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Abstract An indirect comparison has been made between the air-kerma standards of the PTB and the BIPM in the medium-energy x-ray range. The results show the standards to be in general agreement at the level of the stated standard uncertainty, although the result for the 100 kV radiation quality differs significantly from that for the other qualities.

1. Introduction

An indirect comparison has been made between the air-kerma standards of the Physikalisch-Technische Bundesanstalt (PTB), Germany, and the Bureau International des Poids et Mesures (BIPM) in the x-ray range from 100 kV to 250 kV. Two spherical cavity ionization chambers were used as transfer instruments. The measurements at the BIPM took place in March 1999 and those at the PTB in February 1999, using the reference conditions recommended by the CCRI [1].

2. Determination of the air-kerma rate

For a free-air ionization chamber standard with measuring volume V, the air-kerma rate is determined by the relation

$$\dot{K} = \frac{I}{\rho_{\mathrm{air}} V} \frac{W_{\mathrm{air}}}{e} \frac{1}{1 - g_{\mathrm{air}}} \prod_i k_i \tag{1}$$

where ρ_{air} is the density of air under reference conditions, I is the ionization current under the same conditions, W_{air} is the mean energy expended by an electron of charge e to produce an ion pair in air, g_{air} is the mean fraction of the initial electron energy lost by bremsstrahlung production in air, and $\Pi\ k_{\mathrm{i}}$ is the product of the correction factors to be applied to the standard.

The values used for the physical constants ρ_{air} and W_{air}/e are given in Table 1. For use with this dry-air value for ρ_{air}, the ionization current I must be corrected for humidity and for the difference between the density of the air of the measuring volume at the time of measurement and the value given in the table[1].

3. Details of the standards

The free-air chamber standard of the BIPM is of the conventional parallel-plate design, whereas the PTB Faßkammer standard has a cylindrical geometry in which the inner collector rod and the outer electrode are concentric and the entrance aperture is displaced from the axis of cylindrical symmetry by 4.5 cm. This latter design requires the use of an additional correction factor, k_{sh}, to account for the shadow effect of the central electrode. For both chamber types the measuring

[1] For an air temperature $T \sim 293$ K, air pressure P and relative humidity ~50 % in the measuring volume, this involves a temperature correction T/T_0, a pressure correction P_0/P, a humidity correction $k_{\mathrm{h}} = 0.9980$, and the factor 1.0002 to account for the change in the compressibility of dry air between $T \sim 293$ K and $T_0 = 273.15$ K.

volume V is defined by the diameter of the defining aperture and the length of the collecting region. The BIPM air-kerma standard is described in [2]. Details of the PTB "Faßkammer" standard, which has not previously been compared with the BIPM standard, are given in [3]. Although an indirect comparison between the BIPM and the PTB was carried out in 1975, the standard used by the PTB at that time differs from the present standard. The main dimensions, the measuring volume and the polarizing voltage for each standard are shown in Table 2.

Table 1. Physical constants used in the determination of the air-kerma rate

Constant	Value	$u_i^{\dagger}$
$\rho_{\text{air}}^{\ddagger}$	1.293 0 kg m^{-3}	0.000 1
W_{air} / e	33.97 J C^{-1}	0.001 5

† u_i is the relative standard uncertainty.
‡ Density of dry air at T_0 = 273.15 K and P_0 = 101 325 Pa.

Table 2. Main characteristics of the standards

Standard	BIPM	PTB
Aperture diameter / cm	0.9939	2.000 9
Air path length / cm	28.15	48.1
Collecting length / cm	6.000 4	20.0015
Electrode separation / cm	18.0	19.65 †
Collector width / cm	20.0	0.7 ‡
Measuring volume / cm^3	4.655 4	62.893 1
Polarizing voltage / V	4 000	3 000

† The difference in radius between the outer electrode (20 cm) and the collector rod.
‡ The diameter of the collector rod.

4. The transfer instruments

4.1 Determination of the calibration coefficient for a transfer instrument

The air-kerma calibration coefficient N_K for a transfer instrument is given by the relation

$$N_K = \frac{\dot{K}}{I_{\text{tr}}} \tag{2}$$

where $\dot{K}$ is the air-kerma rate determined by the standard using (1) and I_{tr} is the ionization current measured by the transfer instrument and the associated current-measuring system. The current I_{tr} is corrected to the standard conditions of air temperature, pressure and relative humidity chosen for the comparison (T = 293.15 K, P = 101 325 Pa and h = 50 %).

To derive a comparison result from the calibration coefficients $N_{K,\text{BIPM}}$ and $N_{K,\text{NMI}}$ measured, respectively, at the BIPM and at a national measurement institute (NMI), differences in the radiation qualities must be taken into account. Normally, each quality used for the comparison has the same generating potential at each institute, but the half-value layers (HVLs) may differ.

A radiation quality correction factor k_Q is derived for each comparison quality Q. This corrects the calibration coefficient $N_{K,\mathrm{NMI}}$ determined at the NMI into one which applies at the 'equivalent' BIPM quality and is derived by interpolation of the $N_{K,\mathrm{NMI}}$ values in terms of log(HVL). The comparison result at each quality is then taken as

$$R_{K,\mathrm{NMI}} = \frac{k_Q N_{K,\mathrm{NMI}}}{N_{K,\mathrm{BIPM}}}. \tag{3}$$

In practice, the half-value layers normally differ by only a small amount and k_Q is close to unity.

4.2 Details of the transfer instruments

Two spherical cavity ionization chambers belonging to the PTB were used as transfer instruments for the comparison. Their main characteristics are given in Table 3. The reference point for each chamber was taken to be at the centre of the sphere. Each chamber was oriented so that the line marked on the chamber stem was facing towards the source.

Table 3. Main characteristics of the transfer chambers

Chamber type	Exradin A3	Exradin A4
Serial number	169	224
Geometry	spherical	spherical
External diameter / cm	1.900	3.842
Wall material	C552	C552
Wall thickness / cm	0.025	0.05
Nominal volume / cm^3	3.6	30
Polarizing voltage / V	+500	+500

5. Calibration at the BIPM

5.1 BIPM irradiation facility and reference radiation qualities

The BIPM medium-energy x-ray laboratory houses a constant-potential generator and a tungsten-anode x-ray tube with an inherent filtration of 2.3 mm aluminium. Both the generating potential and the tube current are stabilized using feedback systems constructed at the BIPM; this results in a very high stability and obviates the need for a transmission current monitor. The radiation qualities used in the range from 100 kV to 250 kV are those recommended by the CCRI [1] and are given in Table 4.

The irradiation area is temperature-controlled at around 20 °C and is stable over the duration of a calibration to better than 0.1 °C. Two thermistors, calibrated to a few mK, measure the temperature of the ambient air and the air inside the BIPM standard (which is controlled around 25 °C). Air pressure is measured by means of a calibrated barometer positioned at the height of the beam axis. All ionization current measurements are corrected for air temperature and pressure. The relative humidity is controlled within the range 47 % to 53 % and consequently no humidity correction is applied to the current measured using transfer instruments.

Table 4. Characteristics of the BIPM reference radiation qualities

Generating potential / kV	100	135	180	250
Additional Al filtration / mm	1.203 2	-	-	-
Additional Cu filtration / mm	-	0.232 1	0.484 7	1.570 1
Al HVL / mm	4.027	-	-	-
Cu HVL / mm	0.148	0.494	0.990	2.500
μ_{air} † / m^{-1}	0.035 5	0.023 5	0.019 8	0.017 2
$\dot{K}_{BIPM}$ / mGy s^{-1}	0.21	0.20	0.29	0.38

† Air-attenuation coefficient at 293.15 K and 100 kPa, measured at the BIPM for an air path length of 270 mm.

5.2 BIPM standard and correction factors

The defining plane of the aperture of the BIPM standard was positioned at 1 200 mm from the radiation source, with a reproducibility of 0.03 mm. The standard was aligned on the beam axis to an estimated uncertainty of 0.1 mm. The beam diameter in the reference plane is 105 mm for all radiation qualities; an off-axis displacement of 0.1 mm changes the measured current by no more than 0.03 % at 100 kV.

During the calibration of the transfer chambers, measurements using the BIPM standard were made at both polarities to correct for any polarity effect in the standard. The measured difference was typically 3×10^{-4} in relative value. The leakage current for the BIPM standard, relative to the ionization current, was measured to be around 1×10^{-4}.

The correction factors applied to the ionization current measured at each radiation quality using the BIPM standard, together with their associated uncertainties, are given in Table 5.

Table 5. Correction factors for the BIPM standard

Generating potential / kV	100	135	180	250	u_{iA}	u_{iB}
Air attenuation k_a †	1.010 0	1.006 6	1.005 6	1.004 9	0.000 3	0.000 1
Scattered radiation k_{sc}	0.994 8	0.996 2	0.996 7	0.996 9	-	0.000 7
Electron loss k_e	1.000 0	1.002 3	1.005 2	1.007 8	-	0.001 0
Ion recombination k_s	1.000 5	1.000 5	1.000 5	1.000 5	0.000 2	0.000 1
Field distortion k_d	1.000 0	1.000 0	1.000 0	1.000 0	-	0.000 7
Aperture edge transmission k_l	0.999 9	0.999 8	0.999 7	0.999 6	-	0.000 1
Wall transmission k_p	1.000 0	1.000 0	0.999 9	0.998 8	0.000 1	-
Humidity k_h	0.998 0	0.998 0	0.998 0	0.998 0	-	0.000 3
$1 - g_{air}$	0.999 9	0.999 9	0.999 8	0.999 7	-	0.000 1

† Nominal values for 293.15 K and 100 kPa; each measurement is corrected using the air density measured at the time.

The factors k_a correct for the attenuation of the x-ray fluence along the air path between the reference plane and the centre of the collecting volume. They are evaluated using the measured air-attenuation coefficients μ_{air} given in Table 4. In practice, the values used for k_a take account of the temperature and pressure of the air in the standard. Ionization current measurements (both for the standard and for transfer chambers) are also corrected for changes in air attenuation arising from variations in the temperature and pressure of the ambient air between the radiation source and the reference plane.

5.3 Transfer chamber positioning and calibration at the BIPM

The reference point for each chamber was positioned in the reference plane, with a reproducibility of 0.03 mm. Each transfer chamber was aligned on the beam axis to an estimated uncertainty of 0.1 mm.

The leakage current was measured before and after each series of ionization current measurements and a correction made using the mean value. The relative leakage current for the both transfer chambers was less than 1×10^{-4}.

The relative standard uncertainty of the mean of each of two series of ten measurements at each radiation quality was typically 1.5×10^{-4} for transfer chamber A3. Repeatability was around 3×10^{-4}, except for the two sets at 250 kV which differed by 1.8×10^{-3}. The results for the larger chamber A4 were better, the relative standard uncertainty of a series being typically 5×10^{-5} and the repeatability around 2×10^{-4}. Curiously, the two sets at 250 kV again differed by a much larger amount, 1.5×10^{-3}. Despite the poorer behaviour at 250 kV, the comparison results for this quality are not significantly different from those for the other qualities.

6. Calibration at the PTB

6.1 PTB irradiation facility and reference radiation qualities

The Seifert ISOVOLT 320 converter-type generator at the PTB operates at a frequency of 500 Hz and yields a constant potential in the range from 20 kV and 320 kV, in steps of 0.1 kV. The bipolar, tungsten-anode x-ray tube MB 350/1 has a 7 mm beryllium window and a nominal focal spot size of 16 mm^2. The high voltage is measured using a calibrated voltage divider and has been checked using a high-purity Ge spectrometer (also used to measure x-ray spectra). Consistency between the two methods of 0.5 kV is obtained. The x-ray output is monitored and normalized using a transmission ionization chamber.

The characteristics of the PTB realization of the CCRI comparison qualities [1] are given in Table 6. These qualities are not used routinely at the PTB and were established in preparation for the present comparison using aluminium and copper filtrations similar to those used at the BIPM. No values for the HVLs are given as these have not yet been measured. However, the air-attenuation coefficients measured at the BIPM and at the PTB are in reasonable agreement, from which one can infer that differences in the radiation qualities should have little effect on the comparison results. The μ_{air} values given for the PTB in Table 6 and used for the present comparison are calculated and agree with the values measured at the PTB within the stated uncertainty of the attenuation correction.

The irradiation area at the PTB is temperature-controlled at around 20 °C and is stable over the duration of a calibration to better than 0.1 °C. Three thermistors, calibrated with an uncertainty of 20 mK, measure the temperature of the ambient air close to the monitor and transfer chamber, and the air inside the PTB standard. The ambient air pressure is measured using a barometer (Setra capacitance-sensing circuit system) calibrated with an uncertainty of 6 Pa. All ionization current measurements are corrected for air temperature and pressure. There is no air humidity control in the laboratory but the relative humidity cannot exceed 60 %. Variations in the humidity are taken into account by a type B relative standard uncertainty of 4×10^{-4} for the PTB standard (Table 7) and similarly for the transfer chamber calibration (Table 9). No humidity correction is applied to the ionization current measured using transfer instruments.

Table 6. Characteristics of the PTB reference radiation qualities

Generating potential / kV	100	135	180	250
Additional Al filtration / mm	3.506	2.302	2.302	2.302
Additional Cu filtration / mm	-	0.222	0.512	1.590
$\mu_{air}{}^{\dagger}$ / m^{-1}	0.0371	0.0232	0.0197	0.0170
$\dot{K}_{PTB}$ / mGy s^{-1}	0.14	0.14	0.14	0.14

† Calculated air-attenuation coefficient at 293.15 K and 100 kPa.

6.2 PTB standard and correction factors

The defining plane for the PTB standard was positioned at 1 200 mm from the radiation source, with a reproducibility of 0.05 mm. The standard was aligned on the beam axis to an estimated uncertainty of 0.1 mm. The beam diameter in the reference plane is 115 mm for all radiation qualities. Beam homogeneity is measured using the PTB standard and a series of apertures with diameters in the range from 8 mm to 30 mm. The ionization current per unit aperture area remains constant to within 1×10^{-3} in relative value.

During the calibration of the transfer chambers, measurements using the PTB standard were made at a single polarity. The polarity correction in the standard was measured previously and is within 5×10^{-4} of unity. The relative leakage current was measured to be less than 2×10^{-4}.

The correction factors applied to the ionization current measured at each radiation quality using the PTB standard, together with their associated uncertainties, are given in Table 7. The correction factor k_a is evaluated using the air-attenuation coefficients μ_{air} given in Table 6. In practice, the values used for k_a take account of the temperature and pressure of the air in the standard at the time of the measurements.

Two differences in the PTB and BIPM correction factors are noted. The PTB standard involves the correction factor k_{sh} for the shadow effect of the central collector in the cylindrical free-air chamber design. The PTB correction factor for ionization gain k_{sc} includes not only the effect of scattered photons, but also that of fluorescence photons. The effect of fluorescence photons in the BIPM chamber is discussed in Section 9.

6.3 Transfer chamber positioning and calibration at the PTB

The reference point for each transfer chamber was positioned at the reference distance, with a reproducibility of 0.1 mm. Alignment on the beam axis was to an estimated uncertainty of 0.2 mm.

The leakage current was measured before and after each series of ionization current measurements and a correction made using the mean value. The relative leakage current for each transfer chamber was less than 1×10^{-4}. The relative standard uncertainty of the mean of three series of five measurements at each radiation quality was typically 3×10^{-4} for transfer chamber A3 and 7×10^{-5} for chamber A4.

Table 7. Correction factors for the PTB Faßkammer standard †

Generating potential / kV	100	135	180	250	u_{iA}	u_{iB}
Air attenuation k_a ‡	1.0180	1.0112	1.0095	1.0082	-	0.0010
Ionization gain k_{sc} §	0.9915	0.9936	0.9947	0.9958	-	0.0005
Electron loss k_e	1.0000	1.0000	1.0004	1.0019	-	0.0005
Ion recombination k_s	1.0017	1.0018	1.0018	1.0018	0.0005	-
Field distortion k_d	1.0000	1.0000	1.0000	1.0000	-	0.0010
Polarity effect k_{pol}	1.0000	1.0000	1.0000	1.0000	0.0005	-
Shadow effect, k_{sh}	1.0009	1.0020	1.0023	1.0032	-	0.0005
Aperture edge transmission k_l	1.0000	1.0000	0.9999	0.9994	-	0.0005
Wall transmission k_p	1.0000	1.0000	1.0000	1.0000	0.0005	-
Humidity k_h	0.9980	0.9980	0.9980	0.9980	-	0.0004
$1 - g_{air}$	0.9999	0.9999	0.9998	0.9997	-	-

† Component uncertainties below 0.0002 have been neglected.
‡ Nominal values for 293.15 K and 100 kPa; each measurement is corrected using the air density measured at the time.
§ This corrects for the re-absorption of scattered radiation and of fluorescence photons.

7. Additional corrections to transfer chamber measurements

7.1 Ion recombination, polarity and beam non-uniformity

As can be seen from Tables 4 and 6, the air-kerma rates at the PTB are lower than those at the BIPM, by almost a factor of three at 250 kV. At the time of the comparison, a volume recombination correction based on Boag [4] was applied to both transfer chambers at both institutes. However, in doing so the comparison results for the larger chamber A4 showed a systematic effect which implied an overestimate of the effect of volume recombination.

Subsequently, measurements were made at the PTB using both chambers over the range from 0.06 mGy s^{-1} to 1.1 mGy s^{-1} which should, following Boag [4], result in a relative change in the volume recombination correction for chamber A4 of 1.4×10^{-2}. However, the calibration coefficients were found to be independent of the air-kerma rate at the level of 3×10^{-4} in relative value. Consequently, all recombination corrections $k_{s,tr}$ for the transfer chambers have been removed. There is no explanation for the disagreement noted above for chamber A4 and a relative uncertainty in the comparison results of 1×10^{-3} is included for this chamber.

Each transfer chamber was used with the same polarity at each institute and so no corrections $k_{pol,tr}$ are applied for polarity effects in the transfer chambers. The relative standard uncertainty introduced by this simplified approach is taken to be 1×10^{-4}.

No correction $k_{rn,tr}$ is applied at either institute for the radial non-uniformity of the radiation field. For the small transfer chamber A3 the effect of beam non-uniformities on the comparison results should be less than 1×10^{-4} in relative value. For the larger chamber A4, the relative uncertainty is estimated to be 1×10^{-3} at both the BIPM and the PTB. In this context, the PTB normally applies a correction for the effect of stray radiation on transfer chamber response. Given that the field sizes were reasonably matched, no such correction was applied.

7.2 Radiation quality correction factors k_Q

As noted in Section 4.1, slight differences in radiation qualities may require a correction factor k_Q. As discussed in Section 6.1, the radiation qualities at the BIPM and at the PTB are reasonably matched and so the correction factor k_Q is taken to be unity for all qualities. From the variation in the calibration factor with μ_{air} and the differences in the μ_{air} values for the BIPM and the PTB (Tables 4 and 6), the standard uncertainty of this value for k_Q is estimated to be 8×10^{-4}.

8. Uncertainties

The uncertainties associated with the primary standards are listed in Table 8, those for the transfer chamber calibrations in Table 9 and those for the comparison results in Table 10. The relative combined standard uncertainty u_c of the comparison result $R_{K,\mathrm{PTB}}$ takes into account correlations in the type B uncertainties associated with the physical constants.

Table 8. Uncertainties associated with the standards

Standard	BIPM		PTB†	
Relative standard uncertainty	u_{iA}	u_{iB}	u_{iA}	u_{iB}
Ionization current	0.000 3	0.000 2	0.000 8	-
Volume	0.000 1	0.000 5	0.000 4	-
Positioning	0.000 1	0.000 1	-	-
Correction factors	0.000 4	0.001 5	0.000 9	0.001 8
Physical constants	-	0.001 5	-	0.001 5
$\dot{K}_{std}$	0.000 5	0.002 2	0.001 3	0.002 3

† Component uncertainties below 0.0002 have been neglected.

9. Results and discussion

The calibration coefficients determined at the BIPM and at the PTB are given in Table 11. No systematic changes are observed in the calibration coefficients determined at the PTB before and after the calibrations at the BIPM. For transfer chamber A3, the pre- and post-comparison calibrations at the PTB agree at a level which is significantly better than one would expect from the uncertainties associated with chamber positioning and ionization current measurements. For transfer chamber A4, differences between the pre- and post-calibrations are larger at 100 kV and 250 kV and are more consistent with the uncertainties.

Table 12 gives the comparison results for each transfer chamber and, in bold, the unweighted mean values. For the 135 kV, 180 kV and 250 kV radiation qualities, the results for each chamber show a standard deviation of around 0.000 5, which is reasonably consistent with the reproducibility of chamber positioning and ionization current measurements. No trend with radiation quality is evident and no significant difference is observed in the results for the two transfer chambers. The overall mean result for these three qualities, 0.996 4, differs from unity by around one combined standard uncertainty (u_c of Table 10).

However, the result for the 100 kV quality is significantly higher for each of the transfer standards. To date, no explanation has been found for this difference. Nevertheless, the agreement between the two standards at 100 kV is well within the comparison uncertainty.

Table 9. Uncertainties associated with the calibration of the transfer chambers

Institute	BIPM		PTB†	
Relative standard uncertainty	$u_{i\mathrm{A}}$	$u_{i\mathrm{B}}$	$u_{i\mathrm{A}}$	$u_{i\mathrm{B}}$
$\dot{K}_{\mathrm{std}}$	0.000 5	0.002 2	0.001 3	0.002 3
Positioning of transfer chamber	0.000 1	0.000 1	0.000 2	-
I_{tr}	0.000 3	0.000 2	0.000 5	-
Humidity k_{h}	-	-	-	0.000 4
Radial non-uniformity $k_{\mathrm{rn,tr}}$ ‡	-	0.000 1	-	-
$N_{K,\mathrm{std}}$	0.000 6	0.002 2	0.001 4	0.002 3

† Component uncertainties below 0.0002 have been neglected.
‡ Values for chamber A3. For the larger chamber A4, the $u_{i\mathrm{B}}$ value is 0.0010 at each laboratory.

Table 10. Uncertainties associated with the comparison results

Relative standard uncertainty	$u_{i\mathrm{A}}$	$u_{i\mathrm{B}}$
$N_{K,\mathrm{PTB}}/N_{K,\mathrm{BIPM}}$	0.001 5	0.002 4†
$k_{\mathrm{s,tr}}$	-	0.000 2‡
$k_{\mathrm{pol,tr}}$	-	0.000 1
k_{Q}	-	0.000 8
$R_{K,\mathrm{PTB}}$	0.001 5	0.002 5
	$u_{\mathrm{c}} = 0.003\,0$	

† Takes account of correlations in type B uncertainties.
‡ Value for chamber A3. For chamber A4, the value is 0.001 0.

As noted in Section 6.2, the correction factors k_{sc} applied to the PTB standard include the effect of fluorescence radiation generated by argon in the air of the free-air chamber. The effect of fluorescence for the BIPM standard has been calculated by Burns [5] using the Monte Carlo code EGSnrc [6]. The calculated values for k_{e}, k_{sc} and the fluorescence correction k_{fl} for the BIPM standard are given in Table 13, and the effect of including these new values in the present comparison are given in the final row of Table 12.

Table 11. Calibration coefficients for the transfer chambers

Generating potential / kV	100	135	180	250
Transfer chamber A3				
$N_{K,\mathrm{PTB}}$ (pre-comp) / Gy μC^{-1}	7.766 4	7.844 1	7.952 3	8.067 0
$N_{K,\mathrm{BIPM}}$ / Gy μC^{-1}	7.766 0†	7.868 7	7.974 2	8.098 9
$N_{K,\mathrm{PTB}}$ (post-comp) / Gy μC^{-1}	7.767 8	7.843 6	7.952 7	8.065 8
Transfer chamber A4				
$N_{K,\mathrm{PTB}}$ (pre-comp) / Gy μC^{-1}	1.039 2	1.033 5	1.041 0	1.053 8
$N_{K,\mathrm{BIPM}}$ / Gy μC^{-1}	1.041 7	1.037 5	1.045 5	1.057 2
$N_{K,\mathrm{PTB}}$ (post-comp) / Gy μC^{-1}	1.040 1	1.033 4	1.040 9	1.053 1

† This calibration was repeated and the BIPM in June 1999, giving the result 7.7633 Gy μC^{-1} .

Table 12. Comparison results

Generating potential / kV	100	135	180	250
$N_{K,\mathrm{PTB}}/N_{K,\mathrm{BIPM}}$ for chamber A3	1.000 1	0.996 8	0.997 3	0.996 0
$N_{K,\mathrm{PTB}}/N_{K,\mathrm{BIPM}}$ for chamber A4	0.998 0	0.996 1	0.995 7	0.996 5
$\boldsymbol{R_{K,\mathrm{PTB}}}$	**0.999 1**	**0.996 5**	**0.996 5**	**0.996 2**
Using Burns [5] for BIPM standard	1.000 2	0.998 4	0.997 8	0.995 0

Table 13. Values for correction factors for BIPM standard calculated by Burns [5]†.

Generating potential / kV	100	135	180	250
k_{e}	1.000 1	1.001 5	1.004 8	1.008 7
k_{sc}	0.995 2	0.995 9	0.996 4	0.997 4
k_{fl}	0.998 4	0.999 2	0.999 4	0.999 8

† The type A uncertainties associated with the stated values are less than 0.000 1. The type B uncertainties have yet to be evaluated rigorously, but approximate values are: 0.000 4 for k_{sc}, 0.000 4 for k_{fl}, 0.000 6 for the k_{e} value at 250 kV, 0.000 3 for k_{e} at 180 kV and 135 kV, and less than 0.000 1 for k_{e} at 100 kV.

At a first glance, the results incorporating new values for the correction factors appear to be poorer, showing a trend with radiation quality for the 135 kV, 180 kV and 250 kV qualities which is not present in the results using the existing values for the correction factors. However, in the revised values the result for the 100 kV quality forms part of this progression, rather than standing alone. Furthermore, a similar progression has been seen in a number of other comparisons with the BIPM (see Figure 1) and therefore the trend observed may be attributable to the same underlying cause, which is unknown. It should be noted, however, that the new values for correction factors for the BIPM standard have not yet been adopted and therefore the comparison results stand as those given in bold in Table 12.

A summary of the results of BIPM comparisons of air-kerma standards for medium-energy x-rays, including the present comparison, is presented in Figure 1.

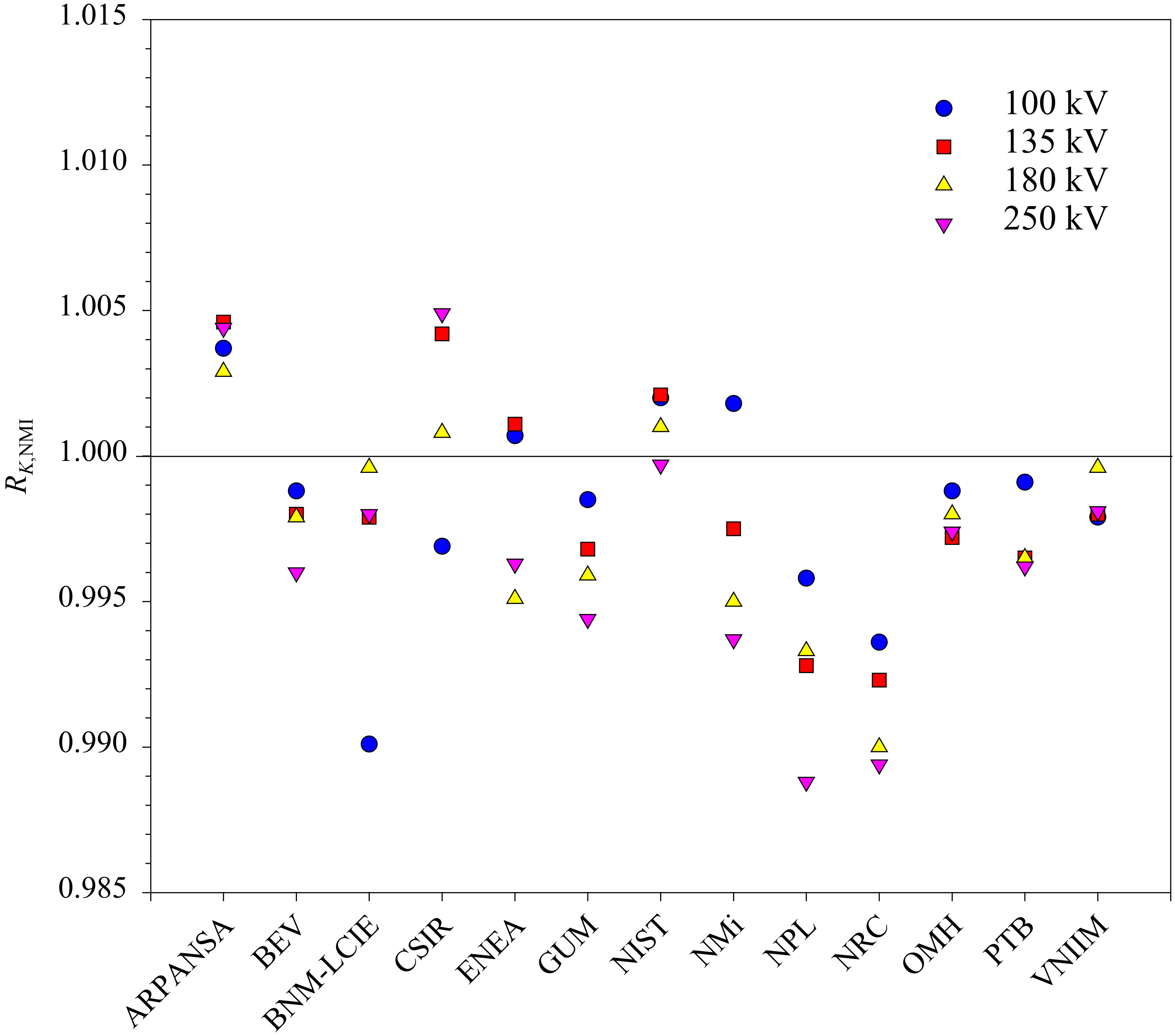

Figure 1. Results of BIPM medium-energy x-ray comparisons, expressed as the ratio $R_{K,\mathrm{NMI}}$ of the air-kerma rate detemined by the standard of the national metrology institute (NMI) to that determined by the BIPM standard. For NMIs that have compared more than once with the BIPM, only the results of the most recent comparison are included.

References

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