BRACHYTHERAPY WELL-TYPE IONIZATION CHAMBER CALIBRATION PROCEDURES AT THE IAEA DOSIMETRY LABORATORY

1 INTRODUCTION

Well-type ionization chambers are typically used for brachytherapy dosimetry [1,2]. The IAEA Dosimetry Laboratory (DOL) provides calibrations for well-type ionization chambers and electrometers in terms of reference air kerma rate, for Low Dose Rate Brachytherapy (LDRBT) – ^{137}Cs sources and for High Dose Rate Brachytherapy (HDRBT) – ^{60}Co and ^{192}Ir sources.

Calibrations are performed using the reference air kerma rates that are measured using the appropriate IAEA reference standard chamber. The reference air kerma rate of the LDRBT sources was determined and certified by the Primary Standards Dosimetry Laboratory (PSDL) of Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig, Germany. The IAEA HDRBT reference standards are also calibrated at the PTB.

In 2016 the International Commission on Radiation Units and Measurements (ICRU) published the Report 90 “Key Data for Ionizing-Radiation Dosimetry: Measurement Standards and Applications” [3]. This report recommends revised values and uncertainties for some physical data required for realization of reference air-kerma rate quantity by primary measurement standards. The change to the IAEA standards has been implemented on all calibrations performed after 1st of January 2019.

Calibrations are either made for a system composed of an ionization chamber plus an electrometer (hence system calibration) or for an ionization chamber only. For system calibrations, the internal bias supply of the user electrometer is used to apply polarizing voltage. For calibrations of the well-type ionization chamber only, the ionization current is measured with an IAEA reference electrometer.

2 CALIBRATIONS IN TERMS OF REFERENCE AIR KERMA RATE

The calibration coefficient N_K of the system is determined as the ratio of the reference air kerma rate $\dot{K}_R$ obtained with the IAEA reference standard, and the reading M of the user equipment, corrected for recombination and to the reference ambient conditions (atmospheric pressure P, and temperature T).

2.1 Reference conditions

The ambient conditions (temperature, pressure and humidity), prevailing at the IAEA Laboratory during the calibrations, are monitored continuously. The relative air humidity (R.H.) is kept between 45% and 55%. Therefore, no correction is applied for the humidity. The calibration coefficients are established for the reference conditions T = 20.0°C, P = 101.325 kPa and R.H. = 50.0%.

2.2 Calibration sources and afterloader used at the DOL

Details of the LDRBT and HDRBT sources used at the DOL are shown in Table 1. The reference air kerma rates are traceable to the primary standards at the PTB (Germany). The SagiNova® (Eckert and Ziegler, Bebig) afterloader is used to operate the HDRBT sources (either ^{60}Co or ^{192}Ir).

Table 1. Low and high dose rate (LDR and HDR) brachytherapy sources of the IAEA.

Level	**Radionuclide**	**Source model**	**Half-life value used** [http://www.nucleide.org/DDEP_WG/DDEPdata.htm]
HDR	^{60}Co	Co0.A86	5.2711 years
HDR	^{192}Ir	Ir2.A85-2	73.827 days
LDR	^{137}Cs	CSM-3	30.05 years
LDR	^{137}Cs	CSM-40	30.05 years

2.3 Positioning

The well-type chamber during calibration is positioned in the room, more than 1 m from the adjacent walls, and approximately 0.9 m from the floor level.

2.3.1 HDRBT

The central point of the source is positioned on the central axis of the well-type chamber in the source holder approximately at the point of maximum response of a well-type ionization chamber (so called "sweet spot"). Its position is determined by measurements as the distance of the central point of the source from the bottom of the source holder (Figure 1). It is reported in the Calibration Certificate, however the user needs to determine the point of measurement at the actual conditions (source type, source holder, etc.).

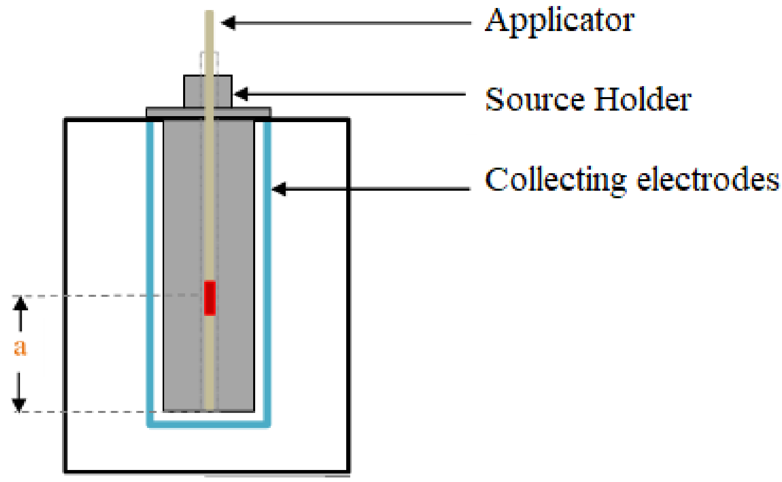

Figure 1: *Measurement setup for the calibration of the well-type chamber using HDRBT sources. The height "a" is the point of maximum response of a well-type ionization chamber "sweet spot".*

For well-type chambers used for HDRBT, the calibration is carried out with the source driven into the applicator LAA-1400 GYN with an external diameter of 3 mm, which is inserted into the source holder provided by the user. If other applicator or source holder is used, it is reported as a comment in the calibration certificate.

2.3.2 LDRBT

For LDRBT measurements the point of the maximum response of the well-type chamber is not measured. For chambers that are identical to the IAEA chamber (Standard Imaging type HDR1000 Plus), the sources are inserted in to the removable source holder, model 70020, which has a 42 mm built-in spacer. If other spacer length is used, this information is added as a comment in the Calibration Certificate.

2.4 Polarizing voltage

The polarity and magnitude of polarizing voltage used during the calibration at the IAEA are reported in the calibration certificate.

2.5 Correction for ion recombination

2.5.1 HDBRT

For HDRBT sources, ^{60}Co and ^{192}Ir, the calibration coefficients determined at the IAEA are corrected for ion recombination. The correction is determined as a part of the calibration procedure for each chamber calibrated.

2.5.2 LDR

For LDBRT sources the calibration coefficients determined at the IAEA are not corrected for recombination. The correction is almost negligible (due to low air kerma rate) and is taken into account in the uncertainty budget. If the instrument is used with sources whose reference kerma rate is significantly different from those listed in the calibration certificate, the user is advised to correct for this effect.

2.6 Calibration uncertainty

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 [4] and [5]. All sources of uncertainty are identified and classified as Type A or Type B, as per ISO classification. The uncertainty associated with 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 reference kerma rate of the brachytherapy source, and
2. uncertainties related to the instruments to be calibrated (user's instrument). Instruments calibrated at the IAEA are reference class instruments and typical uncertainties are assumed for these instruments in the uncertainty budget.

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 2 and 3.

Table 2. Estimated relative standard uncertainty in the IAEA calibration
^{137}Cs gamma radiation, low dose rate brachytherapy: Reference air kerma rate.

Reference air kerma rate	*Uncertainty (%)* Type A	Type B
Step 1: Reference standard		
Calibration from BIPM/PSDL		1.00
Long term stability of the secondary standard		0.40
Decay correction		0.20
Relative combined standard uncertainty in Step 1	-	*1.10*
Step 2: Instrument to be calibrated		
Current measurement	0.06	0.20
Temperature and pressure correction		0.05
Setup and source positioning		0.17
Relative combined standard uncertainty in Step 2	*0.06*	*0.27*
Relative combined standard uncertainty (Steps 1 + 2)	*0.06*	*1.13*
Standard combined uncertainty (k = 1)	*1.13*	
Relative expanded uncertainty (k = 2)		**2.3**

Table 3. Estimated relative standard uncertainty in the IAEA calibration
^{192}Ir and ^{60}Co gamma radiation, high dose rate brachytherapy: Reference air kerma rate.

Reference air kerma rate	*Uncertainty (%)* Type A	Type B
Step 1: Reference standard		
Calibration from BIPM/PSDL		1.25
Long term stability of the secondary standard		0.13
Current measurement	0.05	0.12
Recombination		0.04
Decay correction		0.20
Temperature and pressure correction		0.05
Setup and source positioning		0.17
Relative combined standard uncertainty in Step 1	*0.05*	*1.29*
Step 2: Instrument to be calibrated		
Current measurement	0.06	0.20
Recombination		0.04
Decay correction		0.20
Temperature and pressure correction		0.05
Setup and source positioning		0.17
Relative combined standard uncertainty in Step 2	*0.06*	*0.34*
Relative combined standard uncertainty (Steps 1 + 2)	*0.08*	*1.33*
Standard combined uncertainty (k = 1)	*1.34*	
Relative expanded uncertainty (k = 2)		**2.7**

3 USE OF CALIBRATION COEFFICIENTS

The reference instruments calibrated at the IAEA can be used, with other sources, to determine the reference air kerma rate $\dot{K}_R$ as

$$\dot{K}_R = N_K \, . M . k_{T,p} \, .k_{pol} \, . k_{ion} \, .k_{appl} . k_{sg}$$

where

N_K RAKR calibration coefficient,
M ionization current measured,
$k_{T,p}$ air pressure and temperature correction,
k_{pol} polarity effect of the bias voltage correction,
k_{ion} unsaturated ion collection efficiency- charge lost due to recombination,
k_{appl} correction factor accounting for attenuation in the applicator and/or source holder wall (if different from that/those used during calibration),
k_{sg} source geometry correction (if the source model is different from the one used during calibration).

If the measurement conditions differ significantly from the reference conditions at the IAEA, additional corrections for the difference may be needed. In particular:

- **Relative humidity**
  Outside the range of 30% – 70%, corrections based on [6] should be made.

- **Radiation source, holders and applicators**
  Some information on this effect and correction factors can be found in [7].

- **Source activity**
  The user is advised to do a correction due to ion recombination, especially for HDRBT.

- **Polarity**
  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.

4 REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Calibration of photon and beta ray sources used in brachytherapy, Guidelines on standardized procedures at Secondary Standards Dosimetry Laboratories (SSDLs) and hospitals, IAEA-TECDOC-1274, IAEA, Vienna (2002).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Radiation Oncology Physics: A Handbook for Teachers and Students, IAEA, Vienna (2005)

[3] INTERNATIONAL COMMISSION ON RADIATION UNITS AND MEASUREMENTS Key data for ionizing-radiation dosimetry: Measurement standards and applications J. ICRU 14 Report 90, Oxford University Press (2016)

[4] 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

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

[6] 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

[7] Shipley D R, Sander T, Nutbrown R F, Source geometry factors for HDR ^{192}Ir brachytherapy secondary standard well-type ionization chamber calibrations, Phys. Med. Biol. 60 (2015) 2573-2586.