APPENDIX TO IAEA CALIBRATION CERTIFICATE

RADIATION PROTECTION IONIZATION CHAMBER CALIBRATION PROCEDURES AT THE IAEA DOSIMETRY LABORATORY

1 INTRODUCTION

1.1 General

Ionization chambers and electrometers are calibrated at the IAEA Dosimetry Laboratory (DOL) in terms of air kerma (N_K), ambient dose equivalent (H*(10)) and personal dose equivalent (H_P(10)), in ^{60}Co, ^{137}Cs gamma radiations and ISO 4037 X-ray narrow spectra series [1]. Calibrations are either made for a system composed of an ionization chamber plus an electrometer (hence system calibration) or for an ionization chamber only.

Calibrations are performed using the beam output data that are measured using the appropriate IAEA reference standard chamber. In case of the X-ray beams the tube output is normalised to the monitor chamber. The reference standards are calibrated at the BIPM or at another Primary Standards Dosimetry Laboratory (PSDL) every 3 years. For calibrations of the ionization chamber only, the current is measured with an IAEA reference electrometer. For system calibrations, the internal bias supply in the electrometer/dosimeter is used for the polarizing voltage. No correction for the possible lack of saturation is applied. The relative air humidity at the dosimetry laboratory is kept between 30 % and 70 %. No correction is applied for the humidity.

The air kerma calibration coefficient N_K [mGy/nC] of the chamber alone is determined as the ratio of the air kerma rate $\dot{K}_{\text{air}}$ [mGy/s] obtained with the IAEA reference standard, and the ionization current I [nA] from the chamber under calibration corrected for the influence quantities for pressure (P) and temperature (T). The ambient conditions (temperature, pressure and humidity), prevailing at the IAEA Laboratory during the calibrations, are monitored continuously. Typically, the temperature fluctuations in the laboratory are within 20°C - 24°C and during measurements about 0.5 °C.

The air kerma calibration coefficient N_K [mGy/scale unit] of the system is determined as the ratio of the air kerma rate $\dot{K}_{\text{air}}$ [mGy/s] obtained with the IAEA reference standard, and the reading rate $\dot{M}$ [scale units/s] of the system corrected for the influence quantities P and T.

The same procedure is followed to determine the calibration coefficient in terms of ambient and personal dose equivalent quantities.

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 chamber. If the chamber stem has a mark, this mark is oriented towards the radiation source during the calibration. The distance from the source to the reference point of the chamber is 3 m. For calibrations of ionization chambers having a smaller volume, or for calibrations in terms of personal dose equivalent H_P(10) the distance from the source to the reference point of the chamber is 2 m. The calibration coefficients refer to T=293.15 K and P=101.325 kPa.

2 CALIBRATIONS IN TERMS OF AIR KERMA

2.1 ^{137}Cs and ^{60}Co gamma radiation

The chamber, with the build-up cap (where applicable), is positioned free in air, so that its reference point is on the central axis of the beam. The chamber reference plane is perpendicular to the central axis of the beam. The size of the radiation field (50 % isodose level) at the reference plane is ∅ 80 cm. Fig. 1 shows the set-up.

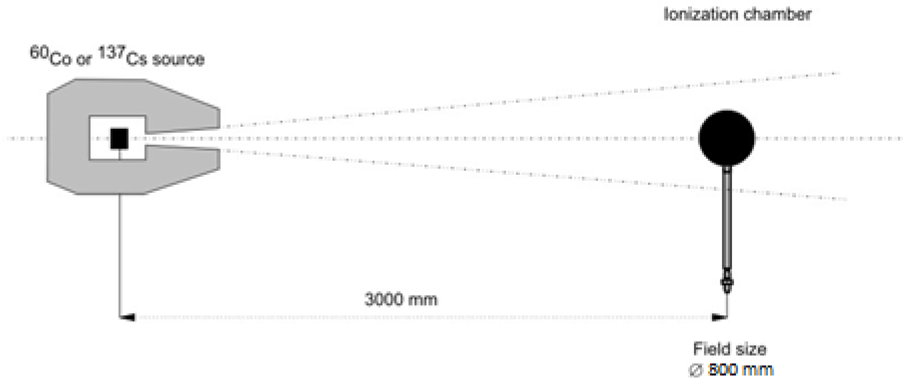

Fig. 1 Set-up for calibration in terms of air kerma for ^{137}Cs and ^{60}Co gamma radiation.

2.2 X-ray beams

Two X-ray tubes are used to generate the ISO 4037 narrow spectrum X-ray reference radiation qualities. The characteristics of the radiation qualities used for calibrations are shown in TABLE I [1].

The chamber, with its build-up cap (if applicable), is positioned free in air, so that its reference point is on the central axis of the beam. The reference plane of the chamber must be perpendicular to the central axis of the beam. The size of the radiation field (50 % isodose level) at the reference plane is ∅ 26 cm. Fig. 2 shows the set-up.

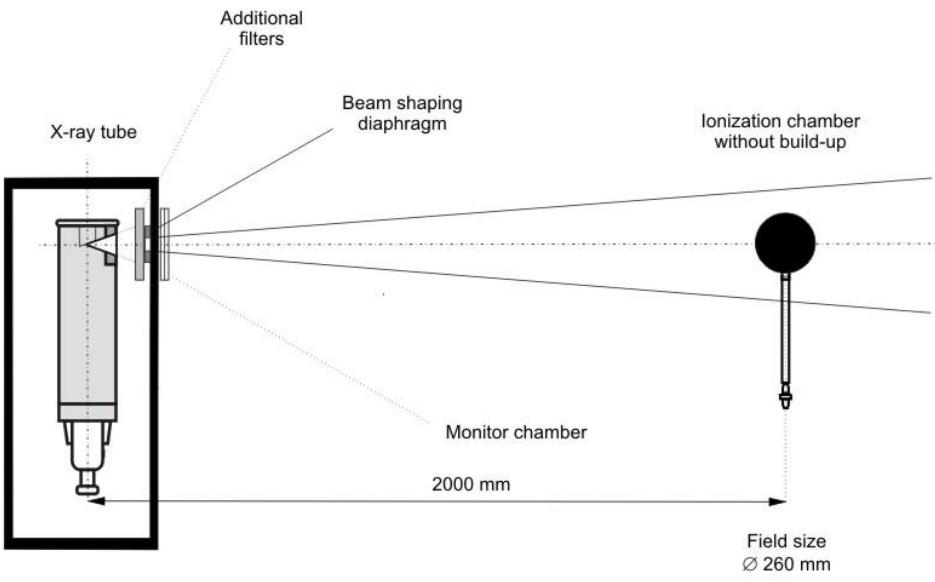

Fig. 2 Set-up for calibration in terms of air kerma for X-ray beams.

TABLE I Radiation qualities at the IAEA for the ISO 4037 Narrow Spectrum Series [1]

Radiation quality	H.V. [kV]	Added filtration *				1st HVL	
		Al [mm]	Cu [mm]	Sn [mm]	Pb [mm]	Al [mm]	Cu [mm]
N40	40	4.0	0.22			2.72	
N60	60	4.0	0.74				0.24
N80	80	4.0	2.0				0.59
N100	100	4.0	5.0				1.13
N120	120	4.0	5.0	1.0			1.75
N150	150	4.0		2.5			2.42
N200	200	4.0	2.0	3.0	0.5		3.92
N250	250	4.0		2.1	2.0		5.18
N300	300	4.0		3.0	3.9		6.20

*) Inherent filtration is 3 mm Be

3 CALIBRATIONS IN TERMS OF AMBIENT DOSE EQUIVALENT AND PERSONAL DOSE EQUIVALENT

The ambient dose equivalent, H^*, and the personal dose equivalent are operational quantities. Definitions of operational quantities used in radiation protection dosimetry are given in IAEA Basic Safety Standards [3] and IAEA Safety Series No.16 [4]. The set-up used for the calibration of ionization chambers in terms of ambient dose equivalent is identical to that of calibrations in terms of air kerma. In the case of calibrating ionization chambers in terms of $H_P(10)$, the distance from the source to the reference point of the chamber is 2 m. The angle of incidence, α, for $H_P(10)$ determination is 0°.

4 USE OF CALIBRATION COEFFICIENTS

The reference instruments calibrated at the IAEA can be used, in another radiation beam, to determine that beam's output rate (air kerma or ambient dose equivalent or personal dose equivalent), 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 [5] should be made.
- If the conditions of measurement differ significantly from those at the IAEA, additional corrections for the difference may be needed. In particular:
  - the radiation quality (particularly for X-ray beams);
  - the calibration distance and beam dimensions of the radiation beam;
  - the radial non-uniformity of the beam over the cross section of the ionization chamber;
  - the beam intensity. It should be noted that the calibration coefficients determined at the IAEA are not corrected for the lack of saturation due to recombination. If the instrument is used in beams different from those listed in the calibration certificate, the user is advised to correct for this effect. Additional information on this effect can be found in [6]; and
  - the polarity and scale used during the calibration at the IAEA are 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 [6].

5 CALIBRATION UNCERTAINTIES

The methodology for estimating the uncertainties of calibrations at the IAEA Dosimetry Laboratory is based on the recommendations of the ISO and IAEA guides on uncertainty [7] and [8]. All sources of uncertainty are identified and classified as Type A or Type B, as per ISO classification.

The uncertainty associated to IAEA calibrations is a 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 uncertainty in the calibration coefficient are determined in 2 steps:

1. uncertainties arising from measurements made to determine the output rate (air kerma rate or absorbed dose to water rate) of the radiation beams, with the IAEA reference instrument (including the stability of the measurement standards), and
2. uncertainties related to the instruments to be calibrated (user's instrument). Instruments calibrated at the IAEA are reference class instruments. Typical uncertainties are assumed for these instruments.

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 II-VI.

6 REFERENCES

[1] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, X and gamma reference radiation for calibrating dosemeters and doserate meters and for determining their response as a function of photon energy, ISO 4037 Parts 1-3, Geneva (1999).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Calibration of Dosimeters Used in Radiotherapy, Technical Report Series No. 374, IAEA, Vienna (1994).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, International Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources, Safety Series No. 115, IAEA, Vienna (1996).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Calibration of Radiation Protection Monitoring Instruments, Safety Series No.16, IAEA, Vienna (2000).

[5] BUREAU INTERNATIONAL DES POIDS ET MESURES, Correction d'humidité, in Com. Cons. Etalons des Ray. Ionisants (Section 1), BIPM, PARIS (1977), 4, R(I)6.

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Absorbed Dose Determination in External Radiotherapy: an International Code of Practice for Dosimetry Based on Standards on Absorbed Dose to Water, Technical Reports Series No. 398, IAEA, Vienna (2000).

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Measurement Uncertainty A Practical Guide for Secondary Standards Dosimetry Laboratories, TECDOC-1585, IAEA, VIENNA (2008).

[8] JOINT COMMITTEE FOR GUIDES IN METROLOGY (BIPM, IEC, IFCC, ISO, IUPAC, IUPAP AND OIML), Guide to the Expression of Uncertainty in Measurement, JCGM 100: 2008, http://www.bipm.org/utils/common/documents/jcgm/JCGM_100_2008_E.pdf.

Table II

Estimated relative standard uncertainty in the IAEA calibration

ISO 4037 X-ray Narrow Spectrum Series: Air kerma rate

(IAEA CMCs Identifier in the BIPM KCDB): EUR-RAD-IAEA-1006 and EUR-RAD-IAEA-1007

Air kerma rate	Type A	Type B	
Using DOL electrometer	*Uncertainty (%)*		
Step 1: Reference standard			
Calibration from BIPM/PSDL		0.39	
Long term stability of the secondary standard		0.29	
Temperature and Pressure	0.06	0.10	
Current	0.06	0.10	
Monitor chamber	0.01		
Relative combined standard uncertainty in Step 1	*0.09*	*0.51*	
Step 2: Instrument to be calibrated			
Temperature and Pressure	0.03	0.10	
Electrometer reading	0.06	0.20	
Chamber positioning		0.01	
Monitor chamber	0.01		
Radiation quality		0.17	
Uniformity of radiation field		0.12	
Relative combined standard uncertainty in Step 2	*0.09*	*0.31*	
Relative combined standard uncertainty (Steps 1 + 2)	***0.12***	***0.59***	
Relative expanded uncertainty (k=2)		**1.2**	**%**

Table III

Estimated relative standard uncertainty in the IAEA calibration

^{60}Co and ^{137}Cs gamma radiation: Air kerma rate

(IAEA CMCs Identifier in the BIPM KCDB): EUR-RAD-IAEA-1008 and EUR-RAD-IAEA-1009

Air kerma rate	Type A	Type B	
Using DOL electrometer	*Uncertainty (%)*		
Step 1: Reference standard			
Calibration from BIPM/PSDL		0.25	
Long term stability of the secondary standard		0.17	
Temperature and Pressure	0.03	0.10	
Current	0.05	0.10	
Relative combined standard uncertainty in Step 1	*0.06*	*0.33*	
Step 2: Instrument to be calibrated			
Temperature and Pressure	0.03	0.10	
Electrometer reading	0.06	0.20	
Chamber positioning		0.01	
Uniformity of radiation field		0.10	
Relative combined standard uncertainty in Step 2	*0.07*	*0.25*	
Relative combined standard uncertainty (Steps 1 + 2)	***0.09***	***0.41***	
Relative expanded uncertainty (k=2)		**0.8**	**%**

Table IV

Estimated relative standard uncertainty in the IAEA calibration

ISO 4037 Narrow Spectrum Series: Ambient dose equivalent rate

(IAEA CMCs Identifier in the BIPM KCDB): EUR-RAD-IAEA-1010 and EUR-RAD-IAEA-1011

Ambient dose equivalent rate *Using DOL electrometer*	Type A	Type B	
	Uncertainty (%)		
Step 1: Reference standard			
Calibration from BIPM/PSDL		1.50	
Long term stability of the secondary standard		0.25	
Temperature and Pressure	0.03	0.10	
Current	0.06	0.10	
Monitor chamber	0.01		
Uniformity of radiation field		0.12	
Relative combined standard uncertainty in Step 1	*0.07*	*1.53*	
Step 2: Instrument to be calibrated			
Temperature and Pressure	0.03	0.10	
Electrometer reading	0.06	0.20	
Chamber positioning		0.03	
Monitor chamber	0.01		
Radiation quality		0.20	
Uniformity of radiation field		0.40	
Relative combined standard uncertainty in Step 2	*0.07*	*0.50*	
Relative combined standard uncertainty (Steps 1 + 2)	**0.10**	**1.61**	
Relative expanded uncertainty (k=2)		**3.3**	**%**

Table V

Estimated relative standard uncertainty in the IAEA calibration

^{137}Cs gamma radiation: Ambient dose equivalent rate

(IAEA CMCs Identifier in the BIPM KCDB): EUR-RAD-IAEA-1012

Ambient dose equivalent rate *Using DOL electrometer*	Type A	Type B	
	Uncertainty (%)		
Step 1: Reference standard			
Calibration from BIPM/PSDL		0.52	
Long term stability of the secondary standard		0.17	
Temperature and Pressure	0.03	0.10	
Current	0.05	0.10	
Relative combined standard uncertainty in Step 1	*0.06*	*0.57*	
Step 2: Instrument to be calibrated			
Temperature and Pressure	0.03	0.10	
Electrometer reading	0.06	0.20	
Chamber positioning		0.05	
Uniformity of radiation field		0.10	
Relative combined standard uncertainty in Step 2	*0.07*	*0.25*	
Combined standard uncertainty (Steps 1 + 2)	**0.09**	**0.62**	
Relative expanded uncertainty (k=2)		**1.2**	**%**

Table VI

Estimated relative standard uncertainty in the IAEA calibration

^{60}Co gamma radiation: Ambient dose equivalent rate

(IAEA CMCs Identifier in the BIPM KCDB): EUR-RAD-IAEA-1013

Ambient dose equivalent rate *Using DOL electrometer*	Type A	Type B *Uncertainty (%)*	
Step 1: Reference standard			
Calibration from BIPM/PSDL		0.29	
Long term stability of the secondary standard		0.05	
Temperature and Pressure	0.03	0.10	
Current	0.05	0.10	
Relative combined standard uncertainty in Step 1	*0.06*	*0.37*	
Step 2: Instrument to be calibrated			
Temperature and Pressure	0.03	0.10	
Electrometer reading	0.06	0.15	
Chamber positioning		0.05	
Uniformity of radiation field		0.10	
Relative combined standard uncertainty in Step 2	*0.07*	*0.21*	
Combined standard uncertainty (Steps 1 + 2)	***0.09***	***0.39***	
Relative expanded uncertainty (k=2)		**0.8**	**%**

Table VII

Estimated relative standard uncertainty in the IAEA calibration

ISO 4037 Narrow Spectrum Series: Personal dose equivalent rate

(IAEA CMCs Identifier in the BIPM KCDB): EUR-RAD-IAEA-1014 and EUR-RAD-IAEA-1015

Ambient dose equivalent rate *Using DOL electrometer*	Type A	Type B *Uncertainty (%)*	
Step 1: Reference standard			
Calibration from BIPM/PSDL		1.50	
Long term stability of the secondary standard		1.50	
Temperature and Pressure	0.03	0.1	
Current	0.5	0.05	
Monitor chamber	0.01		
Uniformity of radiation field			
Relative combined standard uncertainty in Step 1	*0.50*	*2.12*	
Step 2: Instrument to be calibrated			
Temperature and Pressure	0.03	0.1	
Current	0.5	0.05	
Chamber positioning		0.03	
Monitor chamber	0.01		
Radiation quality			
Uniformity of radiation field		0.5	
Relative combined standard uncertainty in Step 2	*0.50*	*0.51*	
Relative combined standard uncertainty (Steps 1 + 2)	***0.71***	***2.19***	
Relative expanded uncertainty (k=2)		**5**	**%**

Table VIII

Estimated relative standard uncertainty in the IAEA calibration

^{137}Cs gamma radiation: Personal dose equivalent rate

(IAEA CMCs Identifier in the BIPM KCDB): EUR-RAD-IAEA-1016

Ambient dose equivalent rate	Type A	Type B	
Using DOL electrometer	*Uncertainty (%)*		
Step 1: Reference standard			
Calibration from BIPM/PSDL		2.0	
Long term stability of the secondary standard		0.3	
Temperature and Pressure	0.03	0.1	
Current	0.5	0.05	
Uniformity of radiation field			
Relative combined standard uncertainty in Step 1	*0.50*	*2.03*	
Step 2: Instrument to be calibrated			
Temperature and Pressure	0.03	0.1	
Current	0.5	0.5	
Chamber positioning		0.03	
Uniformity of radiation field		0.5	
Relative combined standard uncertainty in Step 2	*0.50*	*0.71*	
Relative combined standard uncertainty (Steps 1 + 2)	**0.71**	**2.15**	
Relative expanded uncertainty (k=2)		**5**	**%**