APPENDIX TO IAEA CALIBRATION CERTIFICATE

RADIATION PROTECTION IONIZATION CHAMBER CALIBRATION PROCEDURES AT THE IAEA DOSIMETRY LABORATORY

1 INTRODUCTION

Ionization chambers and electrometers are calibrated at the IAEA Dosimetry Laboratory (DOL) in terms of air kerma (K_{air}) in ^{60}Co, ^{137}Cs gamma radiations and ISO 4037 X-ray narrow spectra series [1]. 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.

The International Commission on Radiation Units and Measurements (ICRU) published the Report 90 "*Key Data for Ionizing-Radiation Dosimetry: Measurement Standards and Applications*" in October 2016 [2]. This report recommends revised values and uncertainties for some physical data required for realization of air kerma, reference air kerma and absorbed dose to water quantities of photon radiation by primary measurement standards. Details of these changes were published in 2018 [3]. The IAEA's dosimetry standards are traceable to BIPM and PTB. The change to the IAEA standards were implemented for all calibrations performed after 1st of January 2019. The implementation was done either through a new calibration of the IAEA standard or using values given in the notification letter [4].

2 CALIBRATION PROCEDURES

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.

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.

2.1 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. Some typical geometries are given in FIG 1. 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 2.5 m for ^{137}Cs and ^{60}Co gamma beams and for X-ray beams.

The calibration coefficients refer to air temperature T = 20°C, air pressure 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.

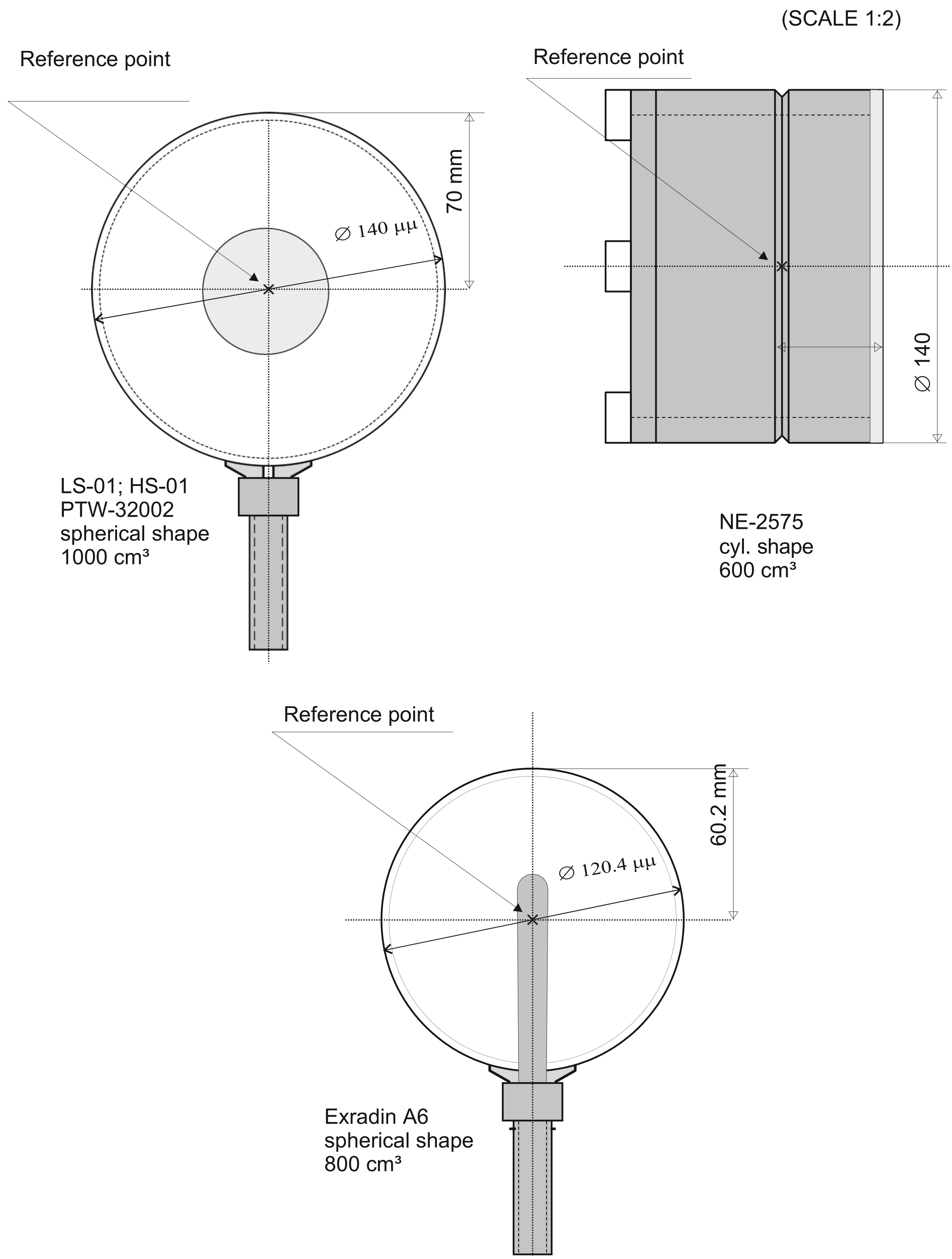

FIG. 1. Reference points of some typical reference ionization chambers used for radiation protection calibrations.

2.2 CALIBRATIONS IN TERMS OF AIR KERMA

2.2.1 ^{137}Cs and ^{60}Co gamma radiation beam set-up

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 ∅ 670 mm. FIG. 2 shows the set-up.

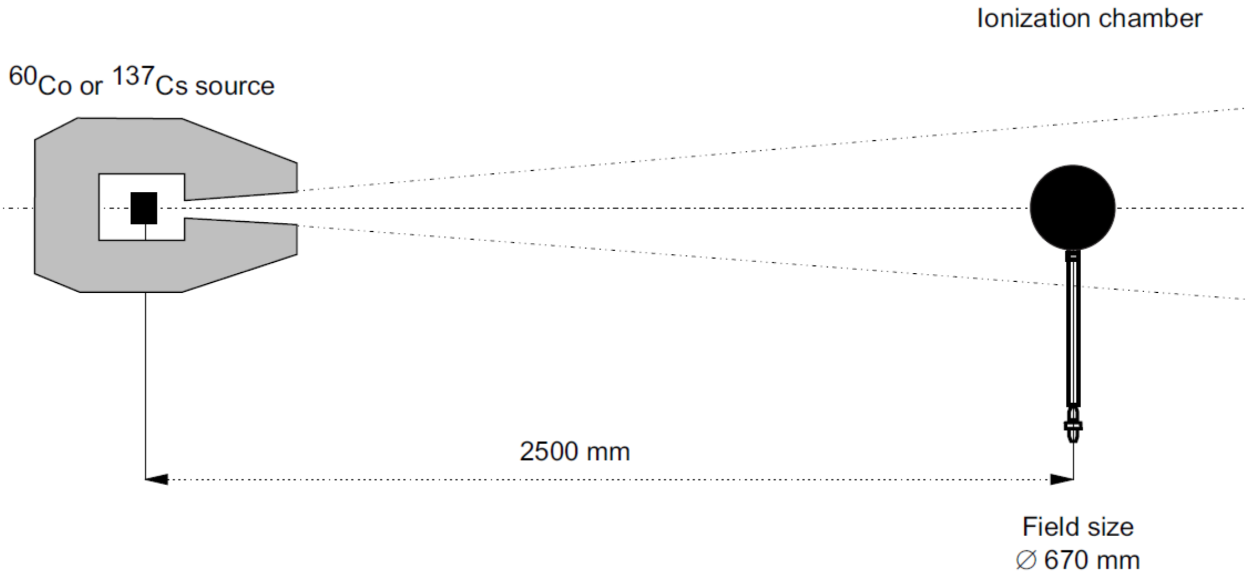

FIG. 2. Set-up for calibration in terms of air kerma for ^{137}Cs and ^{60}Co gamma beams.

2.2.2 X-ray beam set-up

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 ∅ 340 mm. FIG. 3 shows the set-up.

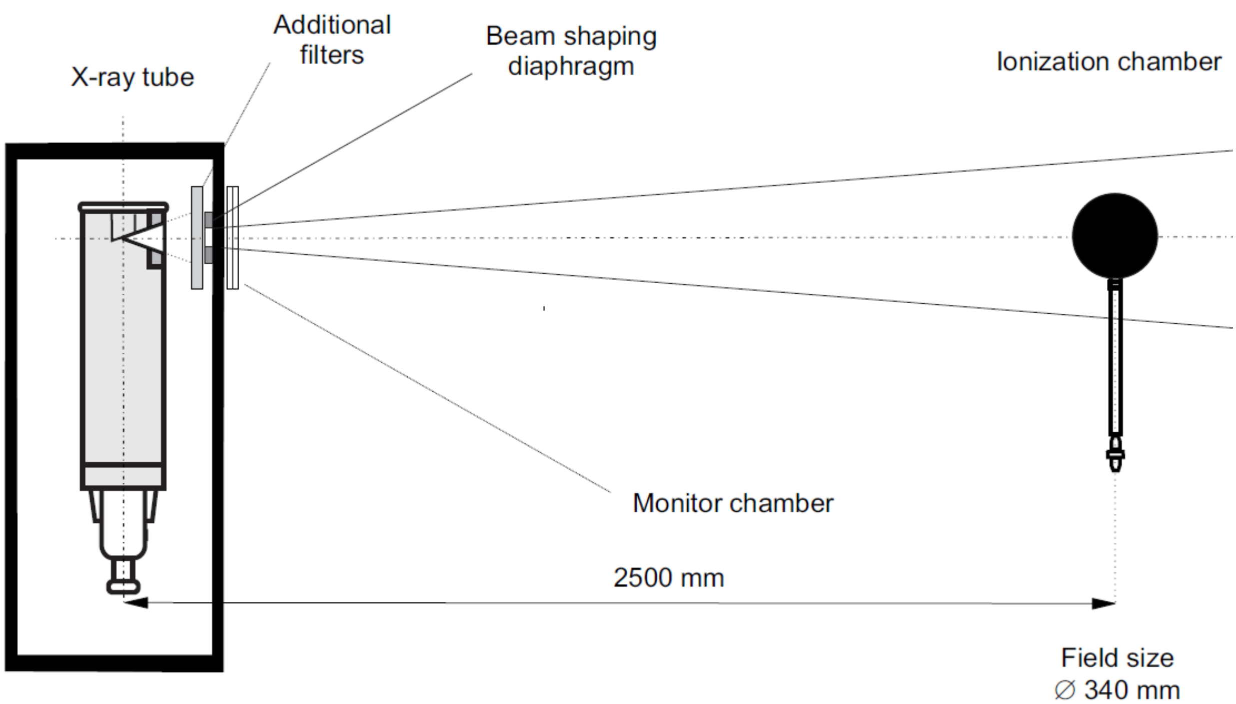

FIG. 3. Set-up for calibration in terms of air kerma for X-ray beams.

TABLE I Radiation qualities at the IAEA for the ISO 4037 Narrow Spectrum Series (tungsten anode) [1].

Radiation quality	Tube voltage [kV]	Added filtration *				1st HVL	
		Al [mm]	Cu [mm]	Sn [mm]	Pb [mm]	Al [mm]	Cu [mm]
N40	40	4.0	0.22			2.69	
N60	60	4.0	0.74				0.25
N80	80	4.0	2.0				0.59
N100	100	4.0	5.0				1.09
N120	120	4.0	5.0	1.0			1.75
N150	150	4.0		2.5			2.46
N200	200	4.0	2.0	3.0	1.0		4.14
N250	250	4.0		2.1	3.0		5.36
N300	300	4.0		3.0	5.0		6.32

*) Inherent filtration is 3 mm Be

3 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), 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 [7] 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 [8]; 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 [8].

4 CALIBRATION UNCERTAINTIES

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

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)

Uncertainty component	*Uncertainty (%)*	
	Type A	Type B
Step 1: Reference standard		
Calibration from BIPM/PSDL		0.52
Long term stability of the secondary standard		0.29
Spectral difference PSDL/IAEA		0.17
Current measurement - Ref. Std.	0.05	0.10
Temperature and pressure correction - Ref. Std.		0.05
Current measurement - Monitor	0.05	0.10
Temperature and pressure correction - Monitor		0.05
Relative combined standard uncertainty in Step 1	*0.07*	*0.64*
Step 2: Instrument to be calibrated		
Current measurement - User Chamber	0.06	0.20
Temperature and pressure correction - User Chamber		0.05
Current measurement - Monitor	0.05	0.10
Temperature and pressure correction - Monitor		0.05
Stability of the monitor chamber		0.09
Difference in radial non-uniformity of the beam		0.09
Chamber positioning		0.01
Relative combined standard uncertainty in Step 2	*0.08*	*0.26*
Relative combined standard uncertainty (Steps 1 + 2)	*0.11*	*0.69*
Standard combined uncertainty (k = 1)	*0.70*	
Relative expanded uncertainty (*k* = 2)	**1.4**	

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)

Uncertainty component	*Uncertainty (%)* Type A	Type B
Step 1: Reference standard		
Calibration from BIPM/PSDL*		0.22
Long term stability of the secondary standard		0.20
Spectral difference PSDL/IAEA		0.00
Current measurement - Ref. Std.	0.05	0.10
Temperature and pressure correction - Ref. Std.		0.05
Relative combined standard uncertainty in Step 1	*0.05*	*0.32*
Step 2: Instrument to be calibrated		
Current measurement - User Chamber	0.06	0.20
Temperature and pressure correction - User Chamber		0.05
Difference in radial non-uniformity of the beam		0.09
Chamber positioning		0.01
Relative combined standard uncertainty in Step 2	*0.06*	*0.23*
Relative combined standard uncertainty (Steps 1 + 2)	*0.08*	*0.39*
Standard combined uncertainty (k = 1)	*0.40*	
Relative expanded uncertainty (k = 2)	**0.8**	

**According to ICRU 90 [3] the uncertainty for ^{60}Co is decreasing, however, it will be implemented only after the new calibration of the IAEA standards.*

5 REFERENCES

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