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Report of the indirect comparison of Kerma standards of BIPM and NMi December 1991

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1. Introduction

A comparison of kerma standards was carried out between the Netherlands Measurements Institute (NMi) and the Bureau International des Poids et Mesures (BIPM). The comparison involved the primary standards for X-rays (50 keV - 320 keV) and gamma rays (^{60}Co), using an ionization chamber (NE 2561-246) as a transfer instrument. The transfer instrument is described in section 2.

Before the transfer instrument was transported to BIPM it was calibrated at NMi for X-rays and ^{60}Co. The X-ray qualities match very closely the recommended CCEMRI qualities and are given in appendix 1. The calibration factors are expressed in the unit gray per volt. The output (volt) of the electrometer was measured with a digital multimeter.
These preliminary calibration factors are given in section 3 in table 1.

Because the measurements at BIPM with the ionization chamber connected to the electrometer system were very time consuming, the calibration factors were determined with the transfer ionization chamber NE 2561-246 connected to the charge measuring device of BIPM. These calibration factors are expressed in the unit Gy/μC.
The calibration factor for the ionization chamber connected to the electrometer system was also determined for ^{60}Co. The reason for this additional measurement was to compare the calibration factors determined at BIPM and the preliminary calibration factors determined at NMi before the transportation to BIPM. These calibration factors are given in table 2 in section 4.
The ratio R(e) of the calibration factor expressed in Gy/μC to the calibration factor expressed in Gy/V is considered as a characteristic (constant) of the electrometer system (unit= V/μC). This ratio R(e) can be used as a check of the consistency of the charge measurement devices of the standards of NMi and BIPM.

After completion of the measurements at BIPM and the return of the transfer instrument to the Netherlands, calibrations were performed :

a) with the ionization chamber connected to the electrometer system
b) With the ionisation chambers connected to the charge measurement devices of the NMi-standards.

In addition the capacitors, used in the charge measurement devices, were re-calibrated at the Department of Electrical Standards of NMi.
Furthermore measurements were performed to assess the exact

position of the defining plane of the diaphragm of the X-ray standard. As a result of the additional measurements and recalibration of the capacitors, small adjustments to the calibration factors given in table 1 had to be made.
The final values of the calibration factors are given in table 3 section 5.
The final calibration factors of the ionization chamber determined at NMi were normalised to the values obtained at BIPM. These ratios are given in table 4 in section 6.

At NMi, measurements with a check-source were made before and after the intercomparison, to have a separate check of the stability in time of the transfer instrument. The results of the measurements with the check-source are given in table 5 in section 7.

All measured values are corrected to standard temperature and pressure of 295.15 Kelvin and 101.325 kPa.
Data on uncertainty estimates, physical constants and correction factors concerning the air kerma standards are given in appendix 1 and appendix 2.

2. Transfer instrument

The measurement assembly which was used as transfer between NMi and BIPM consisted of two parts:

a: Ionization chamber NE 2561 serial number 246
Build-up cap N.E. LTD 2565/N.P.L. (used at gamma rays)
Manufacturer: Nuclear Enterprises ltd

b: Electrometer system, consisting of:

- Electrometer NE secondary standard 2560
  serial number 050
- Timer NE 2546 serial number 192
  Manufacturer: Nuclear Enterprises ltd
- Digital Multimeter HP 3468A
  Manufacturer: Hewlett Packard

The check-source was:

NE 2562 ^{90}Sr + ^{90}Y serial number 061
Manufacturer: Nuclear Enterprises ltd

3. Preliminary NMi calibration factors used at BIPM during the intercomparison

The results of the calibration of the transfer instrument before transportation to the BIPM are given in table 1.

Table 1. Calibration factors ionization chamber NE 2561-246 connected to the electrometer system.

nr	quality	calibration factor Gy/V	type A uncertainty %(1σ)
1	100 kV	0.8980	0.06
2	135 kV	0.9064	0.04
3	180 kV	0.9110	0.03
4	250 kV	0.9140	0.04
5	^{60}Co	0.9338	0.07

4. Calibration factors determined at BIPM

The calibration factors determined at BIPM are given in table 2. The calibration factors determined with the ionization chamber connected to the charge measurement device of the BIPM are expressed in Gy/μC.
The calibration factors with the ionization chamber connected to the electrometer system are expressed in Gy/V.

Table 2. Calibration factors determined at BIPM

nr	quality	calibration factor Gy/μC	calibration factor Gy/V	type A uncertainty %(1σ)
1	100 kV	90.09		0.018
2	135 kV	91.21		0.014
3	180 kV	91.84		0.022
4	250 kV	92.38		0.021
5a	^{60}Co		0.93396	0.01
5b	^{60}Co	93.516		0.01

Re(BIPM) = 100.13 V/μC (determined at BIPM)

5. Calibration factors determined at NMi

The final calibration factors of the ionization chamber connected to the electrometer system and connected to the charge measuring devices of the standards determined at NMi are given in table 3.

Table 3. Final calibration factors determined at NMi.

nr	quality	calibration factor Gy/μC	type A uncert. %(1σ)	calibration factor Gy/V	type A uncert. %(1σ)
1	100 kV	90.25	0.03	0.9010	0.03
2	135 kV	90.98	0.05	0.9092	0.07
3	180 kV	91.38	0.14	0.9130	0.03
4	250 kV	91.80	0.06	0.9167	0.02
5	^{60}Co	93.718	0.01	0.9357	0.01

Re(NMi) = 100.12 V/μC (determined with the charge measuring device of the X-rays standard)
Re(NMi) = 100.16 V/μC (determined with the charge measuring device of the ^{60}Co standard)
At NMi the X-ray standard and the ^{60}Co standard have separate charge measurements devices.

The difference between mean Re(NMi) and Re(BIPM) is 0.01%.

6. Results of the comparison

The result of the intercomparison between NMi and BIPM is the ratio of the calibration factors (expressed in Gy/μC) given in table 2 and table 3. This ratio is given in table 4 as a function of the radiation quality.

Table 4. Ratio of the calibration factors determined at NMi and BIPM

nr	quality	ratio NMi/BIPM	type A + type B %(1σ)
1	100 kV	1.0018	0.44
2	135 kV	0.9975	0.44
3	180 kV	0.9950	0.46
4	250 kV	0.9937	0.44
5	^{60}Co	1.0022	0.43

The uncertainty in table 4 is the estimated overall uncertainty (square root of the quadratic sum of type A and type B) of the calibration factors, determined at NMi, at 1 standard deviation level. The uncertainties of the calibration factors determined at BIPM are not included.

The ratios NMi/BIPM for the X-rays are shown in figure 1.

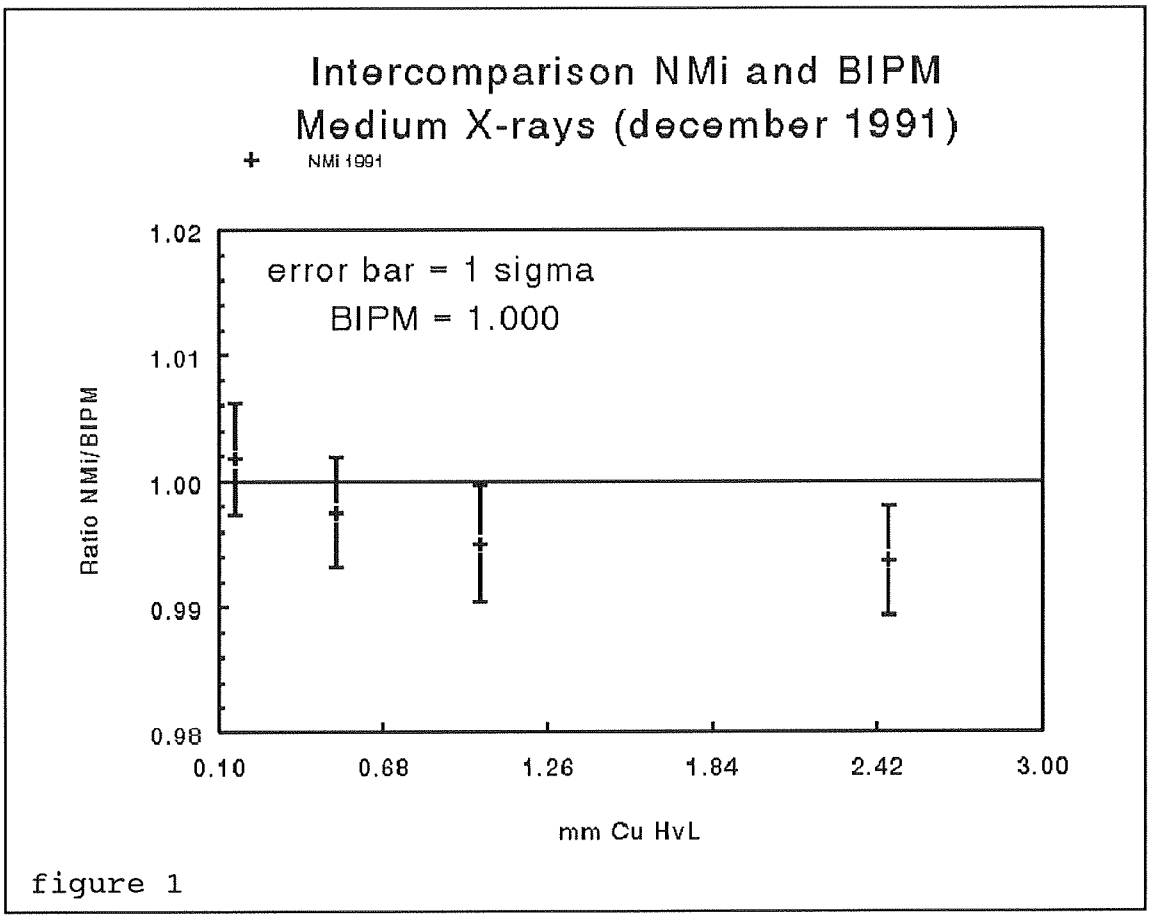

figure 1

7. Check-source measurements

The results of the measurements with the check-source are given in table 5. These are the readings of the ionization chamber connected to the electrometer system, normalised to 1-1-1991.

Table 5. Check-source measurements.

measurement date	reading (V/s) (1-1-1991)	type A (1σ) uncertainty
14-10-1991/05-11-1992	3.1610E-3	0.06%
23-12-1992	3.1614E-3	0.02%

Because of the good agreement of the results of the measurements with the check-source, the assumption can be made that the transfer instrument was stable during the period of the intercomparison.

Appendix 1

The X-ray qualities used in the comparison and the correction factors and their uncertainties are given in table 6.

Table 6. Correction factors and their uncertainties

Tube tension	+100		+135		+180		+250	
filter 4.0 mm Be + mm Al	3.649		1.004		1.004		1.004	
filter + mm Cu	-		0.3022		0.6037		1.7506	
First HvL	4.109	Al	0.5162	Cu	1.025	Cu	2.464	Cu
Second HvL	6.043	Al	0.8343	Cu	1.634	Cu	3.275	Cu
Homogeneity	0.680		0.619		0.627		0.752	
Air attenuation (22°C)	1.0187	±0.1%	1.0122	±0.1%	1.0101	±0.1%	1.0089	±.01%
Kf polarity effect	1.0000	±.03%	1.0000	±.03%	1.0000	±.03%	1.0000	±.03%
Ks recombination loss	1.0006	±0.1%	1.0006	±0.1%	1.0006	±0.1%	1.0006	±.1%
Kl aperture transmission	1.0000	-	1.0000	-	0.9995	±0.05%	0.9990	±.05%
Kp wall transmission	1.0000	-	1.0000	-	1.0000	±0.03%	0.9995	±0.03%
Ke electron dissipation	1.0000	±0.00%	1.0000	±0.00%	1.0010	±0.1%	1.0027	±0.1%
Ksc ionization gain	0.9916	±0.1%	0.9928	±0.1%	0.9933	±0.1%	0.9939	±0.1%
Kd field distortion	1.0000	±0.2%	1.0000	±0.2%	1.0000	±0.2%	1.0000	±0.2%
Kh humidity	0.9980		0.9980		0.9980		0.9980	
St.factor (Gy/pC)	3.589E-6	±.27%	3.570E-6	±.27%	3.566E-6	±.29%	3.567E-6	±.29%

Table 7 Estimated uncertainties in a measurement with the NMi kerma standard (50-250 kV)

		Relative uncertainty type B (1σ)
Collected charge	-potential	0.1
	-capacitor	0.03
Air volume	-diaphragm	0.01
	-collector	0.03
Polarity		0.03
Alignment	-collector plates	0.1
	-diaphragm	0.1
Air density	-pressure	0.03
	-temperature	0.02
Humidity		0.1
Saturation of ion collection		0.1
Scattering of photons by air		0.1
Inadequate plate separation		0.1
Attenuation by air in the standard		0.1
Penetration diaphragm		0.05
Penetration of front wall		0.03
Electron dissipation		0.1
Collector potential		0.05
Field distortion		0.2
Leakage current		0.02
Square root quadratic sum		0.37 +

The comparison with the BIPM standard was done indirectly with the aid of a transfer ionization chamber.
The estimated uncertainties in the determination of a calibration factor at NMi are given in table 8.

Table 8. Estimated uncertainties in the calibration procedure.

	percent
Realisation of the quantity Kerma (square root quadratic sum table 7)	0.37
Monitoring during calibration	
volume fluctuation	0.1
Air density	0.08
Charge measurement	0.1
Distance	0.1
Stray radiation	0.1
total square root quadratic sum	0.44 %

Appendix 2.

5 cm^3 standard gamma radiation nuclide Co-60

The constants, correction factors and uncertainties of the 5 cm^3 graphite standard are given in table 9.

Table 9. constants and correction factors of the 5 cm^3 graphite standard.

p(air)	(STP)	1.19656	kg/m^3
V		4.845 E-06	m^3 ±0.1%
W/e (dry air)		33.97	J/C
(S/)gr,air		1.0007	±0.2 %
(uen/)air,gr		0.9992	±0.05%
1/(1-g) bremsstrahlung		1.0032	
k(s) recombination loss		1.0015	±0.03%
k(st) stem influence		0.999	±0.05%
k(at) wall attenuation		1.026	±0.2 %
k(cep) centre electron production		0.995	±0.2 %
K(rn) radial non-uniformity beam		1.000	±0.03%
k(an) axial non-uniformity beam		1.000	±0.15%
k(h) rel. humidity air		0.997	±0.1 %
Charge measurements	-capacity		±0.03%
	-distance		±0.05%
	-pressure		±0.03%
	-temperature		±0.02%
	-potential		±0.1 %
Total square root quadratic sum 1 standard deviation level			0.42%

I(air)=93.0 eV I(c)=81.3 eV E=30 keV

Standard factor F(k)= 5.9854E+06 Gy/C (22°C 101.325 kPa 70% RH)