Comparison of air kerma standards for medium-energy x radiation between the MKEH and the IAEA

István Csete[1], Ladislav Czap[2], Igor Gomola[2]
[1]Hungarian Trade Licensing Office (MKEH), Budapest, Hungary
[2] International Atomic Energy Agency (IAEA), Vienna, Austria

Abstract

A comparison of the air kerma standards for medium-energy x radiation was performed between the MKEH and the IAEA. Two reference class ionization chambers of the IAEA, traceable to the PTB with volumes 1000 cm^3 and 100 cm^3, and the ISO 4037 N-40, N-60, N-120 and N-300 standard beam qualities were selected for the comparison. The calibration coefficients, N_K, were determined for both chambers at the MKEH in August 2011 and before and after this at the IAEA Dosimetry Laboratory.

The comparison ratio of the calibration coefficients normalized to the previous comparison results of the PTB and MKEH primary air kerma standards were in the range from 0.989 to 0.994 for the beam qualities used. The relative expanded (k = 2) uncertainty for each of these ratios is around 2 %.

1. Introduction

The IAEA Dosimetry Laboratory at Seibersdorf, Austria, calibrates the reference radiation protection dosemeters of IAEA/WHO SSDL Network members (more than 80 laboratories worldwide) free of charge. As a signatory of the CIPM MRA [1] the IAEA laboratory maintains a Quality Management System complying with ISO 17025 and in 2007 the laboratory published its dosimetry calibration and measurement capability (CMC) claims in the Key Comparison Database (KCDB) of the CIPM MRA. To maintain these CMC claims, periodically updated supporting evidence for the measurement capabilities is required in addition to the traceability of the measured quantities. The objective of this comparison is to support the IAEA-RAD-1008 and IAEA-RAD-1011 CMC lines for the calibration of radiation protection dosemeters in the range from 0.6 μGy/h to 10 mGy/h in ISO 4037 narrow beam radiation qualities [2]. The relevant IAEA secondary standard ionization chambers are traceable to the Physikalisch-Technische Bundesanstalt (PTB), Germany in terms of air kerma and ambient dose equivalent. The comparison partner MKEH has a primary standard for air kerma and published degrees of equivalence (DoE) in the KCDB of the CIPM MRA based on the EURAMET.RI-S3 comparison results [3]. The ambient and personal dose equivalent quantities are derived by application of conversion coefficients published in ISO 4037 Part 3, similar to the PTB practice.

2. Procedure and transfer chambers

For the comparison, two IAEA reference-class transfer chambers were selected. The technical details of the chambers are given in the Table 1. Four beam qualities were selected from the ISO narrow beam X-ray series to cover all the qualities from 40 kV to 400 kV. Technical details of the selected qualities are presented in Tables 2 and 3.
This comparison is identified as EURAMET.RI-S3.1, as an extension of the EURAMET.RI-S3 supplementary comparison performed in 2004 and the protocol [4] has been approved by the CCRI(I).

Table 1. Technical data of the transfer chambers

Chamber model	Reference point	Nominal volume / cm^3	*Polarizing voltage / V	Wall thickness / mm	Outer Diameter / mm
PTW 32002, #277 Spherical Chamber	Chamber centre	1000	+400	3	140
Exradin A5, #259 Spherical Chamber	Chamber centre	100	+400	3	62.8

* Polarizing voltage applied to the collector

Table 2. Technical data of the beam qualities at the MKEH

Quality	Tube voltage	*Nom. 1st HVL	Mean energy	Measured 1st HVL	Homogeneity coefficient
	/ kV	/ mm Cu	/ keV	Normalized to the ISO value	
N-40	40	0.084	32.5	0.95	0.94
N-60	60	0.24	48	1.00	0.90
N-120	120	1.71	99	1.02	0.98
N-300	300	6.12	249.6	1.00	0.99

* Stated in ISO 4037 Part 1

Table 3. Technical data of the beam qualities at the IAEA

Quality	Tube voltage	Measured 1st HVL	Homogeneity coefficient
	/ kV	Normalized to the ISO value	
N-40	40	1.03	0.90
N-60	60	0.99	0.77
N-120	120	1.02	0.96
N-300	300	1.01	-

3. Reference conditions

The calibration coefficients for the transfer chambers are evaluated in terms of air kerma per charge in units of Gy/C and refer to standard conditions of air temperature, pressure and relative humidity of T = 293.15 K, P = 101.325 kPa and h = 50 %, respectively. During the calibration the temperature, pressure and humidity in both laboratories were in the ranges from 295 K to 297 K, 99.6 kPa to 101.0 kPa and 45 % to 60 %, respectively. The source-to chamber distance was 2 m in both laboratories except for the Exradin A5 chamber at the MKEH, where the distance was 1 m. The x-ray tube position at MKEH is horizontal while at the IAEA it is vertical. The beam profiles of the Philips MNC 321 x-ray tube at the MKEH and the Comet MXR-321 tube at IAEA ensure uniform irradiation of the transfer chambers in both laboratories. The beam profiles can be seen in Figures 1 and 2. Instead of applying a small radial non-uniformity correction, an additional uncertainty component was introduced. It should be noted that the uncertainty of the beam profile measurement is usually comparable with the magnitude of the correction if the symmetrical profile of the x-ray tube has not more than a 1 % reduction at the edge of the detector.

Figure 1. MKEH beam profile

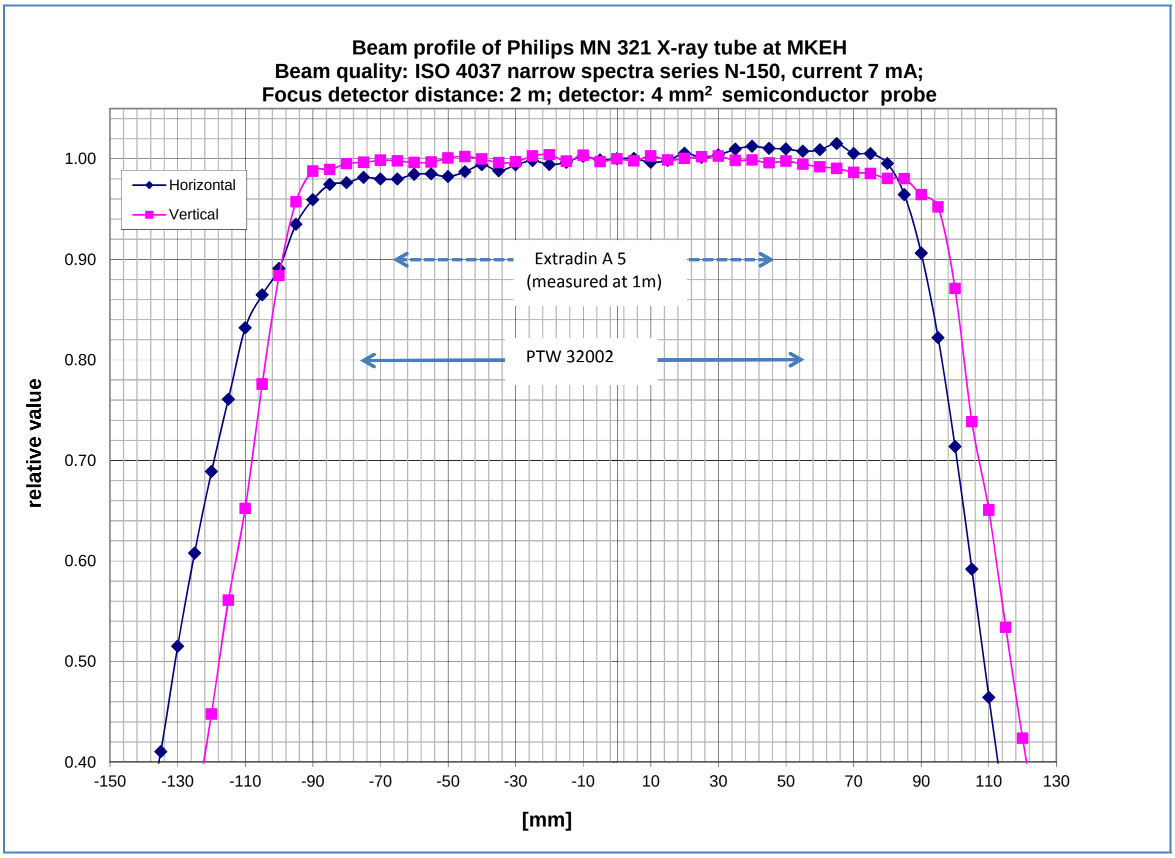
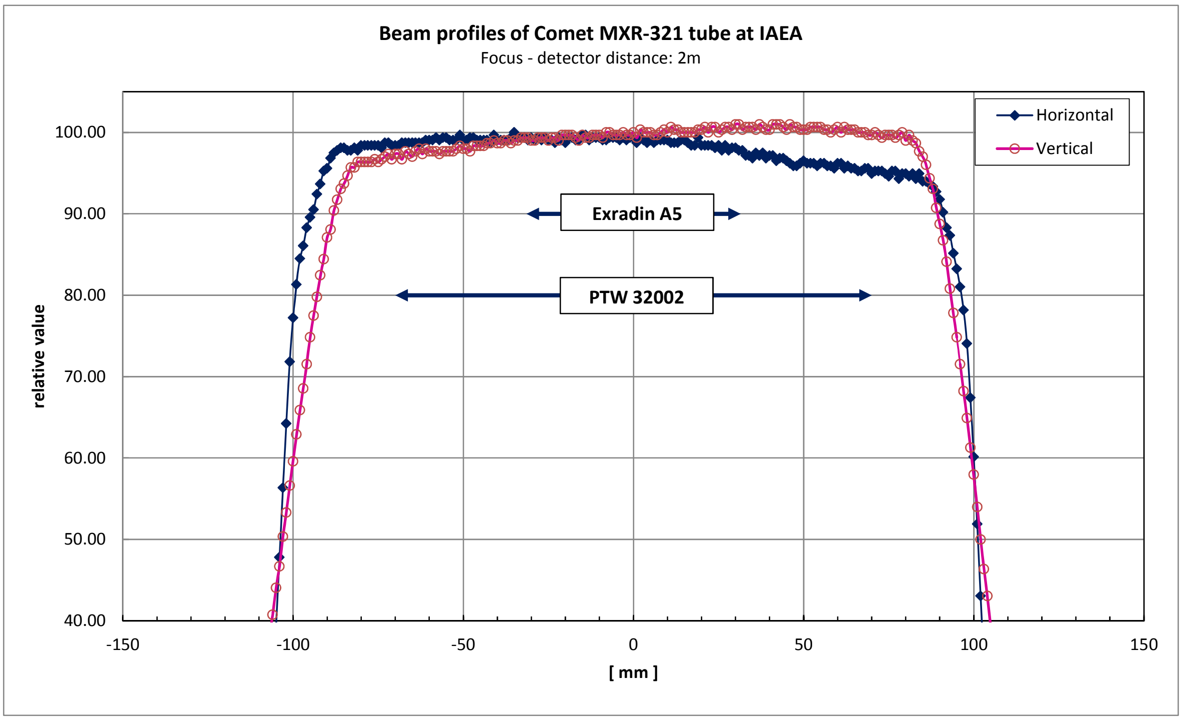


Figure 2. IAEA beam profile



4. Air kerma determination at the MKEH

Details of the MKEH primary standard free-air chamber for air kerma and its uncertainty are given in [3]. For the calibration of the transfer chambers the secondary standard chamber, type ND 1001 (#7807) was used, having a volume of 22 cm^3 and diameter39 mm. The air kerma rates were 37 mGy/h and 9 mGy/h at 1 m and 2 m, respectively, for all beam qualities. All measured ionization currents are normalized to monitor chamber, type ND 1004. A Keithley electrometer, type 617, is used with external feedback capacitance, type General Radio 4740. For the calibration of the electrometers the Keithley calibrator, type 263 is used, being traceable to the METAS (Switzerland) current standard.

5. Air kerma determination at the IAEA

For the ISO 4037 narrow beam x-ray qualities, the IAEA uses an x-ray unit, type Isovolt 320 Titan E with Comet MRX 321 tube, and a high voltage divider, type FUG HVT 160 000 calibrated by the PTB. The ionization currents measured by Keithley K6517 electrometers are normalized to the monitor chamber, type PTW FN 34014. Internal capacitance and ranges of electrometers are calibrated by a Keithley calibrator, type 263 traceable to BEV voltage and capacitance standards. For the calibration of the transfer chambers the IAEA reference standard chamber, type LS-01 #114 was used. This chamber was calibrated at the PTB in 2008. The air kerma rate was 12 mGy/h for all beam qualities. No further corrections (saturation, beam non-uniformity, spectral differences, etc.) were applied for determination of these reference air kerma rates.

6. Measurement results

The measured leakage current was less than 0.02 % of the measured current for both chambers at both laboratories, and was subtracted from the measured current. The calibration coefficients of the two transfer chambers measured at the MKEH and the IAEA, normalized to the reference air density, are given in Tables 4 and 5.

Table 4. Calibration coefficients of the Exradin A5 #259 chamber

X-ray beam quality	MKEH $N_{K\,\mathrm{air}}$ / (Gy/C)	IAEA before $N_{K\,\mathrm{air}}$ / (Gy/C)	IAEA after $N_{K\,\mathrm{air}}$ / (Gy/C)	IAEA average $N_{K\,\mathrm{air}}$ / (Gy/C)	IAEA/MKEH
*N-40	**3.075E+05**	3.086E+05	3.085E+05	**3.085E+05**	**1.003**
N-60	**3.037E+05**	3.033E+05	3.033E+05	**3.033E+05**	**0.999**
N-120	**3.082E+05**	3.087E+05	3.085E+05	**3.086E+05**	**1.001**
N-300	**3.123E+05**	3.114E+05	3.114E+05	**3.114E+05**	**0.997**

*A correction factor 1.0007 was applied to the IAEA values for the difference between the MKEH and IAEA HVL values, based on linear interpolation of chamber response in terms of HVL.

Table 5. Calibration coefficients of the PTW 32002 #277 chamber

X-ray beam quality	MKEH $N_{K\,\mathrm{air}}$ / (Gy/C)	IAEA before $N_{K\,\mathrm{air}}$ / (Gy/C)	IAEA after $N_{K\,\mathrm{air}}$ / (Gy/C)	IAEA average $N_{K\,\mathrm{air}}$ / (Gy/C)	IAEA/MKEH
*N-40	**2.724E+04**	2.721E+04	2.721E+04	**2.721E+04**	**0.999**
N-60	**2.586E+04**	2.576E+04	2.572E+04	**2.574E+04**	**0.995**
N-120	**2.512E+04**	2.520E+04	2.520E+04	**2.520E+04**	**1.003**
N-300	**2.526E+04**	2.517E+04	2.522E+04	**2.520E+04**	**0.997**

*A correction factor 1.0023 was applied to the IAEA values for the difference between the MKEH and IAEA HVL values, based on linear interpolation of chamber response in terms of HVL.

7. Uncertainties

The uncertainties associated with the measurements made at the MKEH and the IAEA are listed in Tables 6 and 7, respectively. The various sources of uncertainty are grouped according to [5] as Type A (statistical) and Type B (non-statistical, based on scientific judgement). The uncertainty of the calibration coefficient, $N_{K\mathrm{air}}$, was obtained essentially by combining the uncertainties of the reference air kerma rate and the ionization current corrected for all influence quantities.

Table 6. Uncertainty budget for the transfer chamber calibrations at the MKEH

Uncertainty budget for the IAEA chamber calibration at the MKEH				
	Type A	Type B	Type A	Type B
Uncertainty components /%	**FDD = 1 m**		**FDD = 2 m**	
Ref. air kerma rate		0.35		0.4
***Ionization current**	0.05	0.05	0.05	0.05
Position		0.05		0.05
Air density		0.05		0.05
Radial non-uniformity of the beam		0.1	0.1	0.2
Leakage		0.02		0.02
Relative combined standard uncertainty	0.05	0.37	0.11	0.46
Overall relative standard uncertainty		**0.38**		**0.47**

*Including leakage and offset currents of electrometers

Table 7. Uncertainty budget for the transfer chamber calibration at the IAEA

Uncertainty budget for the calibration of transfer chambers at the IAEA		
Uncertainty components /%	Type A	Type B
	FDD = 2 m	
Ref. air kerma rate		0.38
Long term stability		0.3
Ionization current	0.05	0.05
Position		0.05
Air density		0.05
Radial non-uniformity of the beam		0.2
Leakage		0.02
Relative combined standard uncertainty	0.05	0.53
Overall relative standard uncertainty		**0.53**

8. Results and discussion

The comparison results, *R*, for the selected beam qualities are the mean of the IAEA/MKEH ratios in the final column of Tables 4 and 5 for the two transfer chambers. It is interesting to note that these ratios are close to unity despite the fact that the results for the MKEH and the PTB (where the IAEA reference chamber was calibrated) in the EURAMET.RI(I)-S3 have a systematic difference as seen in column 8 of Table 8 showing the PTB/MKEH ratio R_K taken from [3]. Normalizing the present results for IAEA/MKEH to the results for PTB/MKEH obtained in the EURAMET.RI(I)-S3 comparison would give the results R/R_K for IAEA/PTB shown in the last two columns of the table.

Table 8. Comparison result and its uncertainty

X-ray beam quality	IAEA/ MKEH R_1 (Extradin A5)	$u_c(R_1)$ (%)	IAEA/ MKEH R_2 (PTW 32002)	$u_c(R_2)$ (%)	Mean ratio R	$u_c(R)$ (%)	K_{air}(PTB)/ K_{air}(MKEH) *R_K (EURAMET .RI(I)-S3)	** $u_c(R_K)$ (%)	Comp. result R/R_K	*** $u_c(R/R_K)$ (%)
N-40	1.003	0.69	0.999	0.75	1.001	0.75	1.0071	0.49	0.994	0.85
N-60	0.999	0.69	0.995	0.75	0.997	0.75	1.0074	0.46	0.990	0.80
N-120	1.001	0.69	1.003	0.75	1.002	0.75	1.0079	0.51	0.994	0.83
N-300	0.997	0.69	0.997	0.75	0.997	0.75	1.0080	0.53	0.989	0.84

*Expected result assuming nothing has changed since the EURAMET.RI(I)-S3 comparison in 2004
**Taking into account the fully correlated physical constants of the MKEH and PTB primary standards
***All Type B uncertainties for the MKEH and PTB primary standards cancel in the evaluation of R/R_K

Degrees of equivalence for the IAEA air kerma standard can be calculated from the product of the mean IAEA/MKEH ratios, R, and the ratios of MKEH to the EURAMET.RI-S3 comparison reference values, together with their combined uncertainties. These latter ratios, the resulting differences D for the IAEA from the EURAMET.RI-S3 comparison reference values [3] and the associated expanded uncertainties U_D are listed in Table 9, which therefore shows the degrees of equivalence (D,U_D). It should be noted that the degrees of equivalence for the EURAMET.RI-S3 participants were established using the results for the smallest transfer chamber from the three transfer chambers used.

Table 9. Degrees of Equivalence (D,U_D) for the IAEA air kerma standard for radiation protection

X-ray beam quality	K_{air}(MKEH)/K_{air}(ref) R_{MKEH}	$u_c(R_{MKEH})$ /%	K_{air}(IAEA)/K_{air}(ref)	IAEA D / (mGy/Gy)	*$U(D)$ / (mGy/Gy)
N-40	0.9972	0.41	0.9983	-1.7	15.4
N-60	0.9977	0.39	0.9947	-5.3	15.2
N-120	0.9972	0.42	0.9994	-0.6	15.5
N-300	1.0035	0.52	1.0008	0.8	16.4

*All Type B uncertainties for the MKEH standard cancel in the evaluation of K_{air}(IAEA)/K(ref)

9. Conclusion

This is the first bilateral comparison since the completion of the EURAMET.RI-S3 comparison. Both, the normalized comparison results R/R_K (representing IAEA/PTB) and the IAEA differences from the EURAMET.RI(I)-S3 reference values are well within their expanded uncertainties and consequently support the relevant IAEA CMC claims. The systematic deviation from unity for the R/R_K values might come from changes in the two primary standards and/or the calibration practices at the PTB and MKEH since the supplementary comparison was performed in 2004. The relatively high uncertainty in the R/R_K values comes from the uncertainties in the degrees of equivalence for the two primary laboratories. Further similar bilateral comparisons, involving the participants of the EURAMET.RI-S3 comparison, are encouraged to validate the participants' uncertainties for the calibration of radiation protection dosemeters in medium energy X-ray beam qualities.

References

[1] CIPM MRA: *Mutual recognition of national measurement standards and of calibration and measurement certificates issued by national metrology institutes*, International Committee for Weights and Measures, 1999, 45 pp http://www.bipm.org/pdf/mra.pdf.

[2] ISO 4037 X and gamma reference radiation for calibrating dosemeters and doserate meters and for determining their response as a function of photon energy: Part 1, 1996, Radiation characteristics and production methods; Part 3, 1999, Calibration of area and personal dosemeters and the measurement of their response as a function of energy and angle of incidence. ISO Standards.

[3] Büermann L, O'Brien M, Butler D, Csete I, Gabris F, Hakanen A, Lee J-H, Palmer M, Saito N, Vries W de, 2008, Comparison of national air kerma standards for ISO 4037 narrow spectrum series in the range 30 kV to 300 kV, *Metrologia* **45** *Tech. Suppl.* 06013

[4] Technical protocol for the EURAMET.RI(I)-S3.1 comparison.

[5] GUM, 2008, *Evaluation of measurement data – Guide to the expression of uncertainty in measurement*, JCGM 100:2008