RADIOTHERAPY 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 in terms of air kerma free in air, N_K, for low and medium energy X ray beams and for ^{60}Co gamma radiation. Calibrations in terms of absorbed dose to water for ^{60}Co gamma radiation are provided only for SSDLs and hospitals who have adopted a code of practice based on absorbed dose to water, such as IAEA TRS-398 [1]. Calibrations are either made for a system composed of an ionization chamber plus an electrometer (from here on called "system calibration") or for an ionization chamber only.

All therapy calibrations are performed by the substitution method [2] using the IAEA reference standard chamber. This reference standard is calibrated at the BIPM or a Primary Standards Dosimetry Laboratory (PSDL) participating in the Mutual Recognition Arrangement (MRA), every 3 years. For calibrations of the ionization chamber only, the current is measured with the IAEA reference electrometer. With 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 this influence quantity (see Section 4).

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

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 distance between the reference point and the source is always 1m (see Figures 1 and 2), except for low energy X ray beams where it is 0.5 m.

2 AIR KERMA CALIBRATIONS

2.1 ^{60}Co beam gamma radiation

The chamber, with its build-up cap, is positioned free in air, so that its reference point is on the central axis of the beam. The chamber axis is perpendicular to the central axis of the beam. The distance from the source to the reference point of the chamber is 1 m. The size of the radiation field (50 % isodose level) at the reference plane is 10 cm x 10 cm. Fig. 1 shows the set-up.
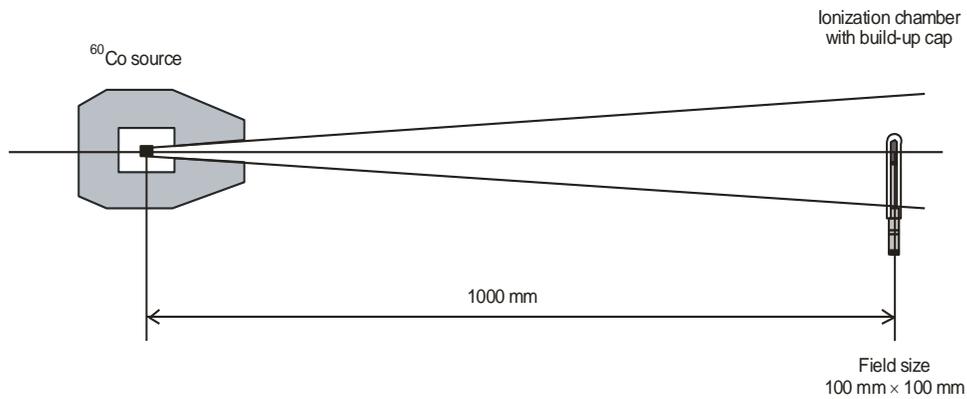
Fig. 1: Set-up for calibration in terms of air kerma for ^{60}Co gamma radiation

2.2   Medium energy X ray beams

The chamber, without its build-up cap, is positioned free in air, so that its reference point is on the central axis of the beam. The chamber 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 is 1 m. The size of the radiation field (50 % isodose level) at the reference plane is $\varnothing$ 10 cm. Fig. 2 shows the set-up.
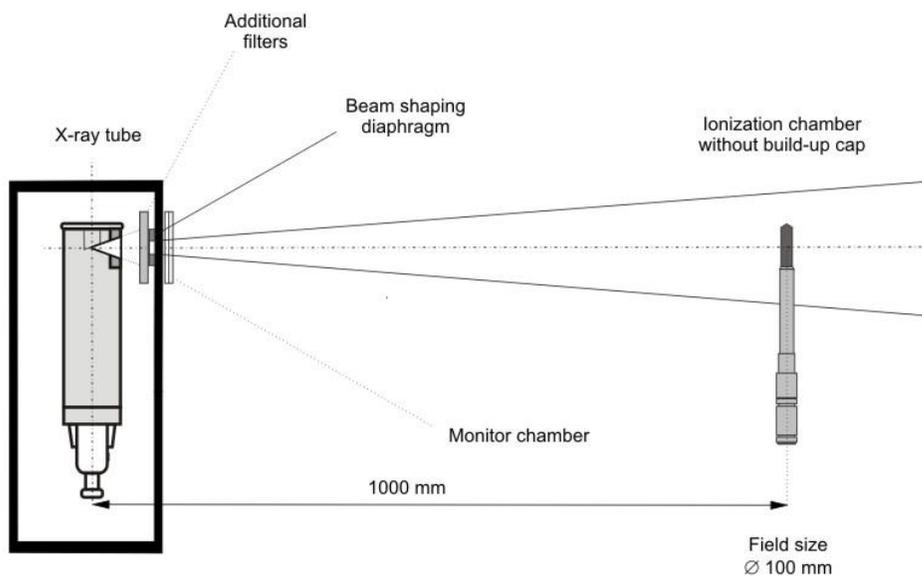

Fig. 2: Set-up for calibration in terms of air kerma for medium energy X ray beams.

The characteristics of the medium energy X ray beams used for calibration are given in Table I below [3].

TABLE I: Medium energy X ray beam qualities

Radiation quality No.	H.V. [kV]	Added filtration *		HVL	
		Al [mm]	Cu [mm]	Al [mm]	Cu [mm]
T1	100	3.65	-	4.03	
T2	135	0.96	0.25		0.52
T3	180	0.96	0.52		1.00
T4	250	0.96	1.69		2.51

*) Permanent filtration is 3 mm Be

2.3   Low energy X ray beams

The chamber, without its build-up cap, is positioned free in air, so that its reference point is on the central axis of the beam. The chamber 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 is 50 cm. The size of the radiation field (50 % isodose level) at the reference plane is $\varnothing$ 10 cm.

The characteristics of the low energy X ray beams used for calibration are given in Table II below [3].

TABLE II. Low energy X ray beam qualities

Radiation quality No	H.V. [kV]	Added filtration *		HVL	
		Al [mm]	Cu [mm]	Al [mm]	Cu [mm]
T7	10	-		0.04	
T8	30	0.20		0.16	
T9	25	0.36		0.23	
T10	50	1.03		1.00	
T11	50	4.02		2.37	

*) Permanent filtration is 0.8 mm Be

3.   ABSORBED DOSE TO WATER CALIBRATIONS IN ^{60}Co-60

Calibrations in terms of absorbed dose to water are available only for ^{60}Co gamma radiation.

The chamber, protected by a PMMA sleeve of 1 mm wall thickness, is positioned in the water phantom, so that its reference point is on the central axis of the beam. The chamber axis is perpendicular to the central axis of the beam. The serial number of the chamber on the stem is set so as to point towards the radiation source. The distance from the source to the reference point of the chamber is 1 m. The reference point of the chamber is at 5g/cm² water depth. The size of the radiation field (50 % isodose level) at the reference plane is 10 cm × 10 cm. Fig. 3 shows the set-up.
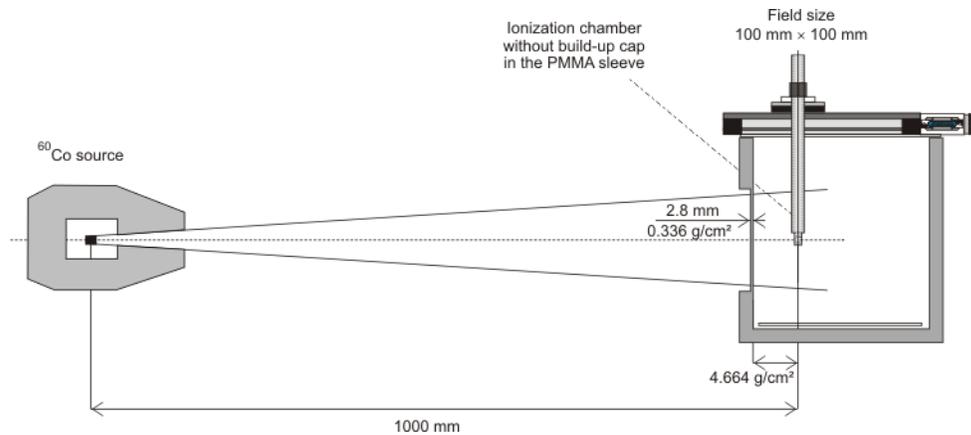
Fig. 3: Set-up for calibrations in terms of absorbed dose to water.

4. USE OF CALIBRATION COEFFICIENTS

The reference instruments calibrated at the IAEA can be used, in another radiation beam, to determine the beam output rate (air kerma or absorbed dose to water), 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 [4] should be made;
- The condition of measurement must not differ significantly from those of the calibration at the IAEA. Otherwise, additional corrections 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 or 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 [1]; 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 [1]

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 [5] and [6]. 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 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 2 components are further divided into sub-components and their classification (Type A or Type B) determined. Uncertainty budgets of IAEA calibrations are given in Tables III-VI.

6. REFERENCES

1. INTERNATIONAL ATOMIC ENERGY AGENCY, Absorbed Dose Determination in External Beam Radiotherapy: An International Code of Practice for Dosimetry based on Standards of Absorbed Dose to Water, Technical Report Series No. 398, IAEA, Vienna (2000).

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

3. BUREAU INTERNATIONAL DES POIDS ET MESURES, Qualités des Rayonnements Ionisants, in Com. Cons. Etalons des Ray. Ionisants (Section 1), BIPM, PARIS (1972), 2, R15.

4. 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

5. INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, GUIDE TO THE EXPRESSION OF UNCERTAINTY IN MEASUREMENT, ISO, GENEVA (1995).

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

Table III

Estimated relative standard uncertainty in the IAEA calibration
^{60}Co gamma radiation: Absorbed dose rate to water
Corresponding to CMC entry: IAEA-RAD-1001

Absorbed dose rate to water	Type A	Type B
Using DOL electrometer	*Uncertainty (%)*	
Step 1: Reference standard		
Calibration from BIPM/PSDL		0.30
Long term stability of the reference standard		0.23
Temperature and Pressure	0.03	0.10
Current	0.05	0.10
Relative combined standard uncertainty in Step 1	**0.06**	**0.40**
Step 2: Instrument to be calibrated		
Temperature and Pressure	0.03	0.10
Electrometer reading	0.05	0.20
Chamber positioning		0.10
Relative combined standard uncertainty in Step 2	**0.06**	**0.24**
Relative combined standard uncertainty (Steps 1 + 2)	**0.08**	**0.47**
Overall relative uncertainty		**0.48**

Relative expanded uncertainty (k=2)   **1.0**   **%**

Table IV

Estimated relative standard uncertainty in the IAEA calibration
^{60}Co gamma radiation: Air kerma rate
Corresponding to CMC entry: IAEA-RAD-1002

Air kerma rate	Type A	Type B
Using DOL electrometer	*Uncertainty (%)*	
Step 1: Reference standard		
Calibration from BIPM/PSDL		0.20
Long term stability of the secondary standard		0.20
Temperature and Pressure	0.03	0.10
Current	0.05	0.10
Relative combined standard uncertainty in Step 1	**0.09**	**0.32**
Step 2: Instrument to be calibrated		
Temperature and Pressure	0.03	0.10
Electrometer reading	0.05	0.20
Chamber positioning		0.01
Relative combined standard uncertainty in Step 2	**0.06**	**0.22**
Relative combined standard uncertainty (Steps 1 + 2)	**0.08**	**0.39**
Overall relative uncertainty		**0.40**
Relative expanded uncertainty (k=2)		**0.8** %

Table V

Estimated relative standard uncertainty in the IAEA calibration
Medium energy X ray beams: Air kerma rate
Corresponding to CMC entry: IAEA-RAD-1003

Air kerma rate	Type A	Type B
Using DOL electrometer	*Uncertainty (%)*	
Step 1: Reference standard		
Calibration from BIPM/PSDL		0.21
Long term stability of the secondary standard		0.20
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**	**0.32**
Step 2: Instrument to be calibrated		
Temperature and Pressure	0.06	0.10
Electrometer reading	0.06	0.20
Chamber positioning		0.01
Monitor chamber	0.01	
Beam quality		0.06
Relative combined standard uncertainty in Step 2	**0.09**	**0.23**
Relative combined standard uncertainty (Steps 1 + 2)	**0.12**	**0.39**
Overall relative uncertainty		**0.42**

Relative expanded uncertainty (k=2)   **0.8**   **%**

Table VI

Estimated relative standard uncertainty in the IAEA calibration
Low energy X ray beams: Air kerma rate
Corresponding to CMC entry: IAEA-RAD-1004

Air kerma rate	Type A	Type B
Using DOL electrometer	*Uncertainty (%)*	
Step 1: Reference standard		
Calibration from BIPM/PSDL		0.20
Long term stability of the secondary standard		0.20
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**	**0.32**
Step 2: Instrument to be calibrated		
Temperature and Pressure	0.06	0.10
Electrometer reading	0.06	0.20
Chamber positioning		0.01
Monitor chamber	0.01	
Beam quality		0.06
Relative combined standard uncertainty in Step 2	**0.09**	**0.23**
Relative combined standard uncertainty (Steps 1 + 2)	**0.12**	**0.39**
Overall relative uncertainty		**0.41**

Relative expanded uncertainty (k=2)   **0.8   %**