taiwan	INER, Taiwan	150	10 cm × 10 cm square	0.35	0.34	0.50	0.64
KRISS, Korea	BIPM	120	10.8 cm in diameter	0.31	0.31	0.44	0.60
Nuclear Malaysia	NPL, UK (for S/N 2340 transfer chamber calibration)	100	10.5 cm in diameter	1.09	1.16	1.41	1.46
	IAEA (for S/N 2251 transfer chamber calibration)			0.44	0.44	0.97	1.00
NMIJ, Japan	NMIJ, Japan	120	13 cm in diameter	0.21	0.21	0.30	0.40
NMISA, South Africa	BIPM	86	6.5 cm in diameter	1.83	1.93	1.98	2.20
PTB, Germany	PTB, Germany	100	10 cm in diameter	0.14	0.14	0.14	0.14

Table 5. Main characteristics of the transfer chambers

Type and serial number	Geometry	Inner diameter (cm)	Wall (Rod) material	Wall thickness (g cm^{-2})	Nominal volume (cm^3)	Polarizing potential (V)
PTW* 30001 S/N 2251 and PTW 30001 S/N 2340	Cylindrical	0.688	PMMA+ Graphite (Aluminum)	0.045	0.6	+400

*PTW, Physikalisch-Technische Werkstätten Ltd

Table 6. Key comparison ratios NMI/BIPM for the BIPM medium-energy x-ray beam qualities for the ARPANSA and the PTB [5]

Laboratory	Year	X-ray tube voltage / kV				Combined standard uncertainty
		100	135	180	250	
ARPANSA	1988*	1.0049	1.0056	1.0050	1.0051	0.24 %
PTB	1999	1.0002	0.9983	0.9983	0.9963	0.26 %

*A comparison made in 2002, awaiting publication, confirms this data at the 0.1 % level.

Table 7. The calibration coefficients for the PTW-30001 (S/N 2340) transfer chamber for the APMP RI(I)-K3 key comparison

Participant	Calibration coefficient (10^7 Gy C^{-1})				Relative standard uncertainty (%)
	100 kV	135 kV	180 kV	250 kV	
INER	4.755	4.770	4.773	4.786	0.35
Nuc. Malaysia	4.855	4.848	4.820	4.842	0.64
DMSC	4.800	4.739	4.793	4.900	0.65
AECS	4.770	4.810	4.810	4.870	0.52
PTB	4.748	4.761	4.776	4.789	0.35
NMIJ	4.764	4.760	4.761	4.781	0.48
ARPANSA	4.772	4.788	4.782	4.810	0.35
BARC	4.784	N.A.	N.A.	4.831	0.74
NMISA	4.779	4.761	4.769	4.799	0.31
KRISS	4.709	4.752	4.779	4.798	0.30
IAEA	4.770	4.790	4.810	4.830	0.40

Table 8. The calibration coefficients for the PTW-30001 (S/N 2251) transfer chamber for the APMP RI(I)-K3 key comparison

Participant	Calibration coefficient (10^7 Gy C^{-1})				Relative standard uncertainty (%)
	100 kV	135 kV	180 kV	250 kV	
INER	4.809	4.793	4.810	4.833	0.35
Nuc. Malaysia	4.809	4.828	4.848	4.876	0.64
DMSC	4.698	4.824	4.824	4.790	0.65
AECS	4.830	4.840	4.860	4.900	0.52
PTB	4.794	4.790	4.806	4.831	0.35
NMIJ	4.798	4.784	4.791	4.813	0.48
ARPANSA	4.834	4.829	4.826	4.858	0.35
BARC	4.826	N.A.	N.A.	4.877	0.74
NMISA	4.792	4.780	4.803	4.838	0.31
KRISS	4.739	4.781	4.810	4.840	0.30
IAEA	4.800	4.820	4.840	4.870	0.40

Table 9. Comparison ratios between participants and the BIPM using the values of the linking laboratories from Table 6

Participant	Comparison ratio with BIPM									
	Link via ARPANSA					Link via PTB				
	100 kV	135 kV	180 kV	250 kV	Combined standard uncertainty (%)	100 kV	135 kV	180 kV	250 kV	Combined standard uncertainty (%)
INER	1.0005	1.0000	1.0024	1.0000	0.43	1.0025	0.9996	0.9984	0.9962	0.41
Nuc. Malaysia	1.0110	1.0118	1.0113	1.0103	0.67	1.0130	1.0114	1.0073	1.0065	0.66
DMSC	0.9937	0.9999	1.0059	1.0075	0.70	0.9957	0.9995	1.0019	1.0036	0.69
AECS	1.0043	1.0091	1.0115	1.0157	0.53	1.0063	1.0086	1.0075	1.0118	0.52
NMIJ	1.0003	0.9980	0.9991	0.9974	0.54	1.0023	0.9976	0.9952	0.9936	0.53
BARC	1.0053	N.A.	N.A.	1.0093	0.78	1.0073	N.A.	N.A.	1.0054	0.77
NMISA	1.0013	0.9977	1.0012	1.0019	0.32	1.0033	0.9973	0.9973	0.9981	0.30
KRISS	0.9884	0.9968	1.0030	1.0020	0.31	0.9904	0.9964	0.9990	0.9982	0.29
IAEA	1.0012	1.0049	1.0094	1.0084	0.41	1.0031	1.0045	1.0054	1.0046	0.40

Table 10. Combined comparison ratios $R_{NMI,BIPM}$ between participants and the BIPM using the unweighted mean for the two linking laboratories from Table 9

Participant	$R_{NMI,BIPM}$				Combined standard uncertainty $u_{NMI,BIPM}$ (%)
	100 kV	135 kV	180 kV	250 kV	
INER	1.0015	0.9998	1.0004	0.9981	0.39
Nuc. Malaysia	1.0120	1.0116	1.0093	1.0084	0.64
DMSC	0.9947	0.9997	1.0039	1.0055	0.67
AECS	1.0053	1.0089	1.0095	1.0138	0.50
NMIJ	1.0013	0.9978	0.9972	0.9955	0.51
BARC	1.0063	N.A.	N.A.	1.0073	0.76
NMISA	1.0023	0.9975	0.9992	1.0000	0.27
KRISS	0.9894	0.9966	1.0010	1.0001	0.26
IAEA	1.0021	1.0047	1.0074	1.0065	0.37

Table 11. Introductory text and degrees of equivalence for the 100 kV radiation quality

Key comparison BIPM.RI(I)-K3

MEASURAND : Air kerma
Radiation quality 100 kV

For a comparison with NMI i, the key comparison reference value is the BIPM air-kerma determination $x_{R,i}$ and its standard uncertainty $u_{R,i}$

The degree of equivalence of each NMI i with respect to $x_{R,i}$ is given by a pair of terms:
$D_i = (x_i - x_{R,i}) / x_{R,i}$ and $U_i = 2u_i$, its expanded uncertainty (k = 2), both expressed in mGy/Gy.
In evaluating u_i for BIPM comparisons, account is taken of correlation between $u_{NMI\,i}$ and $u_{R,i}$ (see the Summary Report).
In evaluating u_i for regional comparisons, additional uncertainties u_{stab} and u_{LINK} are included (see the Comparison Report).

The degree of equivalence between two NMIs i and j is given by a pair of terms:
$D_{ij} = D_i - D_j$ and $U_{ij} = 2u_{ij}$, its expanded uncertainty (k = 2), both expressed in mGy/Gy.
In evaluating u_{ij} for the matrix of equivalence, account is taken of correlation between u_i and u_j (see the Summary Report).
For regional comparisons involving secondary standards, this includes correlation related to traceability (see the Comparison Report).

NMI j ⟹

NMI i ⇩

NMI i	D_i /(mGy/Gy)	U_i /(mGy/Gy)	ARPANSA D_{ij} /(mGy/Gy)	ARPANSA U_{ij} /(mGy/Gy)	NMi-VSL D_{ij}	NMi-VSL U_{ij}	GUM D_{ij}	GUM U_{ij}	NPL D_{ij}	NPL U_{ij}	ENEA D_{ij}	ENEA U_{ij}	MKEH D_{ij}	MKEH U_{ij}	NRC D_{ij}	NRC U_{ij}	VNIIM D_{ij}	VNIIM U_{ij}	PTB D_{ij}	PTB U_{ij}	NIM D_{ij}	NIM U_{ij}
ARPANSA	4.9	4.8			2.0	8.1	5.3	6.5	7.2	6.3	3.1	7.1	5.0	6.7	9.2	5.2	5.9	4.6	4.7	6.1	2.8	6.1
NMi-VSL	2.9	8.4	-2.0	8.1			3.3	9.4	5.2	9.3	1.1	9.9	3.0	9.6	7.2	8.5	3.9	8.2	2.7	9.2	0.8	9.1
GUM	-0.4	7.1	-5.3	6.5	-3.3	9.4			1.9	7.9	-2.2	8.5	-0.3	8.5	3.9	7.0	0.6	6.6	-0.6	8.1	-2.5	7.7
NPL	-2.3	6.6	-7.2	6.3	-5.2	9.3	-1.9	7.9			-4.1	8.4	-2.2	8.1	2.0	6.8	-1.3	6.4	-2.5	7.6	-4.4	7.5
ENEA	1.8	7.5	-3.1	7.1	-1.1	9.9	2.2	8.5	4.1	8.4			1.9	8.8	6.1	7.6	2.8	7.2	1.6	8.4	-0.3	8.2
MKEH	-0.1	5.1	-5.0	6.7	-3.0	9.6	0.3	8.5	2.2	8.1	-1.9	8.8			4.2	7.2	0.9	6.9	-0.3	6.5	-2.2	7.7
NRC	-4.3	5.5	-9.2	5.2	-7.2	8.5	-3.9	7.0	-2.0	6.8	-6.1	7.6	-4.2	7.2			-3.3	5.3	-4.5	6.7	-6.4	6.6
VNIIM	-1.0	5.1	-5.9	4.6	-3.9	8.2	-0.6	6.6	1.3	6.4	-2.8	7.2	-0.9	6.9	3.3	5.3			-1.2	6.4	-3.1	6.2
PTB	0.2	5.2	-4.7	6.1	-2.7	9.2	0.6	8.1	2.5	7.6	-1.6	8.4	0.3	6.5	4.5	6.7	1.2	6.4			-1.9	7.3
NIM	2.1	6.2	-2.8	6.1	-0.8	9.1	2.5	7.7	4.4	7.5	0.3	8.2	2.2	7.7	6.4	6.6	3.1	6.2	1.9	7.3		
BEV	0.3	6.8	-4.6	6.6	-2.6	9.5	0.7	8.1	2.6	8.0	-1.5	8.7	0.4	8.3	4.6	7.1	1.3	6.7	0.1	7.8	-1.8	7.8
NIST	0.8	7.3	-4.1	8.0	-2.1	10.6	1.2	9.6	3.1	9.2	-1.0	9.9	0.9	8.3	5.1	8.4	1.8	8.2	0.6	8.3	-1.3	8.9
LNE-LNHB	-1.8	7.8	-6.7	8.6	-4.7	11.0	-1.4	10.0	0.5	9.7	-3.6	10.3	-1.7	8.7	2.5	9.0	-0.8	8.7	-2.0	8.7	-3.9	9.4
INER	1.5	7.9	-3.4	8.2	-1.4	10.7	1.9	9.7	3.8	9.4	-0.3	10.0	1.6	9.1	5.8	8.6	2.5	8.4	1.3	8.7	-0.6	9.1
Nuc. Malaysia	12.0	12.9	7.1	13.5	9.1	15.2	12.4	14.5	14.3	11.0	10.2	14.6	12.1	14.1	16.3	13.7	13.0	13.6	11.8	13.8	9.9	14.0
NMIJ	1.3	10.2	-3.6	10.5	-1.6	12.6	1.7	11.7	3.6	11.5	-0.5	12.0	1.4	11.2	5.6	10.8	2.3	10.6	1.1	10.9	-0.8	11.2
BARC	6.3	15.2	1.4	15.4	3.4	16.9	6.7	16.3	8.6	16.1	4.5	16.4	6.4	15.9	10.6	15.6	7.3	15.5	6.1	15.7	4.2	15.9
NMISA	2.3	5.5	-2.6	7.5	-0.6	10.2	2.7	9.2	4.6	8.8	0.5	9.4	2.4	8.5	6.6	8.0	3.3	7.7	2.1	8.1	0.2	8.5
KRISS	-10.6	5.1	-15.5	7.4	-13.5	10.1	-10.2	9.0	-8.3	8.7	-12.4	9.3	-10.5	8.4	-6.3	7.8	-9.6	7.5	-10.8	7.9	-12.7	8.3
IAEA	2.1	7.5	-2.8	9.1	-0.8	11.4	2.5	10.5	4.4	10.1	0.3	10.7	2.2	9.9	6.4	9.4	3.1	9.2	1.9	9.5	0.0	9.9

NMI i ⇩

NMI i	D_i /(mGy/Gy)	U_i /(mGy/Gy)	BEV D_{ij} /(mGy/Gy)	BEV U_{ij} /(mGy/Gy)	NIST D_{ij}	NIST U_{ij}	LNE-LNHB D_{ij}	LNE-LNHB U_{ij}	INER D_{ij}	INER U_{ij}	Nuc Malay D_{ij}	Nuc Malay U_{ij}	NMIJ D_{ij}	NMIJ U_{ij}	BARC D_{ij}	BARC U_{ij}	NMISA D_{ij}	NMISA U_{ij}	KRISS D_{ij}	KRISS U_{ij}	IAEA D_{ij}	IAEA U_{ij}
ARPANSA	4.9	4.8	4.6	6.6	4.1	8.0	6.7	8.6	3.4	8.2	-7.1	13.5	3.6	10.5	-1.4	15.4	2.6	7.5	15.5	7.4	2.8	9.1
NMi-VSL	2.9	8.4	2.6	9.5	2.1	10.6	4.7	11.0	1.4	10.7	-9.1	15.2	1.6	12.6	-3.4	16.9	0.6	10.2	13.5	10.1	0.8	11.4
GUM	-0.4	7.1	-0.7	8.1	-1.2	9.6	1.4	10.0	-1.9	9.7	-12.4	14.5	-1.7	11.7	-6.7	16.3	-2.7	9.2	10.2	9.0	-2.5	10.5
NPL	-2.3	6.6	-2.6	8.0	-3.1	9.2	-0.5	9.7	-3.8	9.4	-14.3	11.0	-3.6	11.5	-8.6	16.1	-4.6	8.8	8.3	8.7	-4.4	10.1
ENEA	1.8	7.5	1.5	8.7	1.0	9.9	3.6	10.3	0.3	10.0	-10.2	14.6	0.5	12.0	-4.5	16.4	-0.5	9.4	12.4	9.3	-0.3	10.7
MKEH	-0.1	5.1	-0.4	8.3	-0.9	8.3	1.7	8.7	-1.6	9.1	-12.1	14.1	-1.4	11.2	-6.4	15.9	-2.4	8.5	10.5	8.4	-2.2	9.9
NRC	-4.3	5.5	-4.6	7.1	-5.1	8.4	-2.5	9.0	-5.8	8.6	-16.3	13.7	-5.6	10.8	-10.6	15.6	-6.6	8.0	6.3	7.8	-6.4	9.4
VNIIM	-1.0	5.1	-1.3	6.7	-1.8	8.2	0.8	8.7	-2.5	8.4	-13.0	13.6	-2.3	10.6	-7.3	15.5	-3.3	7.7	9.6	7.5	-3.1	9.2
PTB	0.2	5.2	-0.1	7.8	-0.6	8.3	2.0	8.7	-1.3	8.7	-11.8	13.8	-1.1	10.9	-6.1	15.7	-2.1	8.1	10.8	7.9	-1.9	9.5
NIM	2.1	6.2	1.8	7.8	1.3	8.9	3.9	9.4	0.6	9.1	-9.9	14.0	0.8	11.2	-4.2	15.9	-0.2	8.5	12.7	8.3	0.0	9.9
BEV	0.3	6.8			-0.5	9.4	2.1	9.8	-1.2	9.5	-11.7	14.3	-1.0	11.6	-6.0	16.1	-2.0	8.9	10.9	8.8	-1.8	10.3
NIST	0.8	7.3	0.5	9.4			2.6	10.1	-0.7	10.1	-11.2	14.7	-0.5	12.1	-5.5	16.5	-1.5	9.6	11.4	9.5	-1.3	10.8
LNE-LNHB	-1.8	7.8	-2.1	9.8	-2.6	10.1			-3.3	10.6	-13.8	15.1	-3.1	12.4	-8.1	16.8	-4.1	10.1	8.8	9.9	-3.9	11.3
INER	1.5	7.9	1.2	9.5	0.7	10.1	3.3	10.6			-10.5	14.2	0.2	11.4	-4.8	16.0	-0.8	8.7	12.1	8.5	-0.6	10.0
Nuc. Malaysia	12.0	12.9	11.7	14.3	11.2	14.7	13.8	15.1	10.5	14.2			10.7	15.6	5.7	19.3	9.7	11.1	22.6	10.9	9.9	12.2
NMIJ	1.3	10.2	1.0	11.6	0.5	12.1	3.1	12.4	-0.2	11.4	-10.7	15.6			-5.0	17.3	-1.0	10.9	11.9	10.8	-0.8	12.0
BARC	6.3	15.2	6.0	16.1	5.5	16.5	8.1	16.8	4.8	16.0	-5.7	19.3	5.0	17.3			4.0	15.7	16.9	15.6	4.2	16.5
NMISA	2.3	5.5	2.0	8.9	1.5	9.6	4.1	10.1	0.8	8.7	-9.7	11.1	1.0	10.9	-4.0	15.7			12.9	4.3	0.2	6.9
KRISS	-10.6	5.1	-10.9	8.8	-11.4	9.5	-8.8	9.9	-12.1	8.5	-22.6	10.9	-11.9	10.8	-16.9	15.6	-12.9	4.3			-12.7	6.6
IAEA	2.1	7.5	1.8	10.3	1.3	10.8	3.9	11.3	0.6	10.0	-9.9	12.2	0.8	12.0	-4.2	16.5	-0.2	6.9	12.7	6.6		

Table 12. Introductory text and degrees of equivalence for the 135 kV radiation quality

Key comparison BIPM.RI(I)-K3

MEASURAND : **Air kerma**
Radiation quality 135 kV

For a comparison with NMI *i*, the key comparison reference value is the BIPM air-kerma determination $x_{R,i}$ and its standard uncertainty $u_{R,i}$

The degree of equivalence of each NMI *i* with respect to $x_{R,i}$ is given by a pair of terms:
$D_i = (x_i - x_{R,i}) / x_{R,i}$ and $U_i = 2u_i$, its expanded uncertainty (k = 2), both expressed in mGy/Gy.
In evaluating u_i for BIPM comparisons, account is taken of correlation between $u_{NMI\,i}$ and $u_{R,i}$ (see the Summary Report).
In evaluating u_i for regional comparisons, additional uncertainties u_{stab} and u_{LINK} are included (see the Comparison Report).

The degree of equivalence between two NMIs *i* and *j* is given by a pair of terms:
$D_{ij} = D_i - D_j$ and $U_{ij} = 2u_{ij}$, its expanded uncertainty (k = 2), both expressed in mGy/Gy.
In evaluating u_{ij} for the matrix of equivalence, account is taken of correlation between u_i and u_j (see the Summary Report).
For regional comparisons involving secondary standards, this includes correlation related to traceability (see the Comparison Report).

NMI *j* ⇨

NMI *i* ⇩

NMI *i*	D_i /(mGy/Gy)	U_i /(mGy/Gy)	ARPANSA D_{ij} /(mGy/Gy)	ARPANSA U_{ij} /(mGy/Gy)	NMi-VSL D_{ij}	NMi-VSL U_{ij}	GUM D_{ij}	GUM U_{ij}	NPL D_{ij}	NPL U_{ij}	ENEA D_{ij}	ENEA U_{ij}	MKEH D_{ij}	MKEH U_{ij}	NRC D_{ij}	NRC U_{ij}	VNIIM D_{ij}	VNIIM U_{ij}	PTB D_{ij}	PTB U_{ij}	NIM D_{ij}	NIM U_{ij}
ARPANSA	5.6	4.8			6.3	8.1	7.0	6.5	9.6	6.3	2.7	7.1	6.6	6.7	10.6	5.2	5.8	4.6	7.3	6.1	8.2	6.1
NMi-VSL	-0.7	8.4	-6.3	8.1			0.7	9.4	3.3	9.3	-3.6	9.9	0.3	9.6	4.3	8.5	-0.5	8.2	1.0	9.2	1.9	9.1
GUM	-1.4	7.1	-7.0	6.5	-0.7	9.4			2.6	7.9	-4.3	8.5	-0.4	8.5	3.6	7.0	-1.2	6.6	0.3	8.1	1.2	7.7
NPL	-4.0	6.6	-9.6	6.3	-3.3	9.3	-2.6	7.9			-6.9	8.4	-3.0	8.1	1.0	6.8	-3.8	6.4	-2.3	7.6	-1.4	7.5
ENEA	2.9	7.5	-2.7	7.1	3.6	9.9	4.3	8.5	6.9	8.4			3.9	8.8	7.9	7.6	3.1	7.2	4.6	8.4	5.5	8.2
MKEH	-1.0	5.1	-6.6	6.7	-0.3	9.6	0.4	8.5	3.0	8.1	-3.9	8.8			4.0	7.2	-0.8	6.9	0.7	6.5	1.6	7.7
NRC	-5.0	5.5	-10.6	5.2	-4.3	8.5	-3.6	7.0	-1.0	6.8	-7.9	7.6	-4.0	7.2			-4.8	5.3	-3.3	6.7	-2.4	6.6
VNIIM	-0.2	5.1	-5.8	4.6	0.5	8.2	1.2	6.6	3.8	6.4	-3.1	7.2	0.8	6.9	4.8	5.3			1.5	6.4	2.4	6.2
PTB	-1.7	5.2	-7.3	6.1	-1.0	9.2	-0.3	8.1	2.3	7.6	-4.6	8.4	-0.7	6.5	3.3	6.7	-1.5	6.4			0.9	7.3
NIM	-2.6	6.2	-8.2	6.1	-1.9	9.1	-1.2	7.7	1.4	7.5	-5.5	8.2	-1.6	7.7	2.4	6.6	-2.4	6.2	-0.9	7.3		
BEV	-0.1	6.8	-5.7	6.6	0.6	9.5	1.3	8.1	3.9	8.0	-3.0	8.7	0.9	8.3	4.9	7.1	0.1	6.7	1.6	7.8	2.5	7.8
NIST	-4.3	7.3	-9.9	8.0	-3.6	10.6	-2.9	9.6	-0.3	9.2	-7.2	9.9	-3.3	8.3	0.7	8.4	-4.1	8.2	-2.6	8.3	-1.7	8.9
LNE-LNHB	-3.3	7.8	-8.9	8.6	-2.6	11.0	-1.9	10.0	0.7	9.7	-6.2	10.3	-2.3	8.7	1.7	9.0	-3.1	8.7	-1.6	8.7	-0.7	9.4
INER	-0.2	7.9	-5.8	8.2	0.5	10.7	1.2	9.7	3.8	9.4	-3.1	10.0	0.8	9.1	4.8	8.6	0.0	8.4	1.5	8.7	2.4	9.1
Nuc. Malaysia	11.6	12.9	6.0	13.5	12.3	15.2	13.0	14.5	15.6	11.0	8.7	14.6	12.6	14.1	16.6	13.7	11.8	13.6	13.3	13.8	14.2	14.0
NMIJ	-2.2	10.2	-7.8	10.5	-1.5	12.6	-0.8	11.7	1.8	11.5	-5.1	12.0	-1.2	11.2	2.8	10.8	-2.0	10.6	-0.5	10.9	0.4	11.2
NMISA	-2.5	5.5	-8.1	7.5	-1.8	10.2	-1.1	9.2	1.5	8.8	-5.4	9.4	-1.5	8.5	2.5	8.0	-2.3	7.7	-0.8	8.1	0.1	8.5
KRISS	-3.4	5.1	-9.0	7.4	-2.7	10.1	-2.0	9.0	0.6	8.7	-6.3	9.3	-2.4	8.4	1.6	7.8	-3.2	7.5	-1.7	7.9	-0.8	8.3
IAEA	4.7	7.5	-0.9	9.1	5.4	11.4	6.1	10.5	8.7	10.1	1.8	10.7	5.7	9.9	9.7	9.4	4.9	9.2	6.4	9.5	7.3	9.9

NMI *i* ⇩

NMI *i*	D_i /(mGy/Gy)	U_i /(mGy/Gy)	BEV D_{ij} /(mGy/Gy)	BEV U_{ij} /(mGy/Gy)	NIST D_{ij}	NIST U_{ij}	LNE-LNHB D_{ij}	LNE-LNHB U_{ij}	INER D_{ij}	INER U_{ij}	Nuc Malay D_{ij}	Nuc Malay U_{ij}	NMIJ D_{ij}	NMIJ U_{ij}	NMISA D_{ij}	NMISA U_{ij}	KRISS D_{ij}	KRISS U_{ij}	IAEA D_{ij}	IAEA U_{ij}
ARPANSA	5.6	4.8	5.7	6.6	9.9	8.0	8.9	8.6	5.8	8.2	-6.0	13.5	7.8	10.5	8.1	7.5	9.0	7.4	0.9	9.1
NMi-VSL	-0.7	8.4	-0.6	9.5	3.6	10.6	2.6	11.0	-0.5	10.7	-12.3	15.2	1.5	12.6	1.8	10.2	2.7	10.1	-5.4	11.4
GUM	-1.4	7.1	-1.3	8.1	2.9	9.6	1.9	10.0	-1.2	9.7	-13.0	14.5	0.8	11.7	1.1	9.2	2.0	9.0	-6.1	10.5
NPL	-4.0	6.6	-3.9	8.0	0.3	9.2	-0.7	9.7	-3.8	9.4	-15.6	11.0	-1.8	11.5	-1.5	8.8	-0.6	8.7	-8.7	10.1
ENEA	2.9	7.5	3.0	8.7	7.2	9.9	6.2	10.3	3.1	10.0	-8.7	14.6	5.1	12.0	5.4	9.4	6.3	9.3	-1.8	10.7
MKEH	-1.0	5.1	-0.9	8.3	3.3	8.3	2.3	8.7	-0.8	9.1	-12.6	14.1	1.2	11.2	1.5	8.5	2.4	8.4	-5.7	9.9
NRC	-5.0	5.5	-4.9	7.1	-0.7	8.4	-1.7	9.0	-4.8	8.6	-16.6	13.7	-2.8	10.8	-2.5	8.0	-1.6	7.8	-9.7	9.4
VNIIM	-0.2	5.1	-0.1	6.7	4.1	8.2	3.1	8.7	0.0	8.4	-11.8	13.6	2.0	10.6	2.3	7.7	3.2	7.5	-4.9	9.2
PTB	-1.7	5.2	-1.6	7.8	2.6	8.3	1.6	8.7	-1.5	8.7	-13.3	13.8	0.5	10.9	0.8	8.1	1.7	7.9	-6.4	9.5
NIM	-2.6	6.2	-2.5	7.8	1.7	8.9	0.7	9.4	-2.4	9.1	-14.2	14.0	-0.4	11.2	-0.1	8.5	0.8	8.3	-7.3	9.9
BEV	-0.1	6.8			4.2	9.4	3.2	9.8	0.1	9.5	-11.7	14.3	2.1	11.6	2.4	8.9	3.3	8.8	-4.8	10.3
NIST	-4.3	7.3	-4.2	9.4			-1.0	10.1	-4.1	10.1	-15.9	14.7	-2.1	12.1	-1.8	9.6	-0.9	9.5	-9.0	10.8
LNE-LNHB	-3.3	7.8	-3.2	9.8	1.0	10.1			-3.1	10.6	-14.9	15.1	-1.1	12.4	-0.8	10.1	0.1	9.9	-8.0	11.3
INER	-0.2	7.9	-0.1	9.5	4.1	10.1	3.1	10.6			-11.8	14.2	2.0	11.4	2.3	8.7	3.2	8.5	-4.9	10.0
Nuc. Malaysia	11.6	12.9	11.7	14.3	15.9	14.7	14.9	15.1	11.8	14.2			13.8	15.6	14.1	11.1	15.0	10.9	6.9	12.2
NMIJ	-2.2	10.2	-2.1	11.6	2.1	12.1	1.1	12.4	-2.0	11.4	-13.8	15.6			0.3	10.9	1.2	10.8	-6.9	12.0
NMISA	-2.5	5.5	-2.4	8.9	1.8	9.6	0.8	10.1	-2.3	8.7	-14.1	11.1	-0.3	10.9			0.9	4.3	-7.2	6.9
KRISS	-3.4	5.1	-3.3	8.8	0.9	9.5	-0.1	9.9	-3.2	8.5	-15.0	10.9	-1.2	10.8	-0.9	4.3			-8.1	6.6
IAEA	4.7	7.5	4.8	10.3	9.0	10.8	8.0	11.3	4.9	10.0	-6.9	12.2	6.9	12.0	7.2	6.9	8.1	6.6		

Table 13. Introductory text and degrees of equivalence for the 180 kV radiation quality

Key comparison BIPM.RI(I)-K3

MEASURAND : Air kerma
Radiation quality 180 kV

For a comparison with NMI i, the key comparison reference value is the BIPM air-kerma determination $x_{R,i}$ and its standard uncertainty $u_{R,i}$

The degree of equivalence of each NMI i with respect to $x_{R,i}$ is given by a pair of terms:
$D_i = (x_i - x_{R,i}) / x_{R,i}$ and $U_i = 2u_i$, its expanded uncertainty (k = 2), both expressed in mGy/Gy.
In evaluating u_i for BIPM comparisons, account is taken of correlation between $u_{NMI\,i}$ and $u_{R,i}$ (see the Summary Report).
In evaluating u_i for regional comparisons, additional uncertainties u_{stab} and u_{LINK} are included (see the Comparison Report).

The degree of equivalence between two NMIs i and j is given by a pair of terms:
$D_{ij} = D_i - D_j$ and $U_{ij} = 2u_{ij}$, its expanded uncertainty (k = 2), both expressed in mGy/Gy.
In evaluating u_{ij} for the matrix of equivalence, account is taken of correlation between u_i and u_j (see the Summary Report).
For regional comparisons involving secondary standards, this includes correlation related to traceability (see the Comparison Report).

NMI j ⟹

NMI i ⇩

NMI i	D_i /(mGy/Gy)	U_i	ARPANSA D_{ij} /(mGy/Gy)	U_{ij}	NMi-VSL D_{ij} /(mGy/Gy)	U_{ij}	GUM D_{ij} /(mGy/Gy)	U_{ij}	NPL D_{ij} /(mGy/Gy)	U_{ij}	ENEA D_{ij} /(mGy/Gy)	U_{ij}	MKEH D_{ij} /(mGy/Gy)	U_{ij}	NRC D_{ij} /(mGy/Gy)	U_{ij}	VNIIM D_{ij} /(mGy/Gy)	U_{ij}	PTB D_{ij} /(mGy/Gy)	U_{ij}	NIM D_{ij} /(mGy/Gy)	U_{ij}
ARPANSA	5.0	4.8			8.2	8.1	7.3	6.5	9.3	6.3	8.1	7.1	5.2	6.7	12.2	5.2	3.6	4.6	6.7	6.1	8.6	6.1
NMi-VSL	-3.2	8.4	-8.2	8.1			-0.9	9.4	1.1	9.3	-0.1	9.9	-3.0	9.6	4.0	8.5	-4.6	8.2	-1.5	9.2	0.4	9.1
GUM	-2.3	7.1	-7.3	6.5	0.9	9.4			2.0	7.9	0.8	8.5	-2.1	8.5	4.9	7.0	-3.7	6.6	-0.6	8.1	1.3	7.7
NPL	-4.3	6.6	-9.3	6.3	-1.1	9.3	-2.0	7.9			-1.2	8.4	-4.1	8.1	2.9	6.8	-5.7	6.4	-2.6	7.6	-0.7	7.5
ENEA	-3.1	7.5	-8.1	7.1	0.1	9.9	-0.8	8.5	1.2	8.4			-2.9	8.8	4.1	7.6	-4.5	7.2	-1.4	8.4	0.5	8.2
MKEH	-0.2	5.1	-5.2	6.7	3.0	9.6	2.1	8.5	4.1	8.1	2.9	8.8			7.0	7.2	-1.6	6.9	1.5	6.5	3.4	7.7
NRC	-7.2	5.5	-12.2	5.2	-4.0	8.5	-4.9	7.0	-2.9	6.8	-4.1	7.6	-7.0	7.2			-8.6	5.3	-5.5	6.7	-3.6	6.6
VNIIM	1.4	5.1	-3.6	4.6	4.6	8.2	3.7	6.6	5.7	6.4	4.5	7.2	1.6	6.9	8.6	5.3			3.1	6.4	5.0	6.2
PTB	-1.7	5.2	-6.7	6.1	1.5	9.2	0.6	8.1	2.6	7.6	1.4	8.4	-1.5	6.5	5.5	6.7	-3.1	6.4			1.9	7.3
NIM	-3.6	6.2	-8.6	6.1	-0.4	9.1	-1.3	7.7	0.7	7.5	-0.5	8.2	-3.4	7.7	3.6	6.6	-5.0	6.2	-1.9	7.3		
BEV	-2.8	6.8	-7.8	6.6	0.4	9.5	-0.5	8.1	1.5	8.0	0.3	8.7	-2.6	8.3	4.4	7.1	-4.2	6.7	-1.1	7.8	0.8	7.8
NIST	-3.5	7.3	-8.5	8.0	-0.3	10.6	-1.2	9.6	0.8	9.2	-0.4	9.9	-3.3	8.3	3.7	8.4	-4.9	8.2	-1.8	8.3	0.1	8.9
LNE-LNHB	-5.7	7.8	-10.7	8.6	-2.5	11.0	-3.4	10.0	-1.4	9.7	-2.6	10.3	-5.5	8.7	1.5	9.0	-7.1	8.7	-4.0	8.7	-2.1	9.4
INER	0.4	7.9	-4.6	8.2	3.6	10.7	2.7	9.7	4.7	9.4	3.5	10.0	0.6	9.1	7.6	8.6	-1.0	8.4	2.1	8.7	4.0	9.1
Nuc. Malaysia	9.3	12.9	4.3	13.5	12.5	15.2	11.6	14.5	13.6	11.0	12.4	14.6	9.5	14.1	16.5	13.7	7.9	13.6	11.0	13.8	12.9	14.0
NMIJ	-2.8	10.2	-7.8	10.5	0.4	12.6	-0.5	11.7	1.5	11.5	0.3	12.0	-2.6	11.2	4.4	10.8	-4.2	10.6	-1.1	10.9	0.8	11.2
NMISA	-0.8	5.5	-5.8	7.5	2.4	10.2	1.5	9.2	3.5	8.8	2.3	9.4	-0.6	8.5	6.4	8.0	-2.2	7.7	0.9	8.1	2.8	8.5
KRISS	1.0	5.1	-4.0	7.4	4.2	10.1	3.3	9.0	5.3	8.7	4.1	9.3	1.2	8.4	8.2	7.8	-0.4	7.5	2.7	7.9	4.6	8.3
IAEA	7.4	7.5	2.4	9.1	10.6	11.4	9.7	10.5	11.7	10.1	10.5	10.7	7.6	9.9	14.6	9.4	6.0	9.2	9.1	9.5	11.0	9.9

NMI i ⇩

NMI i	D_i /(mGy/Gy)	U_i	BEV D_{ij} /(mGy/Gy)	U_{ij}	NIST D_{ij} /(mGy/Gy)	U_{ij}	LNE-LNHB D_{ij} /(mGy/Gy)	U_{ij}	INER D_{ij} /(mGy/Gy)	U_{ij}	Nuc Malay D_{ij} /(mGy/Gy)	U_{ij}	NMIJ D_{ij} /(mGy/Gy)	U_{ij}	NMISA D_{ij} /(mGy/Gy)	U_{ij}	KRISS D_{ij} /(mGy/Gy)	U_{ij}	IAEA D_{ij} /(mGy/Gy)	U_{ij}
ARPANSA	5.0	4.8	7.8	6.6	8.5	8.0	10.7	8.6	4.6	8.2	-4.3	13.5	7.8	10.5	5.8	7.5	4.0	7.4	-2.4	9.1
NMi-VSL	-3.2	8.4	-0.4	9.5	0.3	10.6	2.5	11.0	-3.6	10.7	-12.5	15.2	-0.4	12.6	-2.4	10.2	-4.2	10.1	-10.6	11.4
GUM	-2.3	7.1	0.5	8.1	1.2	9.6	3.4	10.0	-2.7	9.7	-11.6	14.5	0.5	11.7	-1.5	9.2	-3.3	9.0	-9.7	10.5
NPL	-4.3	6.6	-1.5	8.0	-0.8	9.2	1.4	9.7	-4.7	9.4	-13.6	11.0	-1.5	11.5	-3.5	8.8	-5.3	8.7	-11.7	10.1
ENEA	-3.1	7.5	-0.3	8.7	0.4	9.9	2.6	10.3	-3.5	10.0	-12.4	14.6	-0.3	12.0	-2.3	9.4	-4.1	9.3	-10.5	10.7
MKEH	-0.2	5.1	2.6	8.3	3.3	8.3	5.5	8.7	-0.6	9.1	-9.5	14.1	2.6	11.2	0.6	8.5	-1.2	8.4	-7.6	9.9
NRC	-7.2	5.5	-4.4	7.1	-3.7	8.4	-1.5	9.0	-7.6	8.6	-16.5	13.7	-4.4	10.8	-6.4	8.0	-8.2	7.8	-14.6	9.4
VNIIM	1.4	5.1	4.2	6.7	4.9	8.2	7.1	8.7	1.0	8.4	-7.9	13.6	4.2	10.6	2.2	7.7	0.4	7.5	-6.0	9.2
PTB	-1.7	5.2	1.1	7.8	1.8	8.3	4.0	8.7	-2.1	8.7	-11.0	13.8	1.1	10.9	-0.9	8.1	-2.7	7.9	-9.1	9.5
NIM	-3.6	6.2	-0.8	7.8	-0.1	8.9	2.1	9.4	-4.0	9.1	-12.9	14.0	-0.8	11.2	-2.8	8.5	-4.6	8.3	-11.0	9.9
BEV	-2.8	6.8			0.7	9.4	2.9	9.8	-3.2	9.5	-12.1	14.3	0.0	11.6	-2.0	8.9	-3.8	8.8	-10.2	10.3
NIST	-3.5	7.3	-0.7	9.4			2.2	10.1	-3.9	10.1	-12.8	14.7	-0.7	12.1	-2.7	9.6	-4.5	9.5	-10.9	10.8
LNE-LNHB	-5.7	7.8	-2.9	9.8	-2.2	10.1			-6.1	10.6	-15.0	15.1	-2.9	12.4	-4.9	10.1	-6.7	9.9	-13.1	11.3
INER	0.4	7.9	3.2	9.5	3.9	10.1	6.1	10.6			-8.9	14.2	3.2	11.4	1.2	8.7	-0.6	8.5	-7.0	10.0
Nuc. Malaysia	9.3	12.9	12.1	14.3	12.8	14.7	15.0	15.1	8.9	14.2			12.1	15.6	10.1	11.1	8.3	10.9	1.9	12.2
NMIJ	-2.8	10.2	0.0	11.6	0.7	12.1	2.9	12.4	-3.2	11.4	-12.1	15.6			-2.0	10.9	-3.8	10.8	-10.2	12.0
NMISA	-0.8	5.5	2.0	8.9	2.7	9.6	4.9	10.1	-1.2	8.7	-10.1	11.1	2.0	10.9			-1.8	4.3	-8.2	6.9
KRISS	1.0	5.1	3.8	8.8	4.5	9.5	6.7	9.9	0.6	8.5	-8.3	10.9	3.8	10.8	1.8	4.3			-6.4	6.6
IAEA	7.4	7.5	10.2	10.3	10.9	10.8	13.1	11.3	7.0	10.0	-1.9	12.2	10.2	12.0	8.2	6.9	6.4	6.6		

Table 14. Introductory text and degrees of equivalence for the 250 kV radiation quality

Key comparison BIPM.RI(I)-K3

MEASURAND : Air kerma
Radiation quality 250 kV

For a comparison with NMI *i*, the key comparison reference value is the BIPM air-kerma determination $x_{R,i}$ and its standard uncertainty $u_{R,i}$

The degree of equivalence of each NMI *i* with respect to $x_{R,i}$ is given by a pair of terms:
$D_i = (x_i - x_{R,i}) / x_{R,i}$ and $U_i = 2u_i$, its expanded uncertainty (k = 2), both expressed in mGy/Gy.
In evaluating u_i for BIPM comparisons, account is taken of correlation between $u_{NMI\ i}$ and $u_{R,i}$ (see the Summary Report).
In evaluating u_i for regional comparisons, additional uncertainties u_{stab} and u_{LINK} are included (see the Comparison Report).

The degree of equivalence between two NMIs *i* and *j* is given by a pair of terms:
$D_{ij} = D_i - D_j$ and $U_{ij} = 2u_{ij}$, its expanded uncertainty (k = 2), both expressed in mGy/Gy.
In evaluating u_{ij} for the matrix of equivalence, account is taken of correlation between u_i and u_j (see the Summary Report).
For regional comparisons involving secondary standards, this includes correlation related to traceability (see the Comparison Report).

NMI *j* ⇨

NMI *i* ⇩			ARPANSA		NMi-VSL		GUM		NPL		ENEA		MKEH		NRC		VNIIM		PTB		NIM	
	D_i /(mGy/Gy)	U_i /(mGy/Gy)	D_{ij} /(mGy/Gy)	U_{ij} /(mGy/Gy)	D_{ij} /(mGy/Gy)	U_{ij} /(mGy/Gy)	D_{ij} /(mGy/Gy)	U_{ij} /(mGy/Gy)	D_{ij} /(mGy/Gy)	U_{ij} /(mGy/Gy)	D_{ij} /(mGy/Gy)	U_{ij} /(mGy/Gy)	D_{ij} /(mGy/Gy)	U_{ij} /(mGy/Gy)	D_{ij} /(mGy/Gy)	U_{ij} /(mGy/Gy)	D_{ij} /(mGy/Gy)	U_{ij} /(mGy/Gy)	D_{ij} /(mGy/Gy)	U_{ij} /(mGy/Gy)	D_{ij} /(mGy/Gy)	U_{ij} /(mGy/Gy)
ARPANSA	5.1	4.8			11.3	8.1	10.6	6.5	13.2	6.3	8.7	7.1	7.6	6.7	14.5	5.2	6.9	4.6	8.8	6.1	12.2	6.1
NMi-VSL	-6.2	8.4	-11.3	8.1			-0.7	9.4	1.9	9.3	-2.6	9.9	-3.7	9.6	3.2	8.5	-4.4	8.2	-2.5	9.2	0.9	9.1
GUM	-5.5	7.1	-10.6	6.5	0.7	9.4			2.6	7.9	-1.9	8.5	-3.0	8.5	3.9	7.0	-3.7	6.6	-1.8	8.1	1.6	7.7
NPL	-8.1	6.6	-13.2	6.3	-1.9	9.3	-2.6	7.9			-4.5	8.4	-5.6	8.1	1.3	6.8	-6.3	6.4	-4.4	7.6	-1.0	7.5
ENEA	-3.6	7.5	-8.7	7.1	2.6	9.9	1.9	8.5	4.5	8.4			-1.1	8.8	5.8	7.6	-1.8	7.2	0.1	8.4	3.5	8.2
MKEH	-2.5	5.1	-7.6	6.7	3.7	9.6	3.0	8.5	5.6	8.1	1.1	8.8			6.9	7.2	-0.7	6.9	1.2	6.5	4.6	7.7
NRC	-9.4	5.5	-14.5	5.2	-3.2	8.5	-3.9	7.0	-1.3	6.8	-5.8	7.6	-6.9	7.2			-7.6	5.3	-5.7	6.7	-2.3	6.6
VNIIM	-1.8	5.1	-6.9	4.6	4.4	8.2	3.7	6.6	6.3	6.4	1.8	7.2	0.7	6.9	7.6	5.3			1.9	6.4	5.3	6.2
PTB	-3.7	5.2	-8.8	6.1	2.5	9.2	1.8	8.1	4.4	7.6	-0.1	8.4	-1.2	6.5	5.7	6.7	-1.9	6.4			3.4	7.3
NIM	-7.1	6.2	-12.2	6.1	-0.9	9.1	-1.6	7.7	1.0	7.5	-3.5	8.2	-4.6	7.7	2.3	6.6	-5.3	6.2	-3.4	7.3		
BEV	-7.4	6.8	-12.5	6.6	-1.2	9.5	-1.9	8.1	0.7	8.0	-3.8	8.7	-4.9	8.3	2.0	7.1	-5.6	6.7	-3.7	7.8	-0.3	7.8
NIST	-7.0	7.3	-12.1	8.0	-0.8	10.6	-1.5	9.6	1.1	9.2	-3.4	9.9	-4.5	8.3	2.4	8.4	-5.2	8.2	-3.3	8.3	0.1	8.9
LNE-LNHB	-9.4	7.8	-14.5	8.6	-3.2	11.0	-3.9	10.0	-1.3	9.7	-5.8	10.3	-6.9	8.7	0.0	9.0	-7.6	8.7	-5.7	8.7	-2.3	9.4
INER	-1.9	7.9	-7.0	8.2	4.3	10.7	3.6	9.7	6.2	9.4	1.7	10.0	0.6	9.1	7.5	8.6	-0.1	8.4	1.8	8.7	5.2	9.1
Nuc. Malaysia	8.4	12.9	3.3	13.5	14.6	15.2	13.9	14.5	16.5	11.0	12.0	14.6	10.9	14.1	17.8	13.7	10.2	13.6	12.1	13.8	15.5	14.0
NMIJ	-4.5	10.2	-9.6	10.5	1.7	12.6	1.0	11.7	3.6	11.5	-0.9	12.0	-2.0	11.2	4.9	10.8	-2.7	10.6	-0.8	10.9	2.6	11.2
BARC	7.3	15.2	2.2	15.4	13.5	16.9	12.8	16.3	15.4	16.1	10.9	16.4	9.8	15.9	16.7	15.6	9.1	15.5	11.0	15.7	14.4	15.9
NMISA	0.0	5.5	-5.1	7.5	6.2	10.2	5.5	9.2	8.1	8.8	3.6	9.4	2.5	8.5	9.4	8.0	1.8	7.7	3.7	8.1	7.1	8.5
KRISS	0.1	5.1	-5.0	7.4	6.3	10.1	5.6	9.0	8.2	8.7	3.7	9.3	2.6	8.4	9.5	7.8	1.9	7.5	3.8	7.9	7.2	8.3
IAEA	6.5	7.5	1.4	9.1	12.7	11.4	12.0	10.5	14.6	10.1	10.1	10.7	9.0	9.9	15.9	9.4	8.3	9.2	10.2	9.5	13.6	9.9

NMI *i* ⇩			BEV		NIST		LNE-LNHB		INER		Nuc Malay		NMIJ		BARC		NMISA		KRISS		IAEA	
	D_i /(mGy/Gy)	U_i /(mGy/Gy)	D_{ij} /(mGy/Gy)	U_{ij} /(mGy/Gy)	D_{ij} /(mGy/Gy)	U_{ij} /(mGy/Gy)	D_{ij} /(mGy/Gy)	U_{ij} /(mGy/Gy)	D_{ij} /(mGy/Gy)	U_{ij} /(mGy/Gy)	D_{ij} /(mGy/Gy)	U_{ij} /(mGy/Gy)	D_{ij} /(mGy/Gy)	U_{ij} /(mGy/Gy)	D_{ij} /(mGy/Gy)	U_{ij} /(mGy/Gy)	D_{ij} /(mGy/Gy)	U_{ij} /(mGy/Gy)	D_{ij} /(mGy/Gy)	U_{ij} /(mGy/Gy)	D_{ij} /(mGy/Gy)	U_{ij} /(mGy/Gy)
ARPANSA	5.1	4.8	12.5	6.6	12.1	8.0	14.5	8.6	7.0	8.2	-3.3	13.5	9.6	10.5	-2.2	15.4	5.1	7.5	5.0	7.4	-1.4	9.1
NMi-VSL	-6.2	8.4	1.2	9.5	0.8	10.6	3.2	11.0	-4.3	10.7	-14.6	15.2	-1.7	12.6	-13.5	16.9	-6.2	10.2	-6.3	10.1	-12.7	11.4
GUM	-5.5	7.1	1.9	8.1	1.5	9.6	3.9	10.0	-3.6	9.7	-13.9	14.5	-1.0	11.7	-12.8	16.3	-5.5	9.2	-5.6	9.0	-12.0	10.5
NPL	-8.1	6.6	-0.7	8.0	-1.1	9.2	1.3	9.7	-6.2	9.4	-16.5	11.0	-3.6	11.5	-15.4	16.1	-8.1	8.8	-8.2	8.7	-14.6	10.1
ENEA	-3.6	7.5	3.8	8.7	3.4	9.9	5.8	10.3	-1.7	10.0	-12.0	14.6	0.9	12.0	-10.9	16.4	-3.6	9.4	-3.7	9.3	-10.1	10.7
MKEH	-2.5	5.1	4.9	8.3	4.5	8.3	6.9	8.7	-0.6	9.1	-10.9	14.1	2.0	11.2	-9.8	15.9	-2.5	8.5	-2.6	8.4	-9.0	9.9
NRC	-9.4	5.5	-2.0	7.1	-2.4	8.4	0.0	9.0	-7.5	8.6	-17.8	13.7	-4.9	10.8	-16.7	15.6	-9.4	8.0	-9.5	7.8	-15.9	9.4
VNIIM	-1.8	5.1	5.6	6.7	5.2	8.2	7.6	8.7	0.1	8.4	-10.2	13.6	2.7	10.6	-9.1	15.5	-1.8	7.7	-1.9	7.5	-8.3	9.2
PTB	-3.7	5.2	3.7	7.8	3.3	8.3	5.7	8.7	-1.8	8.7	-12.1	13.8	0.8	10.9	-11.0	15.7	-3.7	8.1	-3.8	7.9	-10.2	9.5
NIM	-7.1	6.2	0.3	7.8	-0.1	8.9	2.3	9.4	-5.2	9.1	-15.5	14.0	-2.6	11.2	-14.4	15.9	-7.1	8.5	-7.2	8.3	-13.6	9.9
BEV	-7.4	6.8			-0.4	9.4	2.0	9.8	-5.5	9.5	-15.8	14.3	-2.9	11.6	-14.7	16.1	-7.4	8.9	-7.5	8.8	-13.9	10.3
NIST	-7.0	7.3	0.4	9.4			2.4	10.1	-5.1	10.1	-15.4	14.7	-2.5	12.1	-14.3	16.5	-7.0	9.6	-7.1	9.5	-13.5	10.8
LNE-LNHB	-9.4	7.8	-2.0	9.8	-2.4	10.1			-7.5	10.6	-17.8	15.1	-4.9	12.4	-16.7	16.8	-9.4	10.1	-9.5	9.9	-15.9	11.3
INER	-1.9	7.9	5.5	9.5	5.1	10.1	7.5	10.6			-10.3	14.2	2.6	11.4	-9.2	16.0	-1.9	8.7	-2.0	8.5	-8.4	10.0
Nuc. Malaysia	8.4	12.9	15.8	14.3	15.4	14.7	17.8	15.1	10.3	14.2			12.9	15.6	1.1	19.3	8.4	11.1	8.3	10.9	1.9	12.2
NMIJ	-4.5	10.2	2.9	11.6	2.5	12.1	4.9	12.4	-2.6	11.4	-12.9	15.6			-11.8	17.3	-4.5	10.9	-4.6	10.8	-11.0	12.0
BARC	7.3	15.2	14.7	16.1	14.3	16.5	16.7	16.8	9.2	16.0	-1.1	19.3	11.8	17.3			7.3	15.7	7.2	15.6	0.8	16.5
NMISA	0.0	5.5	7.4	8.9	7.0	9.6	9.4	10.1	1.9	8.7	-8.4	11.1	4.5	10.9	-7.3	15.7			-0.1	4.3	-6.5	6.9
KRISS	0.1	5.1	7.5	8.8	7.1	9.5	9.5	9.9	2.0	8.5	-8.3	10.9	4.6	10.8	-7.2	15.6	0.1	4.3			-6.4	6.6
IAEA	6.5	7.5	13.9	10.3	13.5	10.8	15.9	11.3	8.4	10.0	-1.9	12.2	11.0	12.0	-0.8	16.5	6.5	6.9	6.4	6.6		

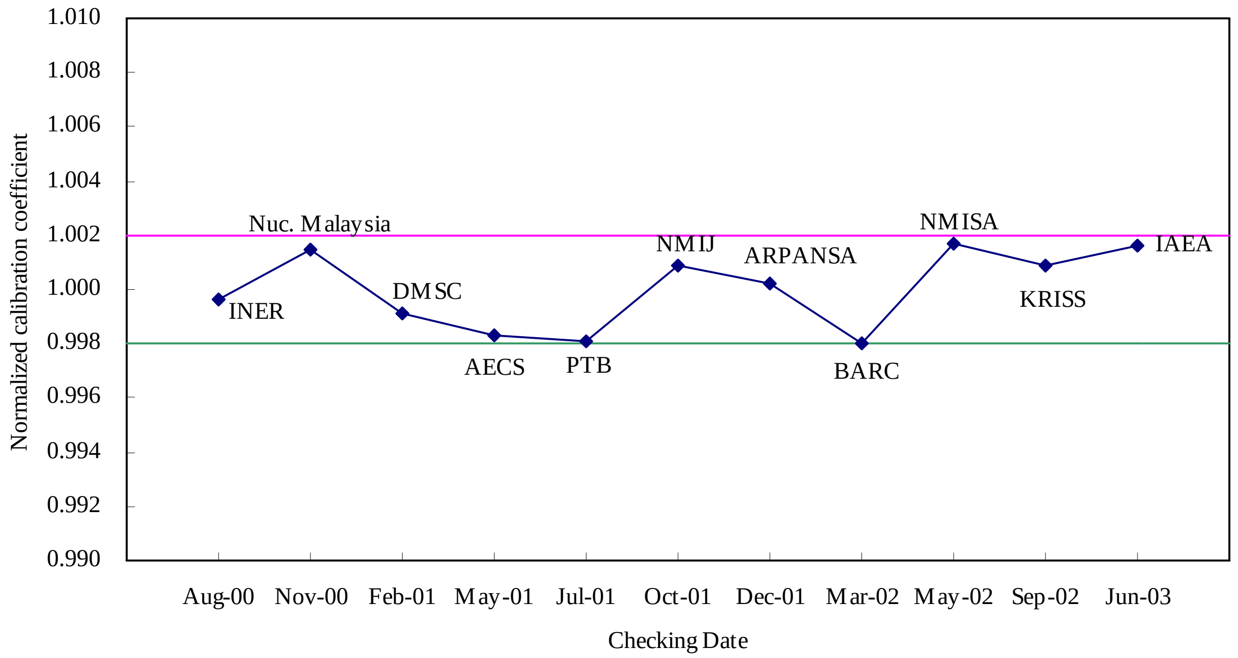

Fig. 1. Stability of PTW-30001 (S/N 2340) transfer chamber
(All measurements made at the INER)

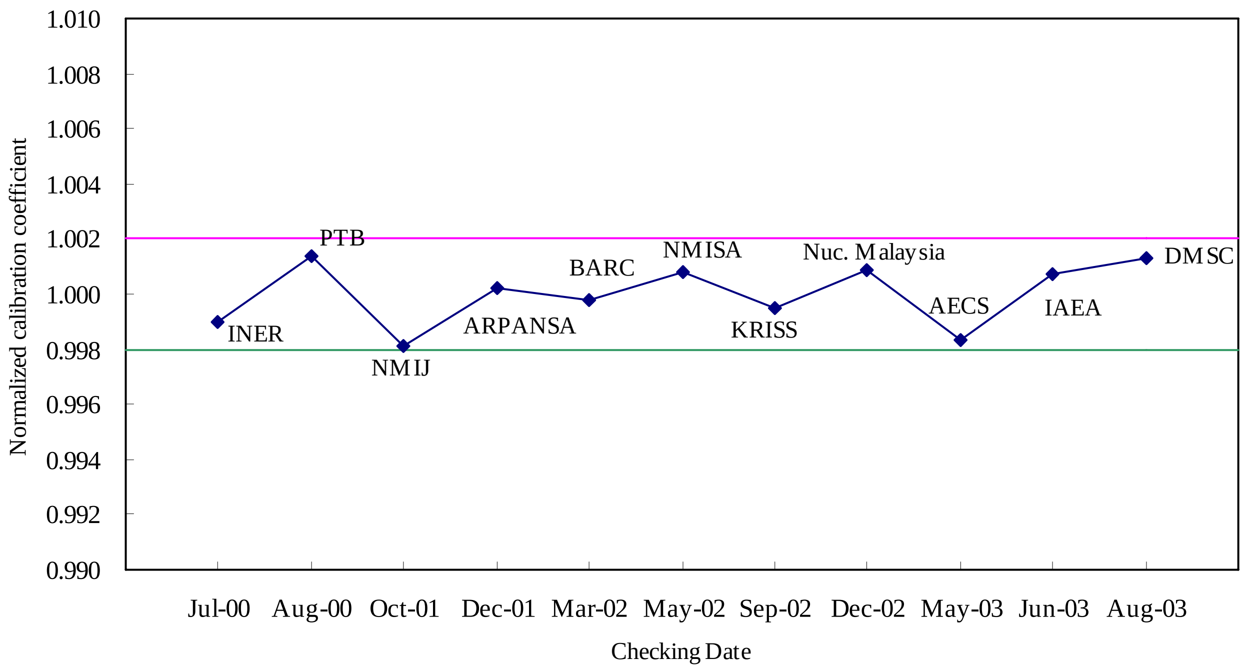

Fig. 2. Stability of PTW-30001 (S/N 2251) transfer chamber
(All measurements made at the INER)

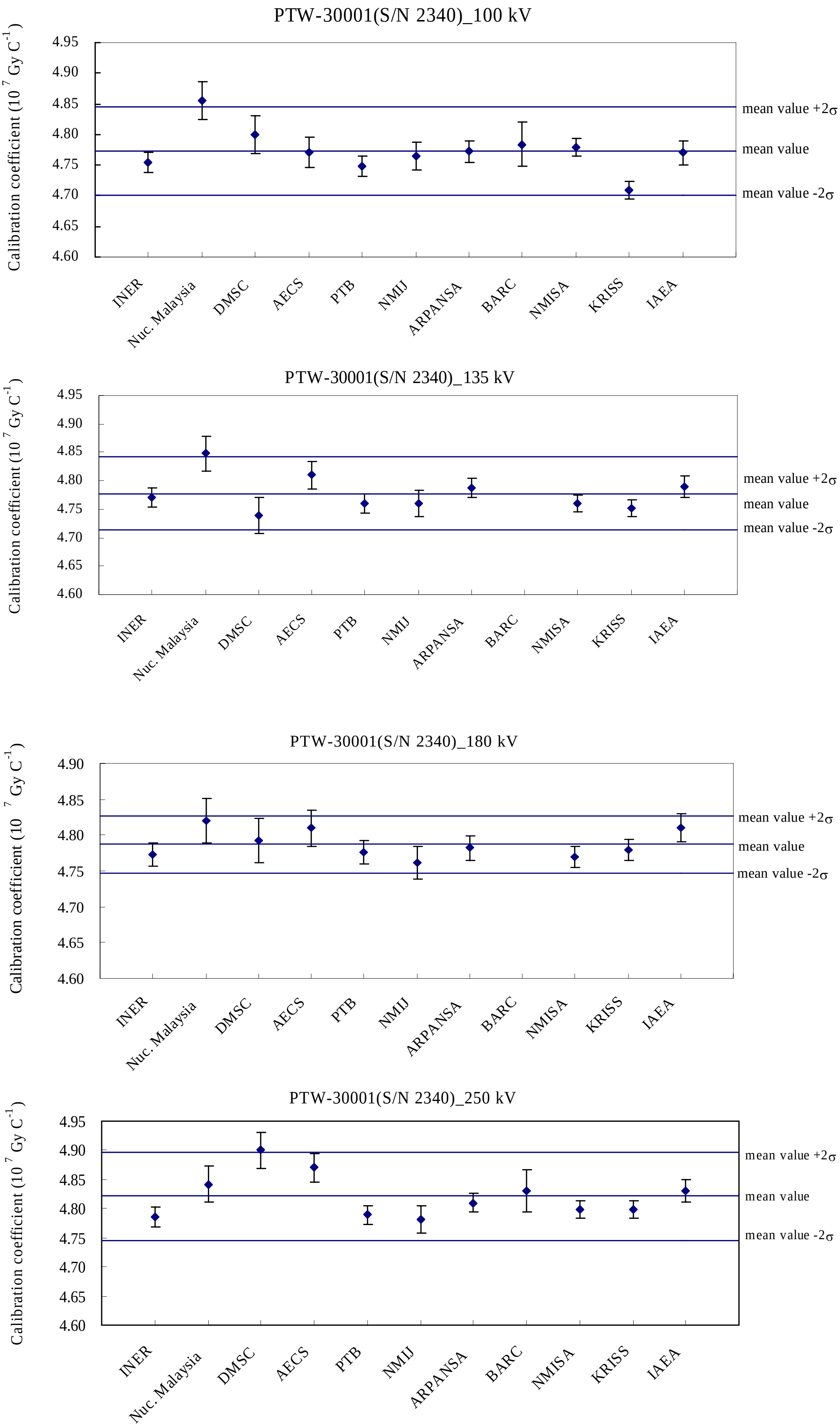

Fig. 3. The distribution of the PTW-30001 (S/N 2340) transfer chamber calibration coefficients with the standard deviation of the distribution indicated

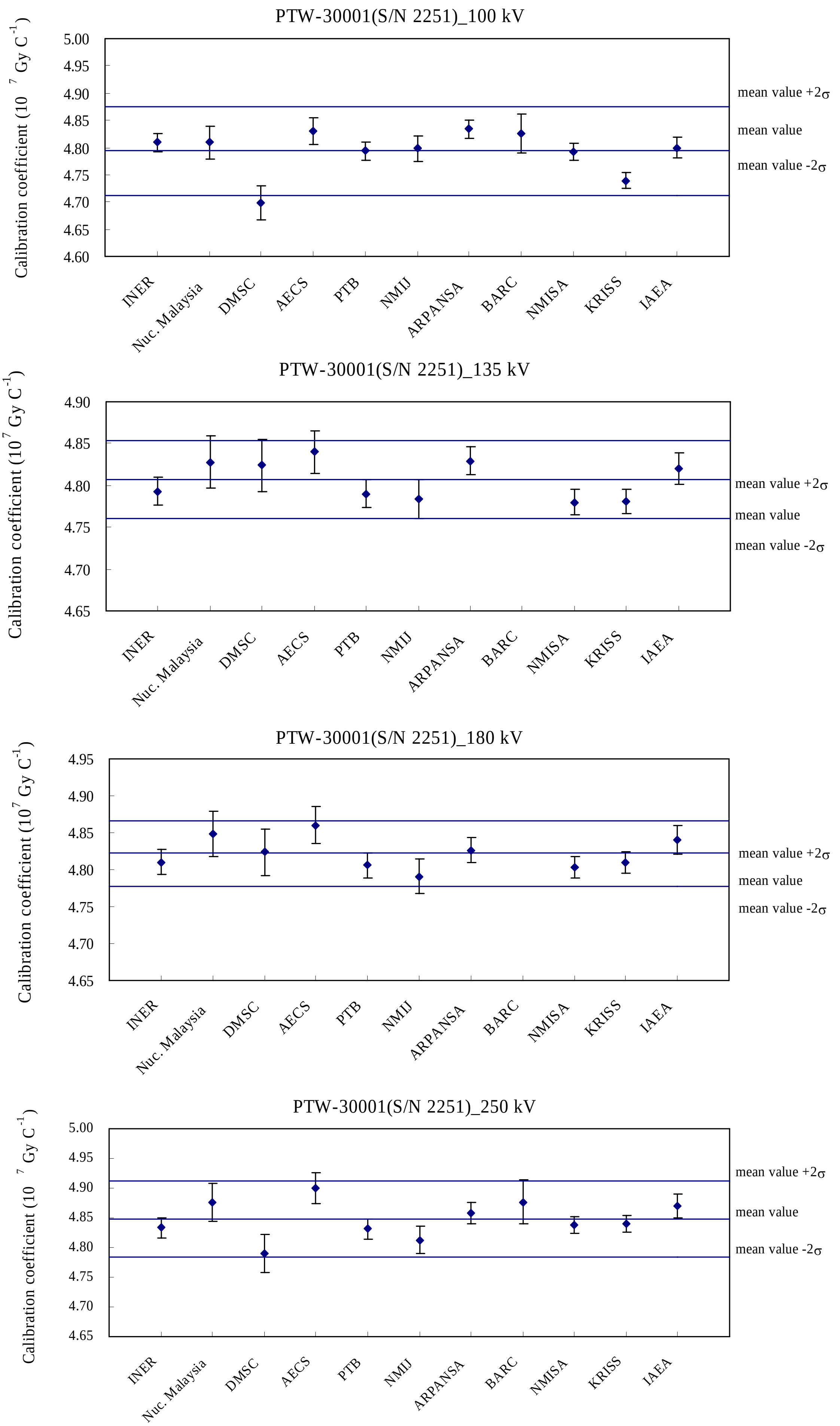

Fig. 4. The distribution of the PTW-30001 (S/N 2251) transfer chamber calibration coefficients with the standard deviation of the distribution indicated

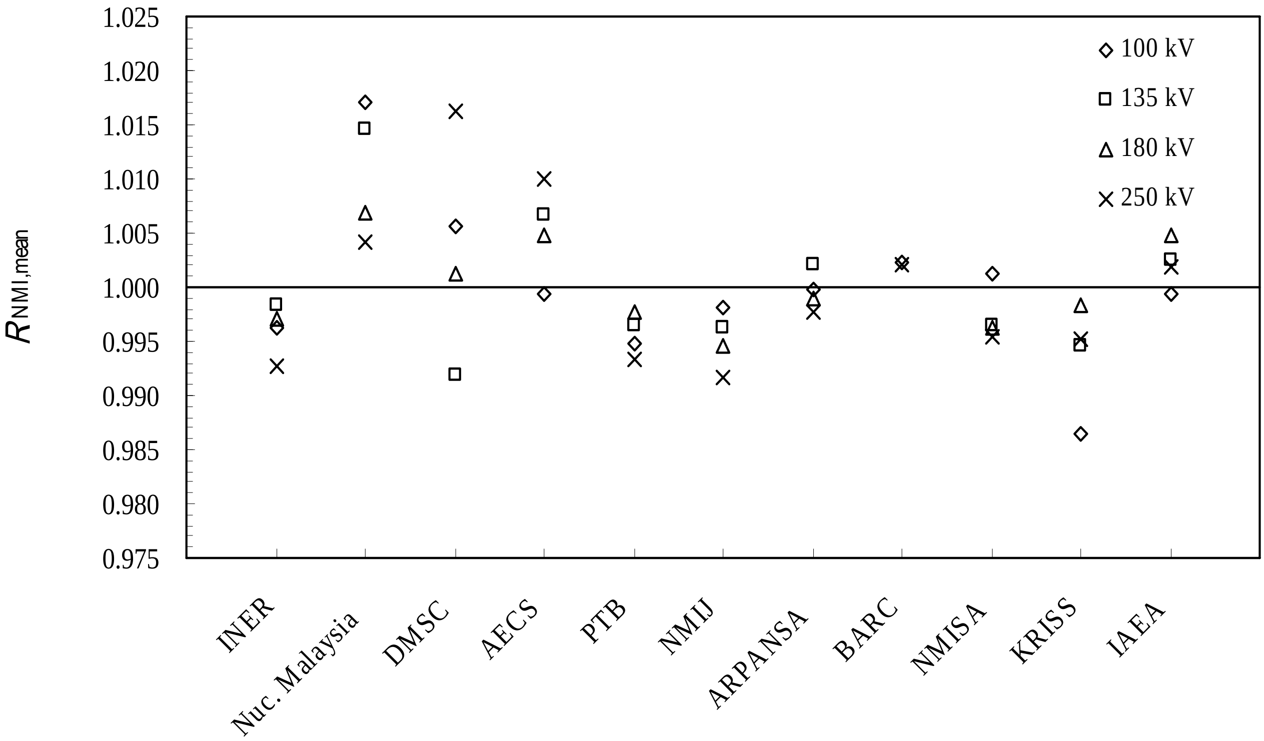

Fig. 5. Ratios $R_{\mathrm{NMI,mean}}$ of PTW-30001 (S/N 2340) transfer chamber calibration coefficients relative to the mean value for all laboratories

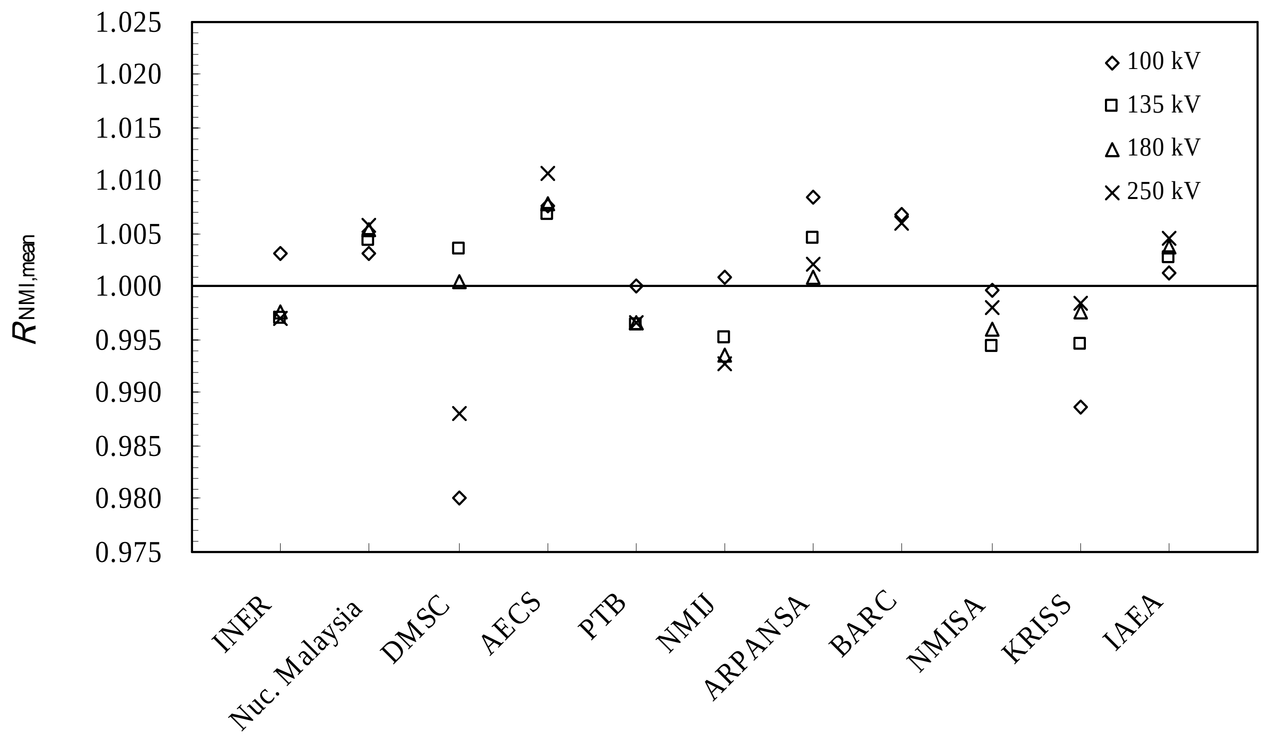

Fig. 6. Ratios $R_{\mathrm{NMI,mean}}$ of PTW-30001 (S/N 2251) transfer chamber calibration coefficients relative to the mean value for all laboratories

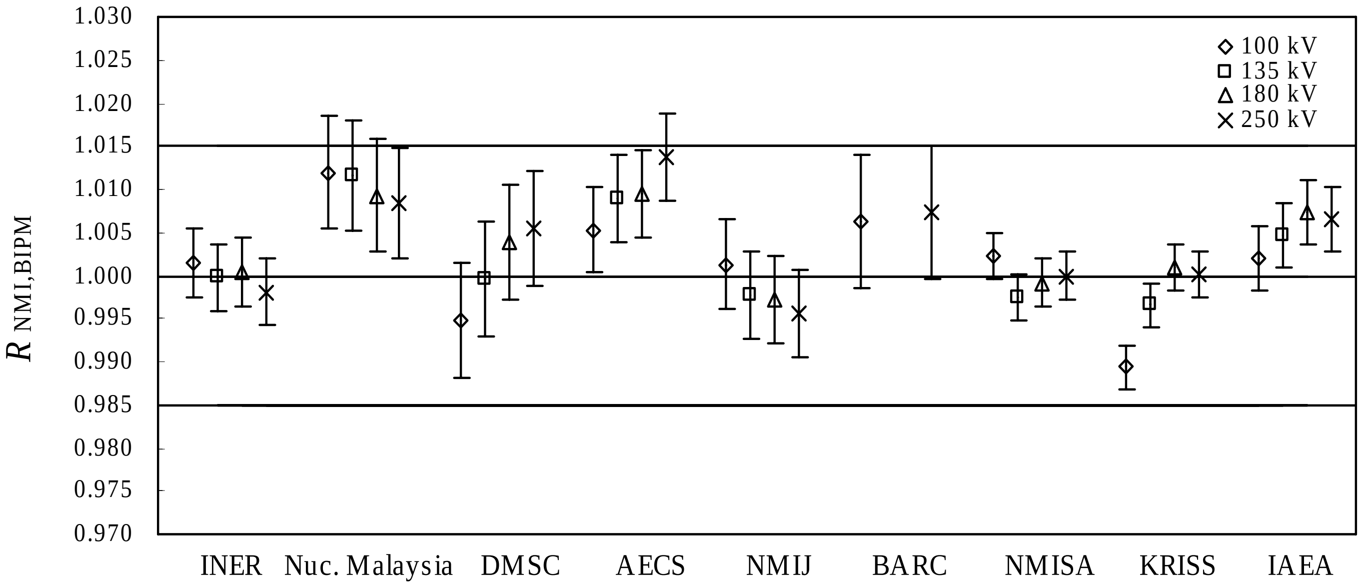

Fig. 7. Final results $R_{NMI,BIPM}$ for each participating laboratory for APMP.RI(I)-K3 comparison

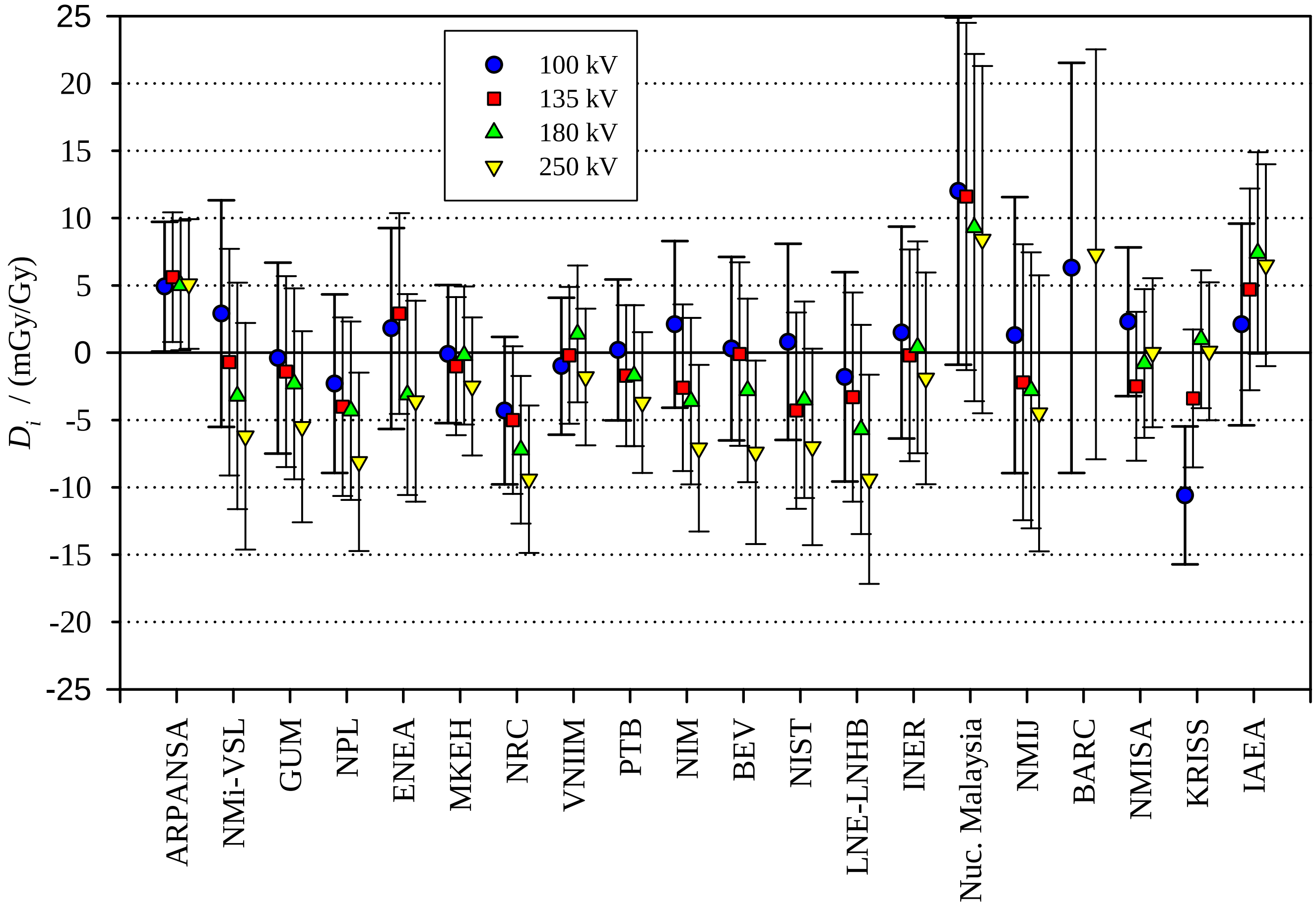

Fig. 8. Degree of equivalence D_i and U_i for each NMI i with respect to the key comparison reference value

Appendix

INER Uncertainty budget

Uncertainty associated with the standard

Source of component	Relative standard uncertainty (%)	
	Type A	Type B
Physical constants		
Dry air density		0.01
W/*e*		0.15
Correction factors		
Electron loss		0.01
Photon scatter		0.07
Air attenuation		0.07
Wall attenuation	0.08	
Ion saturation	0.09	
Humidity		0.10
Volume and current measurement		
Volume		0.06
Current	0.13	0.02
Leakage		0.05
Distance		0.08
Air density correction		0.08
Quadratic sum	0.18	0.25
Combined standard uncertainty	0.31	

Uncertainty associated with the calibration of the transfer chambers

Source of component	Relative standard uncertainty (%)	
	Type A	Type B
Air kerma rate	0.18	0.25
Current	0.12	0.02
Leakage		0.03
Distance		0.08
Air density correction		0.05
Quadratic sum	0.22	0.27
Combined standard uncertainty	0.35	

Nuclear Malaysia Uncertainty budget

Uncertainty associated with the calibration of the transfer chambers

Source of component	Relative standard uncertainty (%)	
	Type A	Type B
Air kerma rate		
N_K of MINT reference chamber		0.48
Charge	0.02	
Charge measurement system		0.29
K_{tp} factor		
Pressure		0.05
Temperature		0.04
Transfer chamber calibration		
Charge	0.02	
Charge measurement system		0.29
K_{tp} factor		
Pressure		0.05
Temperature		0.04
Calibration distance		0.07
Quadratic sum	0.03	0.64
Combined standard uncertainty	0.64	

DMSC Uncertainty budget

Uncertainty associated with the calibration of the transfer chambers

Source of component	**Relative standard uncertainty (%)**	
	Type A	**Type B**
Transfer from primary		0.55
Beam quality		0.10
Distance		0.03
Temperature		0.19
Pressure		0.06
Leakage		0.01
Monitor unit		0.10
Measurement reading	0.25	
Quadratic sum	0.25	0.60
Combined standard uncertainty	0.65	

AECS Uncertainty budget

Uncertainty associated with the calibration of the transfer chambers

Source of component	Relative standard uncertainty (%)	
	Type A	Type B
Air kerma rate		
Temperature and pressure correction factor ($K_{T,P}$)		0.01
Distance (*d*)		0.12
Time (*t*)		0.05
Calibration factor of the reference chamber (N_K)		0.49
Mean value of the reference ionization chamber	0.02	
Transfer chamber calibration		
Temperature and pressure correction factor ($K_{T,P}$)		0.01
Distance (*d*)		0.12
Time (*t*)		0.05
Mean value of the comparison chamber	0.02	
Quadratic sum	0.03	0.52
Combined standard uncertainty	0.52	

PTB Uncertainty budget

Uncertainty associated with the standard

Source of component	Relative standard uncertainty (%)	
	Type A	Type B
Physical constants		
Dry air density		0.01
W/*e*		0.15
g		0.01
Correction factors		
Scattered photons		0.05
Electron loss		0.05
Air attenuation		0.10
Field distortion		0.10
Transmission through edges of diaphragm		0.10
Transmission through walls of standard		0.05
Polarity effect		0.05
Shadow effect of the central electrode		0.10
Humidity		0.04
Volume and current measurement		
Volume		0.06
Ionization charge	0.05	0.05
Leakage		0.06
Distance		0.02
Air density correction		0.08
Quadratic sum	0.05	0.31
Combined standard uncertainty	0.31	

Uncertainty associated with the calibration of the transfer chambers

Source of component	Relative standard uncertainty (%)	
	Type A	Type B
Air kerma rate	0.05	0.31
Ionization charge	0.02	0.05
Leakage		0.01
Air density		0.08
Distance		0.04
Beam non-uniformity		0.10
Quadratic sum	0.06	0.34
Combined standard uncertainty	0.35	

NMIJ Uncertainty budget

Uncertainty associated with the standard

Source of component	Relative standard uncertainty (%)	
	Type A	Type B
Physical constants		
Dry air density (ρ)		0.01
W/e		0.15
1-g		0.03
Correction factors		
Electron loss (k_e)		0.10
Photon scatter (k_s)		0.10
Air attenuation (k_a)		0.20
Electric field distortion (k_f)		0.10
Polarity effect (k_p)		0.05
Wall penetration (k_w)		0.05
Ion saturation (k_i)		0.10
Humidity (k_h)		0.03
Volume and current measurement		
Volume (V_m)		0.20
Current (I)	0.04	0.15
Distance		0.04
Air density correction		0.08
Quadratic sum	0.04	0.43
Combined standard uncertainty	0.43	

Uncertainty associated with the calibration of the transfer chambers

Source of component	Relative standard uncertainty (%)	
	Type A	Type B
Air kerma rate	0.04	0.43
Current	0.05	0.20
Distance		0.04
Air density correction		0.04
Quadratic sum	0.06	0.48
Combined standard uncertainty	0.48	

ARPANSA Uncertainty budget

Uncertainty associated with the standard

Source of component	Relative standard uncertainty (%)	
	Type A	Type B
Mass of air		0.14
W/*e*		0.15
Bremsstrahlung losses		0.03
Scattered radiation		0.10
Electron loss		0.10
Recombination loss		0.03
Air attenuation		0.02
Field distortion		0.01
Diaphragm edge transmission		0.01
Chamber wall transmission		0.01
Humidity		0.05
Current	0.12	0.07
Air density correction		0.03
Quadratic sum	0.12	0.27
Combined standard uncertainty	0.30	

Uncertainty associated with the calibration of the transfer chambers

Source of component	Relative standard uncertainty (%)	
	Type A	Type B
Air kerma rate	0.12	0.27
Humidity		0.05
Current	0.14	0.07
Air density correction		0.03
Quadratic sum	0.19	0.29
Combined standard uncertainty	0.35	

BARC Uncertainty budget

Uncertainty associated with the standard

Source of component	Relative standard uncertainty (%)	
	Type A	Type B
Physical constants		
Dry air density		0.01
W/*e*		0.15
Correction factors		
Ion saturation (k_i)	0.10	
Humidity (k_h)		0.10
Photon scatter (k_p)		0.10
Air attenuation (k_a)		0.20
Inadequacy of plate separation (k_e)		0.10
Wall attenuation (k_w)	0.10	
Volume and current measurements		
Volume (V_m)		0.30
Charge (Q)	0.12	0.03
Leakage		0.05
Distance		0.16
Air density correction		0.10
Quadratic sum	0.19	0.47
Combined standard uncertainty	0.51	

Uncertainty associated with the reference chambers Exradin A2 & NE 2571 (S/N 1692) calibrated at BARC

Source of component	Relative standard uncertainty (%)	
	Type A	Type B
Air kerma rate	0.19	0.47
Charge	0.12	0.03
Distance		0.16
Field size non-uniformity		0.10
Positioning reproducibility	0.10	
Directional dependence	0.10	
Monitor chamber	0.20	
Air density correction		0.12
Leakage		0.05
Exposure time	0.10	
Quadratic sum	0.35	0.52
Combined standard uncertainty	0.63	

Uncertainty associated with the calibration of the transfer chambers

Source of component	Relative standard uncertainty (%)	
	Type A	Type B
Reference chamber measurements	0.35	0.52
Transfer chamber measurements		0.20
Air density correction		0.12
Field size non-uniformity		0.10
Positioning reproducibility	0.10	
Monitor chamber	0.20	
Distance		0.16
Leakage		0.05
Exposure time	0.10	
Quadratic sum	0.43	0.60
Combined standard uncertainty	0.74	

NMISA Uncertainty budget

Uncertainty associated with the calibration of the transfer chambers

Source of component	Relative standard uncertainty (%)	
	Type A	Type B
Calibration of the standard		0.23
Uncertainty related to pressure measurement	0.01	
Uncertainty related to temperature measurement	0.01	
Electrometer calibration		0.01
Positioning the chamber	0.05	
Drift		0.20
Quadratic sum	0.05	0.30
Combined standard uncertainty	0.31	

KRISS Uncertainty budget

Uncertainty associated with the calibration of the transfer chambers

Source of component	Relative standard uncertainty (%)	
	Type A	Type B
Air kerma rate of KRISS		
N_K of KRISS reference chamber		0.24
Standard error of current	0.04	
Current measurement system		0.06
k_{tp} factor		
(Temperature)		0.02
(Pressure)		0.01
Transfer chamber calibration		
Standard error of current	0.02	
Current measurement system		0.06
k_{tp} factor		
(Temperature)		0.02
(Pressure)		0.01
Repeatability of x-ray	0.06	
Calibration distance		0.12
Quadratic sum	0.08	0.29
Combined standard uncertainty	0.30	

IAEA Uncertainty budget

Uncertainty associated with the calibration of the transfer chambers

Source of component	Relative standard uncertainty (%)	
	Type A	Type B
Air kerma rate		
N_K from BIPM (or PSDL)		0.23
Long-term stability of air kerma rate	0.25	
Temperature and air pressure correction ($k_{T,P}$)	0.04	0.06
Current measurements		
Voltage	0.01	0.10
Capacitance	0.04	0.10
Different in energy spectra (BIPM/PSDL-IAEA)		0.10
Related to the instrument to be calibrated		
Positioning in air at the calibration distance		0.04
Temperature and air pressure correction ($k_{T,P}$)	0.04	0.06
Quadratic sum	0.26	0.30
Combined standard uncertainty	0.40	