RADIATION THERAPY IONIZATION CHAMBER CALIBRATION PROCEDURES AT THE IAEA DOSIMETRY LABORATORY

1 INTRODUCTION

Reference ionization chambers and electrometers are calibrated at the IAEA Dosimetry Laboratory (DOL) in terms of air kerma K_{air}, for low and medium energy X-ray beams and for ^{60}Co gamma radiation. Calibrations in terms of absorbed dose to water D_w 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]. All therapy calibrations are performed by the substitution method [2] using the IAEA reference standard chambers. 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 [3]. This report recommends revised values and uncertainties for some physical data required for realization of air kerma, reference air-kerma rate and absorbed dose to water quantities of photon radiation by primary measurement standards. Details of these changes were published in 2018 [4]. The IAEA's dosimetry standards are traceable to BIPM and PTB and the change to the IAEA standards has been implemented on 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 [5].

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 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 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. Correspondingly, the absorbed dose to water calibration coefficient N_D [mGy/scale unit] is determined as the ratio of the absorbed dose to water rate [mGy/s] obtained with the IAEA reference standard, and the reading $\dot{M}$ [scale units/s] of the dosimeter.

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 chambers. If the chamber stem has a mark, this mark is oriented towards the radiation source during the calibration.

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.

2.2 CALIBRATION IN TERMS OF AIR KERMA

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

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.

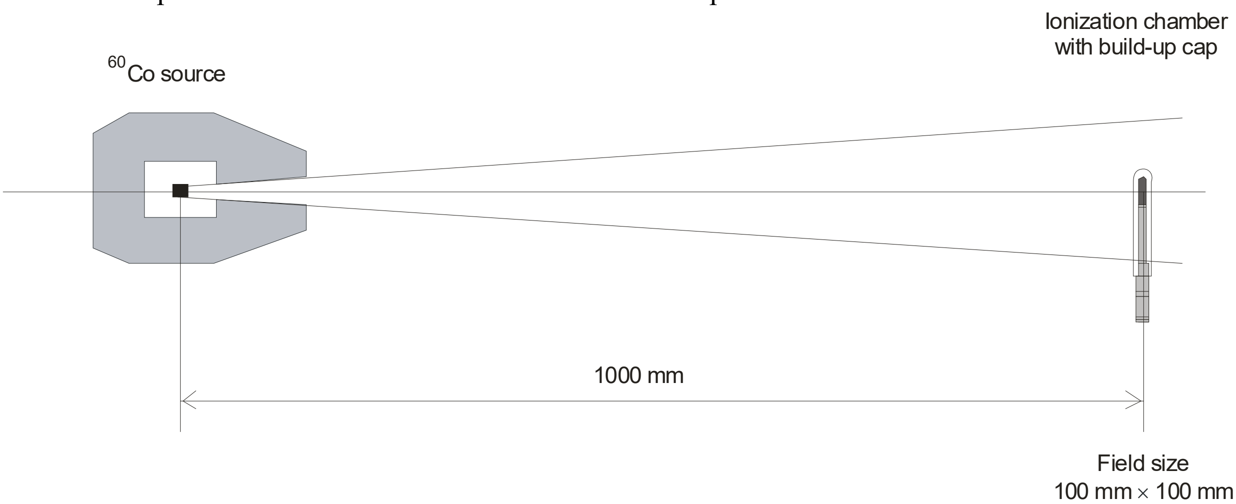


FIG. 1. Set-up for calibration in terms of air kerma for ^{60}Co gamma radiation.

2.2.2 Medium energy X-ray beam set-up

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 ∅ 10 cm. FIG. 2 shows the set-up. The characteristics of the medium energy X-ray beams used for calibration are given in TABLE I below [6].

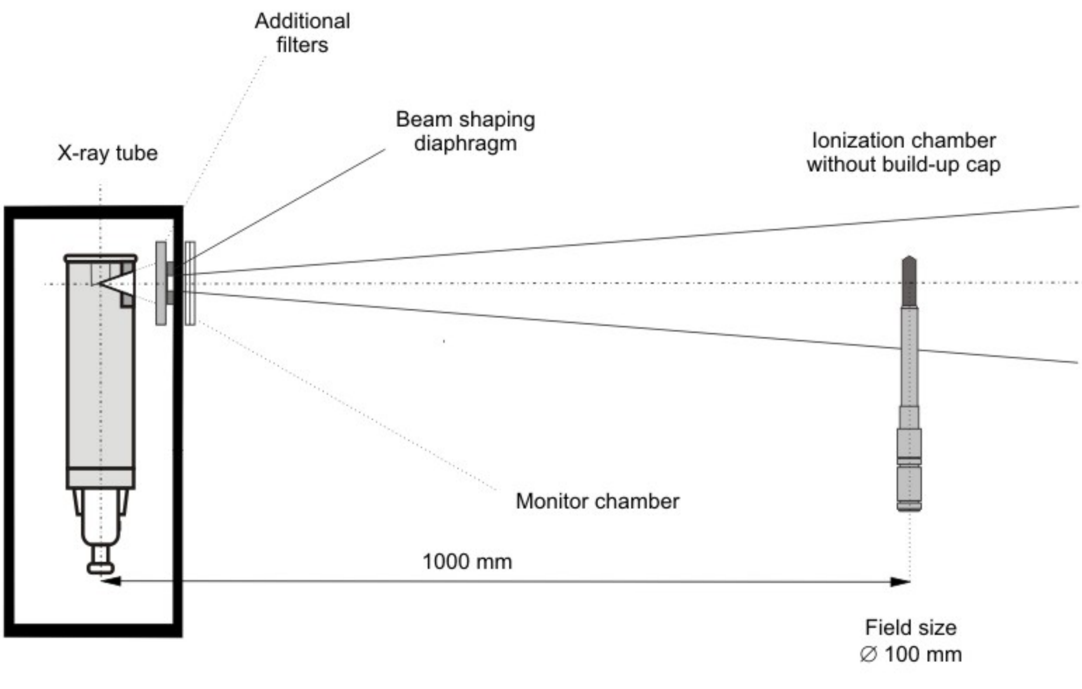


FIG. 2. Set-up for calibration in terms of air kerma for medium energy X-ray beams.

TABLE I Medium energy X-ray radiation qualities with tungsten anode

Radiation quality No.	Tube voltage [kV]	Added filtration *		1st 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

*) Inherent filtration is 3 mm Be

2.2.3 Low energy X-ray beam set-up

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 60 cm. The size of the radiation field (50% isodose level) at the reference plane is ∅ 10 cm. The characteristics of the low energy X-ray beams used for calibration are given in TABLE II below [6].

TABLE II Low energy X-ray radiation qualities with tungsten anode

Radiation quality No	Tube voltage [kV]	Added filtration *		1st 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	

*) Inherent filtration is 0.8 mm Be

2.3 CALIBRATION IN TERMS OF ABSORBED DOSE TO WATER

2.3.1 ^{60}Co gamma radiation beam set-up

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 its 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 5 g/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.

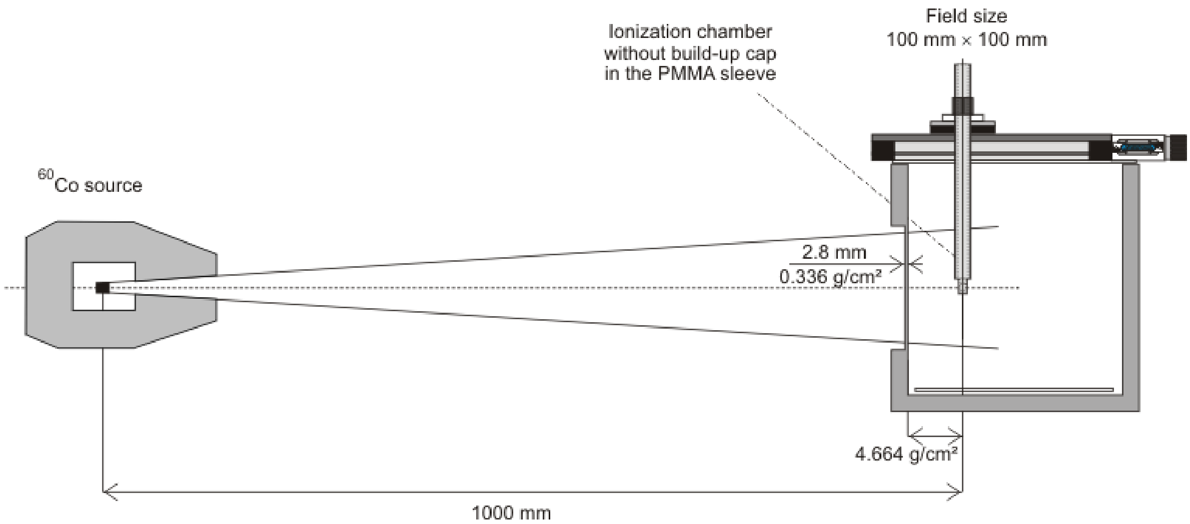


FIG. 3. Set-up for calibrations in terms of absorbed dose to water.

3 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 [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 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].

4 CALIBRATION UNCERTAINTIES

The methodology for estimating the uncertainties of calibrations at the IAEA Dosimetry Laboratory is based on the recommendations of the JCGM [8] and IAEA [9] guides on uncertainty and. All sources of uncertainty are identified and classified as Type A or Type B, as per JCGM 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 or absorbed dose to water 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.

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 III-VI.

Table III

Estimated relative standard uncertainty in the IAEA calibration

^{60}Co gamma radiation: Absorbed dose rate to water

(IAEA CMCs Identifier in the BIPM KCDB): EUR-RAD-IAEA-1001

Uncertainty component	*Uncertainty (%)*	
	Type A	Type B
Step 1: Reference standard		
Calibration from BIPM/PSDL*		0.20
Long term stability of the secondary standard		0.23
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		0.00
Chamber positioning		0.06
Relative combined standard uncertainty in Step 2	*0.06*	*0.21*
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**	

This uncertainty was decreased due changes related to ICRU 90 [3] implementation and the value is lower that stated in the IAEA CMCs is the KCDB. The uncertainty value of 1.0% will still be used in the certificates until the CMCs have been updated.

Table IV

Estimated relative standard uncertainty in the IAEA calibration

^{60}Co gamma radiation: Air kerma rate

(IAEA CMCs Identifier in the BIPM KCDB): EUR-RAD-IAEA-1002

Uncertainty component	*Uncertainty (%)*	
	Type A	Type B
Step 1: Reference standard		
Calibration from BIPM/PSDL*		0.13
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*	*0.26*
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		0.00
Chamber positioning		0.01
Relative combined standard uncertainty in Step 2	*0.06*	*0.21*
Relative combined standard uncertainty (Steps 1 + 2)	*0.08*	*0.34*
Standard combined uncertainty (k = 1)	*0.34*	
Relative expanded uncertainty (k = 2)	**0.7**	

* *This uncertainty was decreased due changes related to ICRU 90 [3] implementation and the value is lower that stated in the IAEA CMCs is the KCDB. The uncertainty value of 0.8% will still be used in the certificates until the CMCs have been updated.*

Table V

Estimated relative standard uncertainty in the IAEA calibration

Low energy X-ray beams: Air kerma rate

(IAEA CMCs Identifier in the BIPM KCDB): EUR-RAD-IAEA-1003)

Uncertainty component	*Uncertainty (%)*	
	Type A	Type B
Step 1: Reference standard		
Calibration from BIPM/PSDL		0.40
Long term stability of the secondary standard		0.20
Spectral difference PSDL/IAEA		0.06
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*	*0.48*
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		0.00
Chamber positioning		0.01
Relative combined standard uncertainty in Step 2	*0.08*	*0.25*
Relative combined standard uncertainty (Steps 1 + 2)	*0.11*	*0.54*
Standard combined uncertainty (k = 1)	*0.55*	
Relative expanded uncertainty (*k* = 2)	**1.1**	

Table VI

Estimated relative standard uncertainty in the IAEA calibration

Medium energy X-ray beams: Air kerma rate

(IAEA CMCs Identifier in the BIPM KCDB): EUR-RAD-IAEA-1004)

Uncertainty component	*Uncertainty (%)*	
	Type A	Type B
Step 1: Reference standard		
Calibration from BIPM/PSDL		0.39
Long term stability of the secondary standard		0.20
Spectral difference PSDL/IAEA		0.06
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*	*0.47*
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		0.00
Chamber positioning		0.01
Relative combined standard uncertainty in Step 2	*0.08*	*0.25*
Relative combined standard uncertainty (Steps 1 + 2)	*0.11*	*0.53*
Standard combined uncertainty (k = 1)	*0.54*	
Relative expanded uncertainty (k = 2)	**1.1**	

5 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). http://www-pub.iaea.org/MTCD/Publications/PDF/TRS398_scr.pdf

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Calibration of Reference Dosimeters for external beam Radiotherapy, Technical Report Series No. 469, IAEA, Vienna (2009). http://www-pub.iaea.org/MTCD/Publications/PDF/trs469_web.pdf

[3] International Commission on Radiation Units and Measurements 2016 Key data for ionizing-radiation dosimetry: Measurement standards and applications J. ICRU 14 Report 90, Oxford University Press (2016)

[4] David Burns, Cecillia Kessler, BIPM, Re-evaluation of the BIPM international dosimetry standards on adaption of the recommendation of ICRU 90 Metrologia 55 (2018) R21-R26

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Notification of changes to the IAEA dosimetry standards according to ICRU Report 90, SSDL Newsletter No. 69, March 2019. https://www.iaea.org/publications/search/type/ssdl-newsletter

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

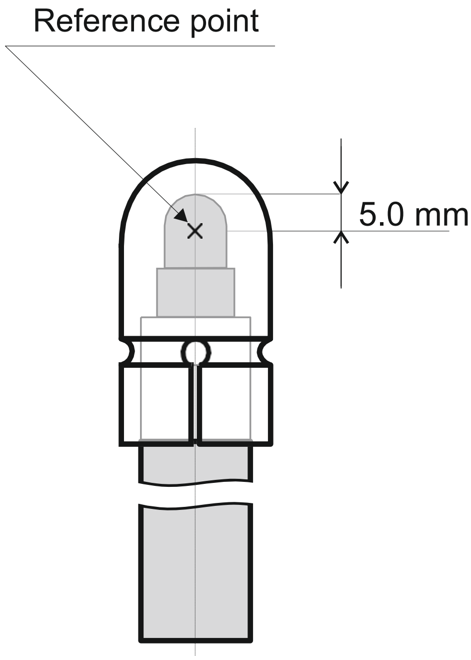
[7] BUREAU INTERNATIONAL DES POIDS ET MESURES, Correction d'humidité, in Com. Cons. Etalons des Ray. Ionisants (Section 1), BIPM, PARIS (1977), 4, R(I)6

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

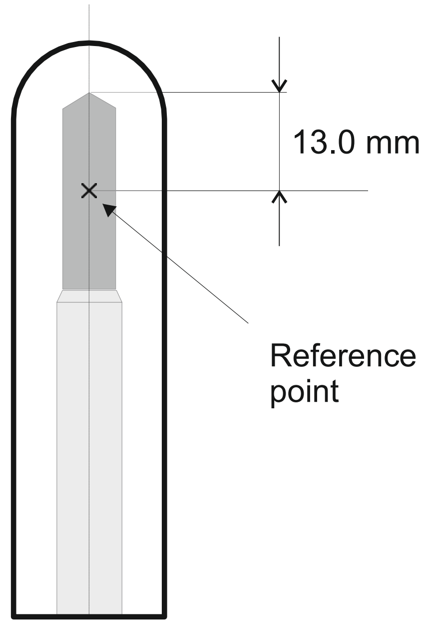
[9] INTERNATIONAL ATOMIC ENERGY AGENCY, Measurement Uncertainty A Practical Guide for Secondary Standards Dosimetry Laboratories, TECDOC-1585, IAEA, VIENNA (2008).

THERAPY-LEVEL IONIZATION CHAMBERS

(SCALE 1:1)



NE-2561; NE-2611
cyl. shape; 0.325 cm³



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PTW-30001; PTW-30012
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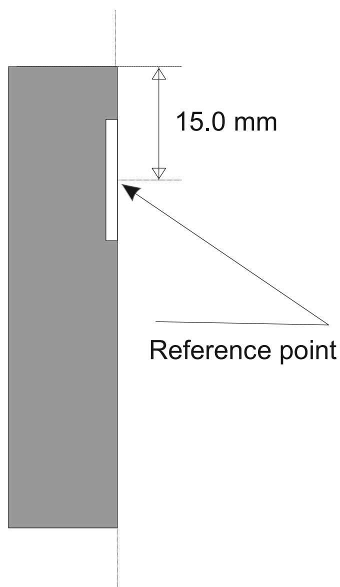

PTW-23344
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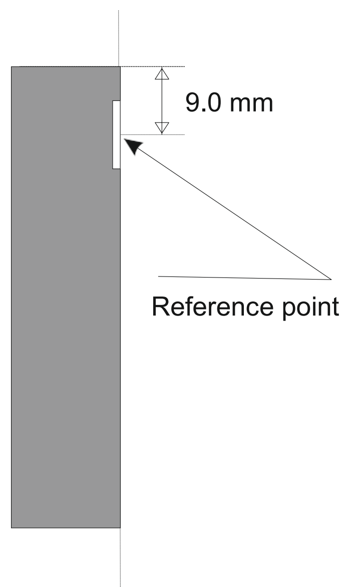
chamber 0.2 cm³



PTW-23342
plane parallel
chamber 0.02 cm³