APPENDIX TO IAEA CALIBRATION CERTIFICATE

CALIBRATION OF REFERENCE DOSIMETERS FOR DIAGNOSTIC RADIOLOGY AT THE IAEA DOSIMETRY

1 INTRODUCTION

1.1 General

Reference dosimeters are calibrated for diagnostic and interventional radiology beams at the IAEA Dosimetry Laboratory (DOL) according to procedures described in the IAEA TRS-457 [1] and in the Chapter 21 of the IAEA Diagnostic Radiology Physics Handbook [2]. The calibrations are performed by the substitution method using monitor chamber for normalization of the X-ray beam output. The IAEA reference standard ionization chambers and current source used for these calibrations are calibrated at the BIPM or other Primary Standard Laboratories every 3 years.

The air kerma calibration coefficient N_K [mGy/scale unit] of the dosimeter under calibration is determined as the ratio of the air kerma rate $\dot{K}_{air}$ [mGy/s] obtained with the IAEA reference standard, and the reading $\dot{M}$ [scale units/s] of the dosimeter corrected for the reference conditions. In terms of air kerma-length, $N_{P_{KL}}$, or air kerma-area products, $N_{P_{KA}}$, this ratio is multiplied with the irradiated length or irradiated area.

Reference dosimeters are typically composed of an ionization chamber plus an electrometer. Calibrations are either made for a system, composed of an ionization chamber plus an electrometer (hence system calibration), or for an ionization chamber only (component calibration). For calibration of the ionization chamber only, the ionization currents are measured with the IAEA electrometers. For system calibrations, the internal bias supply in the user electrometer/dosimeter is used for the polarizing voltage. No correction for the measured ionization currents due to ion recombination is applied.

1.2 Reference conditions

The reference point of the ionization chamber, where the calibration coefficients apply, is considered to be in the geometrical centre of the collecting volume as defined by the external walls (unless another indication is given). Details on the geometrical centre for each specific chamber are given in the operation manual of the ionization chambers. If the chamber stem has a mark, this mark is oriented towards the radiation source during the calibration.

The calibration coefficients refer to T=20°C, P=101.325 kPa and 50% relative air humidity. The ambient conditions (temperature, pressure and humidity), prevailing at the DOL during the calibrations, are monitored continuously. Typically, the temperature in the laboratory is within 20°C-24°C with fluctuations less than 0.5°C. The measured ionization current I [nA] is corrected for the reference temperature 20°C and pressure 101.325 kPa. The relative air humidity at the dosimetry laboratory is kept between 30% and 70%. No correction is applied for the humidity.

1.3 Radiation qualities

The characteristics of the diagnostic radiology X-ray radiation qualities used for calibration are given in Tables I-X below. The applied air kerma rate is 50 mGy/min for the non-attenuated radiation qualities (TABLES I, III, IV, VI, VII, VIII, IX, X) and 3 mGy/min for the attenuated radiation qualities (TABLE II and V).

2 CALIBRATIONS IN TERMS OF AIR KERMA

The chamber is positioned free in air, so that its reference point is on the central axis of the beam. The chamber is mounted vertically and held by the stem. In the case of plane-parallel chamber the entrance surface is perpendicular to the central axis of the beam. In the case of cylindrical chamber its axis is perpendicular to the central axis of the beam. The distance from the focus of the X-ray tube to the reference point of the chamber, FCD, is 1 m. The size of the radiation field (50 % and 99% isodose levels) at the reference plane is ∅ 10 cm and ∅ 8 cm respectively. Fig. 1 shows the set-up.

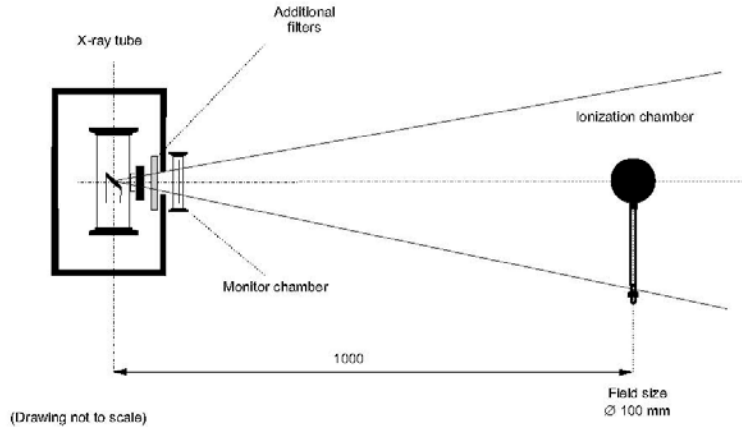

Fig. 1: Set-up for calibration in terms of air kerma for diagnostic radiology X-ray beams

3 CALIBRATIONS IN TERMS OF AIR KERMA-LENGTH PRODUCT, P_{KL} AND AIR KERMA-AREA PRODUCT, P_{KA}

These P_{KL} and P_{KA} quantities are used for the calibration of pencil shape ionization cambers and transmission type plane parallel air kerma-area product meters. Their calibration methods are described in the Chapter 7 of IAEA TRS 457 [1], and their calibration coefficients $N_{P_{KL}}$ (Gy·cm/C) and $N_{P_{KA}}$ (Gy·cm^2/C) are obtained by equations 7.7 and 7.10 respectively. Their calibration setups are shown in Fig. 2 and Fig. 3. Some further considerations related to the calibration of pencil shape chamber and dose area product meters are in [3] and [4].

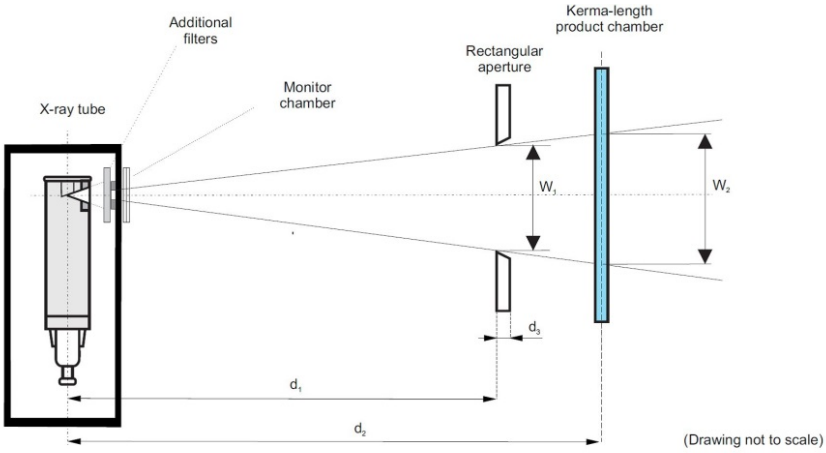

Fig. 2: Set-up for calibration of CT chambers in terms of air kerma-length product *(d_1=950 mm, d_2=1000 mm (reference plane), d_3=5 mm, W_1=50 mm, W_2=52.63 mm)*

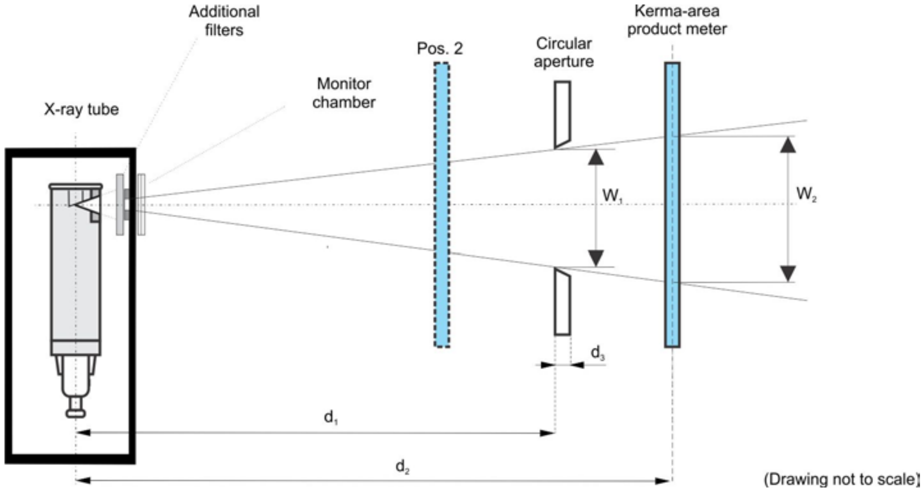

Fig. 3: Set-up for calibration of KAP meters in terms of air kerma-area product in incident and transmitted beam by the KAP meter *(d_1=950 mm, d_2=1000 mm (reference plane), d_3=5 mm, W_1=51 mm, W_2=53.7 mm).* For reference air kerma rate determination of transmitted beam the KAP meter is in position 2.

TABLE I: RQR X-ray radiation qualities [5]

Radiation quality	High voltage [kV]	Added filtration[a] [mm Al]	1st HVL [mm Al]
RQR 2	40	2.44	1.42
RQR 3	50	2.44	1.77
RQR 4	60	2.69	2.18
RQR 5[b]	**70**	**2.88**	**2.59**
RQR 6	80	3.15	3.07
RQR 7	90	3.39	3.57
RQR 8	100	3.52	4.03
RQR 9	120	3.90	5.10
RQR 10	150	4.72	6.74

[a] Inherent filtration 1 mm Be;
[b] Reference radiation quality in the series

TABLE II: RQA X-ray radiation qualities [5]

Radiation quality	High voltage [kV]	Added filtration[a] [mm Al]	1st HVL [mm Al]
RQA 2	40	6.51	2.25
RQA 3	50	12.6	3.82
RQA 4	60	18.9	5.45
RQA 5[b]	**70**	**24.2**	**6.87**
RQA 6	80	29.4	8.16
RQA 7	90	33.4	9.19
RQA 8	100	37.6	10.17
RQA 9	120	44.1	11.75
RQA 10	150	49.9	13.42

[a] Inherent filtration 1 mm Be
[b] Reference radiation quality in the series

TABLE III: RQT X-ray radiation qualities [5]

Radiation quality	High voltage [kV]	Added filtration[a]	1st HVL [mm Al]
RQT 8	100	3.50 mm Al+ 0.21 mm Cu	7.03
RQT 9[b]	**120**	**4.00 mm Al+ 0.26 mm Cu**	**8.49**
RQT 10	150	4.83 mmAl+ 0.31 mm Cu	10.20

[a] Inherent filtration 1 mm Be
[b] Reference radiation quality in the series

TABLE IV: MMR X-ray radiation qualities for molybdenum anode

Radiation quality[a]	High voltage [kV]	Added filtration[b] [mm Mo]	1st HVL [mm Al]
MMR 25	25	0.033	0.29
MMR 28[c]	**28**	**0.033**	**0.32**
MMR 30	30	0.033	0.34
MMR 35	35	0.033	0.38

[a] RQR-M qualities according to [5]
[b] Inherent filtration 1 mm Be
[c] Reference radiation quality in the series

TABLE V: MMA X-ray radiation qualities for molybdenum anode

Radiation quality[a]	High voltage [kV]	Added filtration[b] [mm Al]	1st HVL [mm Al]
MMA 25	25	MMR 25 + 2.02	0.58
MMA 28[c]	**28**	MMR 28 + 2.02	0.63
MMA 30	30	MMR 30 + 2.02	0.65
MMA 35	35	MMR 35 + 2.02	0.73

[a] RQR-A qualities according to [5]
[b] Inherent filtration 1 mm Be
[c] Reference radiation quality in the series

TABLE VI: MRR X-ray radiation qualities for molybdenum anode

Radiation quality	High voltage [kV]	Added filtration[a] [mm Rh]	1st HVL [mm Al]
MRR 25	25	0.0285	0.35
MRR 28[b]	**28**	0.0285	0.39
MRR 30	30	0.0285	0.41
MRR 35	35	0.0285	0.45

[a] Inherent filtration 1 mm Be
[b] Reference radiation quality in the series

TABLE VII: W+Mo X-ray radiation qualities for tungsten anode

Radiation quality	High voltage [kV]	Added filtration[a] [mm Mo]	1^{st} HVL [mm Al]
W+Mo 25	25	0.066	0.340
W+Mo 28 [b]	**28**	**0.066**	**0.357**
W+Mo 30	30	0.066	0.367
W+Mo 35	35	0.066	0.393

[a] Inherent filtration 1 mm Be
[b] Reference radiation quality in the series

TABLE VIII: W+Al X-ray radiation qualities for tungsten anode

Radiation quality	High voltage [kV]	Added filtration[a] [mm Al]	1^{st} HVL [mm Al]
W+Al 25	25	0.500	0.3120
W+ Al 28 [b]	**28**	**0.500**	**0.354**
W+ Al 30	30	0.500	0.380
W+ Al 35	35	0.500	0.435

[a] Inherent filtration 1 mm Be
[b] Reference radiation quality in the series

TABLE IX: W+Rh X-ray beam qualities for tungsten anode

Radiation quality	High voltage [kV]	Added filtration[a] [mm Rh]	1^{st} HVL [mm Al]
W+Rh 25	25	0.0477	0.469
W+ Rh 28 [b]	**28**	**0.0477**	**0.496**
W+ Rh 30	30	0.0477	0.514
W+ Rh 35	35	0.0477	0.549

[a] Inherent filtration 1 mm Be
[b] Reference radiation quality in the series

TABLE X: W+Ag X-ray beam qualities for tungsten anode

Radiation quality	High voltage [kV]	Added filtration[a] [mm Ag]	1^{st} HVL [mm Al]
W+Ag 25	25	0.0492	0.478
W+ Ag 28 [b]	**28**	**0.0492**	**0.534**
W+ Ag 30	30	0.0492	0.559
W+ Ag 35	35	0.0492	0.605

[a] Inherent filtration 1 mm Be
[b] Reference radiation quality in the series

4 USE OF CALIBRATION COEFFICIENTS

The reference instruments calibrated at the DOL can be used, in another radiation beam, to determine the beam output rate (air kerma, air kerma-length product, air kerma-area product), subject to the provisions listed below:

- The humidity conditions should not differ significantly from those prevailing at the IAEA Dosimetry Laboratory. If the relative humidity is outside the range of 30 % - 70 %, corrections based on [6] should be made.
- If the conditions of measurement differ significantly from those at DOL, additional corrections or uncertainty for the differences may be needed. In particular when they are related to:
    - the radiation quality (different HVL and/or photon spectrum), e.g. related uncertainties for mammography can be found in [8];
    - the radial non-uniformity of the beam over the cross section of the ionization chamber;
    - the dose rate and pulse rate. It should be noted that the calibration coefficients determined at the DOL are not corrected for the recombination. Additional information on this effect can be found in [1] and [7].
    - the applied polarity and scale used during the calibration at the DOL reported in the calibration certificate. If the instrument is used with a different polarity or scale from those listed in the calibration certificate, the user is advised to determine the effect of these differences and decide on their effects on the measurements. Additional information on these effects and ways to correct for them can be found in [1].
    - the beam size, in the case of KAP meters. Specific corrections may be required depending on the meter's construction [4].

5 CALIBRATION UNCERTAINTIES

The methodology for estimating the uncertainties of calibrations at the IAEA Dosimetry Laboratory is based on the ISO [9] and IAEA [10] guides on uncertainty. All sources of uncertainty are identified and classified as Type A or Type B, as per ISO classification.

The uncertainty associated to the IAEA calibrations is a relative combined standard uncertainty, with a coverage factor of k = 2, which for a normal distribution corresponds to a level of confidence of approximately 95 %.

The contributions to the total relative uncertainty in the calibration coefficient are determined in 2 steps:

1. uncertainties arising from measurements made by the IAEA reference instrument to determine the reference air kerma rate in the radiation beams where the user's instrument will be calibrated, and
2. uncertainties related to the instruments to be calibrated (user's instrument). Instruments calibrated at the IAEA are usually reference class instruments. Typical uncertainties are assumed for these instruments. In case of the calibrations in terms of air kerma-length and air kerma-area products, further uncertainty components associate with the partial irradiation of pencil shape CT chambers, and KAP meters are listed (step 3).

These two components are further divided into sub-components and their classification (Type A or Type B) is determined. Uncertainty budgets of IAEA calibrations are given in Tables XI-XIV.

Table XI

Estimated relative standard uncertainty in the IAEA calibration.

RQR, RQA and RQT X-ray beams: Air kerma rate.

(IAEA CMCs Identifiers in the BIPM KCDB): EUR-RAD-IAEA 1020-1024

Air kerma rate	*Uncertainty (%)*	
	Type A	Type B
Step 1: Reference standard		
Calibration from BIPM/PSDL		0.40
Long term stability of the reference standard		0.25
Spectral difference of the beam at DOL and PSDL		0.06
Chamber positioning		0.03
Current measurements including range and time base corrections of IAEA electrometer	0.02	0.05
Uncertainty due to temperature measurements		0.03
Uncertainty due to pressure measurements		0.01
Monitor chamber contribution	0.02	
Relative combined standard uncertainty of K_{air} (Step 1)	*0.03*	*0.48*
Step 2: Instrument to be calibrated		
Current measurements including user electrometer	0.10	0.05
Uncertainty due to temperature measurements	0.01	0.03
Uncertainty due to pressure measurements	0.01	0.01
Monitor chamber contribution	0.02	
Chamber positioning		0.03
Difference in radial non-uniformity of the beam		0.20
Relative combined standard uncertainty in Step 2	*0.10*	*0.21*
Relative combined standard uncertainty (Steps 1 + 2)	***0.11***	***0.52***
Relative expanded uncertainty (k=2)		**1.1**

Table XII

Estimated relative standard uncertainty in the IAEA calibration.

MMA, *MMR, MRR, *W+Mo W+Al, W+Rh andW+Ag mammography X-ray beams: Air kerma rate.

(IAEA CMCs Identifier in the BIPM KCDB): EUR-RAD-IAEA 1018-1019

Air kerma rate	*Uncertainty (%)* Type A	Type B
Step 1: Reference standard		
Calibration from BIPM/PSDL		*0.48
Long term stability of the reference standard		0.30
Spectral difference of the beam at DOL and PSDL		0.10
Chamber positioning		0.03
Current measurements including range and time base corrections of IAEA electrometer	0.02	0.05
Uncertainty due to temperature measurements		0.03
Uncertainty due to pressure measurements		0.01
Monitor chamber contribution	0.02	
Relative combined standard uncertainty of K_{air} (Step 1)	*0.03*	*0.58*
Step 2: Instrument to be calibrated		
Current measurements including user electrometer	0.10	0.05
Uncertainty due to temperature measurements	0.01	0.03
Uncertainty due to pressure measurements	0.01	0.01
Monitor chamber contribution	0.02	
Chamber positioning		0.03
Difference in radial non-uniformity of the beam		0.25
Relative combined standard uncertainty in Step 2	*0.10*	*0.26*
Relative combined standard uncertainty (Steps 1 + 2)	***0.11***	***0.63***
Relative expanded uncertainty (k=2)		***1.3**

*In case of the MMR and W+Mo radiation qualities the relative expanded uncertainty is 1.0% due to the different traceability of reference standard (*IAEA CMCs Identifier in the BIPM KCDB): EUR-RAD-IAEA 1019*.

Table XIII

Estimated relative standard uncertainty in the IAEA calibration.

RQR, and RQT X-ray beams: Air kerma-length product.

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(IAEA CMCs Identifier in the BIPM KCDB): EUR-RAD-IAEA 1025

Air kerma rate	*Uncertainty (%)* Type A	Type B
Step 1 and 2:		
Relative combined standard uncertainty (see table IX)	*0.11*	*0.52*
Step 3 Additional components using partial irradiation method of CT chamber		
Ref air kerma behind the diaphragm		0.1
Irradiated length inc. projection		0.2
Residual correction		0.1
Repeatability of setup		0.2
Relative combined standard uncertainty in step 3		*0.3*
Relative combined standard uncertainty (Steps 1+2+3)	***0.11***	***0.61***
Relative expanded uncertainty (k=2)		**1.2**

Table XIV
Estimated relative standard uncertainty in the IAEA calibration.
RQR X-ray beams: Air kerma-area product.

(IAEA CMCs Identifier in the BIPM KCDB): EUR-RAD-IAEA 1026-1027

Air kerma rate	*Uncertainty (%)*	
	Type A	Type B
Step 1 and 2:		
Relative combined standard uncertainty (see table IX)	*0.11*	*0.52*
Step 3 Additional components using partial irradiation method of KAP meters		
Ref air kerma behind the diaphragm		0.1
Irradiated area inc. projection		0.3
Repeatability of setup		0.2
KAP meter resolution		0.1
Relative combined standard uncertainty in step 3		*0.4*
Relative combined standard uncertainty (Steps 1+2+3)	***0.11***	***0.65***
Relative expanded uncertainty (k=2)		**1.3**

6 REFERENCES

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