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Abstract An indirect comparison has been made between the air-kerma standards of the OMH and the BIPM in the medium-energy x-ray range. The results show the standards to be in agreement within the stated uncertainty , although there is evidence of a slight difference in the result at the 100 kV radiation quality.

1. Introduction

An indirect comparison has been made between the air-kerma standards of the Országos Mérésügyi Hivatal (OMH) 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 October 1998 and those at the OMH over the period October - December 1998, 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

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

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 $\Pi\, k_{\text{i}}$ 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

Both free-air chamber standards are of the conventional parallel-plate design. For both chamber types the measuring 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]. The OMH XE-1

[1] For an air temperature T, 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 $k_{\text{h}} = 0.9980$, 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.

standard was previously compared with the BIPM standard in an indirect comparison carried out in 1974, the results of which are reported in [3] and [4]. The main dimensions, the measuring volume and the polarizing voltage for each chamber are shown in Table 2.

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

Constant	Value	$u_i^{\dagger}$
$\rho_{air}^{\ddagger}$	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	OMH XE-1
Aperture diameter / mm	9.939	9.826 7
Air path length / mm	281.5	465
Collecting length / mm	60.004	99.75
Electrode separation / mm	180	320
Collector width / mm	200	320
Measuring volume / mm^3	4 655.4	7 565.2
Polarizing voltage / V	4 000	6 000

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

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

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 %).

In general, to derive a comparison result from the calibration coefficients $N_{K,\mathrm{BIPM}}$ and $N_{K,\mathrm{NMI}}$ measured, respectively, at the BIPM and at a national measurement institute (NMI), differences in the radiation qualities must be taken into account. 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

$$\frac{\dot{K}_{\mathrm{NMI}}}{\dot{K}_{\mathrm{BIPM}}} = \frac{k_{\mathrm{Q}} N_{K,\mathrm{NMI}}}{N_{K,\mathrm{BIPM}}} \tag{3}$$

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 OMH 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 high voltage connection was facing away from the source.

Table 3. Main characteristics of the transfer chambers

Chamber type	ND1002	ND1001
Serial number	7807	7808
Geometry	spherical	spherical
External diameter / cm	1.0	3.8
Wall material	air-equivalent delrin	air-equivalent delrin
Wall thickness / g cm^{-2}	0.06	0.28
Nominal volume / cm^3	0.38	20
Polarizing voltage / V	+250	+250
Polarity effect $I(+)$ / $I(-)$	1.001 2	1.002 3

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 variation in the measured ionization current over the duration of a comparison introduces a relative standard uncertainty of typically 4×10^{-4}. 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.

5.2 BIPM standard and correction factors

The reference plane for 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, and an off-axis displacement of 0.1 mm changes the measured current by no more than 0.03 % at 100 kV.

Table 4. Characteristics of the BIPM reference radiation qualities

Generating potential / kV	100	135	180	250
Al filtration / mm	1.2032	-	-	-
Cu filtration / mm	-	0.2321	0.4847	1.5701
Al HVL / mm	4.027	-	-	-
Cu HVL / mm	0.148	0.494	0.990	2.500
μ_{air}† / 10^{-3} mm^{-1}	0.0355	0.0235	0.0198	0.0172
$\dot{K}_{BIPM}$ / mGy s^{-1}	0.21	0.20	0.29	0.38

† Air attenuation coefficient at 293.15 K and 100 000 Pa, measured at the BIPM for an air path length of 100 mm.

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 2×10^{-4} in relative value. The leakage current for the BIPM standard, relative to the ionization current, was measured to be less than 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	Relative standard uncertainty	
					u_{iA}	u_{iB}
Air attenuation k_a†	1.0100	1.0066	1.0056	1.0049	0.0003	0.0001
Scattered radiation k_{sc}	0.9948	0.9962	0.9967	0.9969	-	0.0007
Electron loss k_e	1.0000	1.0023	1.0052	1.0078	-	0.0010‡
Ion recombination k_s	1.0005	1.0005	1.0005	1.0005	0.0002	0.0001
Field distortion k_d	1.0000	1.0000	1.0000	1.0000	-	0.0007
Aperture edge transmission k_l	0.9999	0.9998	0.9997	0.9996	-	0.0001
Wall transmission k_p	1.0000	1.0000	0.9999	0.9988	0.0001	-
Humidity k_h	0.9980	0.9980	0.9980	0.9980	-	0.0003
$1 - g_{air}$	0.9999	0.9999	0.9998	0.9997	-	0.0001

† These are nominal values for 293.15 K and 100 000 Pa; each measurement is corrected using the air temperature and pressure measured at the time.
‡ The value is less for the 100 kV and 135 kV radiation qualities.

The factor k_a corrects for the attenuation of the x-ray fluence along the air path between the reference plane and the centre of the collecting volume. It is 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 at the time of the measurements. 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 transfer chamber was positioned in the reference plane (1 200 mm from the radiation source), 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 air temperature for the transfer chambers was measured using a calibrated thermistor positioned close to the chamber (outside the radiation field). Air pressure was measured by means of a calibrated barometer positioned at the same height as the transfer chambers. The relative humidity in the BIPM measurement area is controlled within the range 45 % to 55 % and consequently no humidity correction is applied to the transfer chamber current measurements.

The leakage current was measured before and after each series of ionization current measurements and a correction made using the mean value. For the small ND1002 transfer chamber the relative leakage current was 1.0×10^{-3} and for the large ND1001 chamber 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 3×10^{-4} for the small chamber, although the reproducibility was inferior, the standard uncertainty of the mean being typically 1.2×10^{-3}. The results for the large chamber were superior, the relative standard uncertainty of a series being less than 1×10^{-4} and the reproducibility typically 3×10^{-4}.

Table 6. Characteristics of the OMH reference radiation qualities

Generating potential / kV	100	135	180	250
Al filtration / mm	0.7	1.03	1.03	1.03
Cu filtration / mm	-	0.2	0.47	1.6
Al HVL / mm	4.04	-	-	-
Cu HVL / mm	0.152	0.498	0.967	2.46
μ_{air}† / 10^{-3} mm^{-1}	0.033 1	0.022 7	0.019 3	0.016 1
$\dot{K}_{OMH}$ / mGy s^{-1}	0.25	0.25	0.25	0.25

† Air attenuation coefficient at 293.15 K and 100 000 Pa, measured at the OMH for an air path length of 465 mm.

6. Calibration at the OMH

6.1 OMH irradiation facility and reference radiation qualities

The medium-energy x-ray facility at the OMH comprises a constant-potential generator and a tungsten-anode x-ray tube with an inherent filtration of 2.2 mm beryllium and 3.0 mm aluminium. The x-ray output is monitored by means of a transmission ionization chamber whose Mylar windows introduce a filtration of 3 mg cm^{-2}. The stability of the x-ray output is better than 8×10^{-4} in relative value over the course of a day, and the short-term reproducibility of chamber current measurements relative to the transmission monitor is better than 2×10^{-4}. The characteristics of the OMH realization of the CCRI comparison qualities [1] are given in Table 6.

6.2 OMH standard and correction factors

The reference plane for the OMH standard was positioned at 1 000 mm from the radiation source, with a reproducibility of 0.1 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 113 mm for all radiation qualities. The effect of beam non-uniformity is negligible for the OMH standard.

During the calibration of the transfer chambers, measurements using the OMH standard were made at positive polarity. The polarity effect for the OMH standard (that is, the relative difference between measurements made at positive and negative polarity) is typically 3×10^{-4}. The relative leakage current was measured to be 3×10^{-4}.

The correction factors applied to the ionization current measured at each radiation quality using the OMH standard, together with their associated uncertainties, are given in Table 7.

Table 7. Correction factors for the OMH standard

Generating potential / kV	100	135	180	250	Relative standard uncertainty	
					u_{iA}	u_{iB}
Air attenuation k_a †	1.0155	1.0106	1.0090	1.0075	0.0005	0.0010
Scattered radiation k_{sc}	0.9916	0.9927	0.9934	0.9952	-	0.0015
Electron loss k_e	1.0000	1.0000	1.0005	1.0018	-	0.0010 ‡
Ion recombination k_s	1.0010	1.0010	1.0010	1.0010	0.0004	0.0001
Field distortion k_d	1.0000	1.0000	1.0000	1.0000	-	0.0005
Aperture edge transmission k_l	1.0000	1.0000	1.0000	1.0000	-	0.0001
Wall transmission k_p	1.0000	1.0000	1.0000	1.0000	0.0002 §	-
Humidity k_h	0.9980	0.9980	0.9980	0.9980	-	0.0003
$1 - g_{air}$	0.9999	0.9999	0.9998	0.9997	-	0.0001

† These are nominal values for 293.15 K and 100 000 Pa; each measurement is corrected using the air temperature and pressure measured at the time.

‡ Value at 250 kV. The value is 0.000 3 at 100 kV and at 135 kV, and 0.000 7 at 180 kV.

§ The value at 250 kV is 0.000 5.

The correction factor k_a is evaluated using the measured air-attenuation coefficients μ_{air} given in Table 6 (the OMH normally quote μ_{air} at the reference air pressure of 101 325 Pa, but to facilitate comparison with the BIPM values these have been normalized to 100 000 Pa). In practice, the values used for k_a are corrected for variations in the temperature and pressure of the air in the standard. Ionization current measurements (standard and transfer chamber) are also corrected for variations in the temperature and pressure of the ambient air between the radiation source and the reference plane.

6.3 Transfer chamber positioning and calibration at the OMH

The reference point for each transfer chamber was positioned at the reference distance (at the OMH 1000 mm from the radiation source), with a reproducibility of 0.1 mm. Alignment on the beam axis was to an estimated uncertainty of 0.1 mm.

A platinum (Pt 200) temperature probe was used to measure the air temperature. Air pressure was recorded using a calibrated barometer positioned at the height of the transfer chambers. As for the BIPM measurements, no humidity correction was applied as the relative humidity in the OMH measurement area did not extend outside the range from 40 % to 60 %.

For the small ND1002 transfer chamber the relative leakage current was less than 1×10^{-3} and for the large ND1001 chamber much less than 1×10^{-4}.

The relative standard uncertainty of the mean of each series of five measurements was typically 3×10^{-4} and 1.5×10^{-3} for transfer chambers ND1001 and ND1002, respectively. Five such series were carried out at each radiation quality over the period October - December 1998. The relative standard uncertainty of the distribution of these results is typically 7×10^{-4} for chamber ND1001 and 1.1×10^{-3} for chamber ND1002.

7. Additional corrections to transfer chamber measurements

7.1 Beam non-uniformity, ion recombination and polarity

No correction k_{rn} is applied at either laboratory for the radial non-uniformity of the radiation field. For the standards, the aperture diameters are well-matched and any effect will cancel. For the small transfer chamber ND1002 the effect is estimated to be less than 1×10^{-4} at each laboratory. For the large chamber ND1001 the neglect of radial beam non-uniformity introduces a relative uncertainty estimated to be 5×10^{-4} at the BIPM and 1×10^{-3} at the OMH.

As can be seen from Tables 4 and 6, the air-kerma rates are reasonably well matched at the two laboratories and so, for the purpose of the present comparison, no corrections $k_{s,tr}$ are applied for ion recombination in the transfer chambers. This assumed cancellation of volume recombination effects introduces a relative uncertainty of only 1×10^{-4} in the comparison result.

Each transfer chamber was used with the same polarity at each laboratory and so no corrections $k_{pol,tr}$ are applied for polarity effects in the transfer chambers. The relative uncertainty arising in the comparison result from the neglect of polarity effects is estimated from the values for the polarity effect given in Table 3 to be 3×10^{-4}.

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. However, from Tables 4 and 6 it is evident that the radiation qualities at the BIPM and at the OMH are very closely matched in terms of HVL and so the correction factor k_Q is taken to be unity for all qualities, with a negligible uncertainty.

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 ratio $\dot{K}_{\mathrm{OMH}}/\dot{K}_{\mathrm{BIPM}}$ takes into account correlations in the type B uncertainties associated with the physical constants and the humidity correction. Correlations between the values for k_{sc} and k_e will be small; the OMH values are derived from recent Monte Carlo calculations [5], whereas values for the BIPM standard derived from similar calculations [6] have not yet been adopted.

Table 8. Uncertainties associated with the standards

Laboratory	BIPM		OMH	
Relative standard uncertainty	u_{iA}	u_{iB}	u_{iA}	u_{iB}
Ionization current	0.000 3	0.000 2	0.000 5	0.000 5
Volume	0.000 1	0.000 5	0.000 5	-
Positioning	0.000 1	0.000 1	0.000 1	0.000 1
Correction factors (excl. k_h)	0.000 4	0.001 4	0.000 7	0.002 1
Humidity k_h	-	0.000 3	-	0.000 3
Physical constants	-	0.001 5	-	0.001 5
$\dot{K}_{\mathrm{lab}}$	0.000 5	0.002 1	0.001 0	0.002 6

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

Laboratory	BIPM		OMH	
Relative standard uncertainty	u_{iA}	u_{iB}	u_{iA}	u_{iB}
$\dot{K}_{\mathrm{lab}}$	0.000 5	0.002 1	0.001 0	0.002 6
Positioning of transfer chamber	0.000 1	0.000 1	0.000 1	0.000 1
I_{tr}	0.000 3†	0.000 2	0.000 7‡	0.000 5
Radial non-uniformity $k_{\mathrm{rn,tr}}$	-	0.000 5†	-	0.001 0‡
$N_{K,\mathrm{lab}}$	0.000 6†	0.002 2†	0.001 2‡	0.002 8‡

† These are the BIPM values for the large transfer chamber ND1001. For the small chamber ND1002 the corresponding values are 0.001 2 for I_{tr}, less than 0.000 1 for $k_{\mathrm{rn,tr}}$, and 0.001 3 and 0.002 1, respectively, for the type A and type B uncertainties of $N_{\mathrm{K,BIPM}}$.

‡ These are the OMH values for the large transfer chamber ND1001. For the small chamber ND1002 the corresponding values are 0.001 1 for I_{tr}, less than 0.000 1 for $k_{\mathrm{rn,tr}}$, and 0.001 5 and 0.002 7, respectively, for the type A and type B uncertainties of $N_{\mathrm{K,OMH}}$.

Table 10. Uncertainties associated with the comparison results

Relative standard uncertainty	$u_{i\mathrm{A}}$	$u_{i\mathrm{B}}$
$N_{K,\mathrm{OMH}}/N_{K,\mathrm{BIPM}}$	0.001 4	0.002 9†
$k_{\mathrm{s,tr}}$	-	0.000 1
$k_{\mathrm{pol,tr}}$	-	0.000 3
$\dot{K}_{\mathrm{OMH}}/\dot{K}_{\mathrm{BIPM}}$	0.001 4‡	0.002 9‡
	u_c = 0.003 2‡	

† Takes account of correlations in Type B uncertainties.
‡ These are the values for the large transfer chamber ND1001. For the small chamber ND1002 the values are 0.002 0 and 0.002 7, respectively, for the type A and type B uncertainties, and 0.003 4 for the combined uncertainty.

9. Results and discussion

The calibration coefficients determined at the BIPM and at the OMH are given in Table 11. No systematic changes were observed in the calibration results determined at the OMH before and after the calibrations at the BIPM.

Table 11. Calibration coefficients for the transfer chambers

Generating potential / kV	100	135	180	250
Transfer chamber ND1002				
$N_{K,\mathrm{OMH}}$ / Gy μC^{-1}	72.93	72.83	73.40	74.68
$N_{K,\mathrm{BIPM}}$ / Gy μC^{-1}	72.95	73.06	73.54	74.82
Transfer chamber ND1001				
$N_{K,\mathrm{OMH}}$ / Gy μC^{-1}	1.487 1	1.482 1	1.485 9	1.490 2
$N_{K,\mathrm{BIPM}}$ / Gy μC^{-1}	1.490 2	1.485 9	1.488 9	1.495 0

The comparison results are summarized in Table 12. General agreement is observed, the mean ratio $\dot{K}_{\mathrm{OMH}}/\dot{K}_{\mathrm{BIPM}}$ for all eight comparisons (two chambers at four qualities) being 0.997 9 (standard uncertainty of the distribution 9×10^{-4}). The deviation from unity of this mean value is consistent with the stated comparison uncertainty of 3.2×10^{-3} (Table 10). The two results at each radiation quality differ by typically 1×10^{-3}, which is reasonable in view of the statistical uncertainties. No significant trend with radiation quality is observed, except perhaps for the result at 100 kV which is slightly higher.

Table 12. Comparison results

Generating potential / kV	100	135	180	250
$\dot{K}_{\mathrm{OMH}}/\dot{K}_{\mathrm{BIPM}}$ using chamber ND1002	0.999 7	0.996 9	0.998 1	0.998 1
$\dot{K}_{\mathrm{OMH}}/\dot{K}_{\mathrm{BIPM}}$ using chamber ND1001	0.997 9	0.997 4	0.998 0	0.996 8
Mean $\dot{K}_{\mathrm{OMH}}/\dot{K}_{\mathrm{BIPM}}$	**0.998 8**	**0.997 2**	**0.998 0**	**0.997 4**
Previous result (1974)	1.004 0	1.001 3	0.999 4	0.996 1
Previous result with current values for correction factors	1.000 5	0.996 9	0.996 8	0.994 7

The raw results of the previous comparison in 1974 showed a strong dependence on radiation quality (1.3×10^{-2} between 100 kV and 250 kV), whereas it is evident from the results of the present comparison that this trend has not persisted. A significant component of this trend (5×10^{-3}) was known to be due to the air attenuation coefficients used at the OMH, and the results published at the time (as given in Table 12) were corrected using the BIPM values for the air attenuation coefficients for the 180 kV and 250 kV qualities. Small changes to various correction factors for both standards in the intervening period reduce this trend further. Table 12 includes the 1974 results corrected for all of these known changes, and these are in agreement with the new comparison at the level of 2×10^{-3}. Interestingly, the slightly higher result at 100 kV is reproduced in the revised 1974 results.

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

References

[1] BIPM, Qualités de rayonnement, CCEMRI(I), 1972, R15.

[2] BOUTILLON M., Mesure de l'exposition au BIPM dans le domaine des rayons X de 100 à 250 kV, 1978, *Rapport BIPM*-78/3.

[3] BIPM, Calibration of the OMH transfer chambers K-1 and K-2 for 50-250 kV x-rays with the OMH exposure standards, 1975, CCEMRI(I)/75-22.

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[5] GRIMBERGEN T.W.M., VAN DIJK E., DE VRIES W., Correction factors for the NMi free-air ionization chamber for medium-energy x-rays calculated with the Monte Carlo method, 1998, *Physics in Medicine and Biology* 43, 3207-3224.

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Annex A

The results of BIPM comparisons of air-kerma standards for medium-energy x-rays are presented in Table A.1. For NMIs which have compared more than once at the BIPM, only the results of the most recent comparison are included. The same data are presented in graphical form in Figure A.1.

Table A.1 Results of BIPM medium-energy x-ray comparisons, expressed as $\dot{K}_{\mathrm{NMI}} / \dot{K}_{\mathrm{BIPM}}$.

NMI	Country	Date	Generating potential / kV			
			100 kV	135 kV	180 kV	250 kV
OMH	Hungary	1975	1.004 0	1.001 3	0.999 4	0.996 1
PTB	Germany	1975	1.001 6	1.000 3	1.000 2	1.001 6
CSIR	S Africa	1976	0.996 9	1.004 2	1.000 8	1.004 9
BEV	Austria	1982	0.998 8	0.998 0	0.997 9	0.996 0
ARL	Australia	1988	1.003 7	1.004 6	1.002 9	1.004 4
NIST	USA	1991	1.002 0	1.002 1	1.001 0	0.999 7
NMi	Netherlands	1991	1.001 8	0.997 5	0.995 0	0.993 7
GUM	Poland	1994	0.998 5	0.996 8	0.995 9	0.994 4
NPL†	UK	1997	0.995 8	0.992 8	0.993 3	0.988 8
BNM-LCIE	France	1998	0.990 1	0.997 9	0.999 6	0.998 0
ENEA	Italy	1998	1.000 7	1.001 1	0.995 1	0.996 3
OMH	Hungary	1998	0.998 8	0.997 2	0.998 0	0.997 4

† The results for this laboratory are provisional; BIPM reports still in preparation.

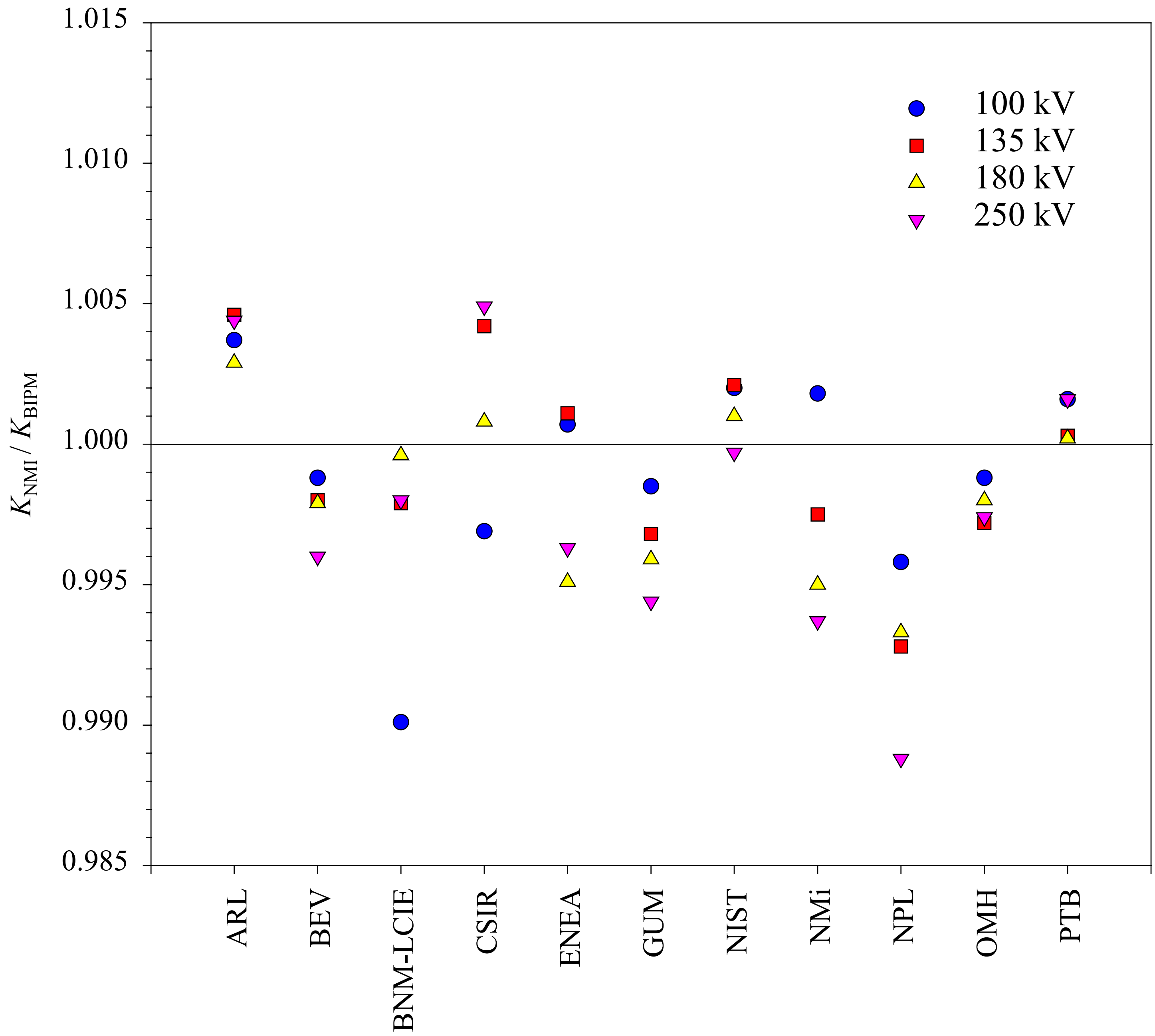

Figure A.1. Results of BIPM medium-energy x-ray comparisons, expressed as the ratio of the air-kerma rate determined by the NMI standard to that determined by the BIPM standard. The results for the NPL are provisional.