

IONIZING RADIATION

approx. 1,3 m flex.

47,6 rigid

5,275

28

90°

$\phi 4,3$

$\phi 7$

$\phi 6,99$

$\phi 6,9$

2,4

# DETECTORS

Including Codes of Practice

2011

PTW

# Looking back on a long history...

PTW-Freiburg is an internationally operating company, manufacturing and marketing specialized dosimetry and quality control equipment for the medical radiology and health physics market. Founded in 1922, the company is located in Freiburg on the western side of the famous Black Forest mountains in southwestern Germany.

## Our Operations

PTW-Freiburg designs, develops, manufactures and distributes high quality dosimetry and QC equipment mainly for use in the medical field, especially in radiation therapy, diagnostic radiology and nuclear medicine. The development and production of mechanical, electronic and software components are all done in house. Our products, especially the PTW ionization chambers, are well known throughout the world and are recognized for their workmanship and high level of quality. PTW-Freiburg is the market leader in its major product lines. The PTW distribution is organized internationally. A number of daughter companies and exclusive PTW representations are established in many countries around the world. We cooperate closely with official public agencies worldwide, and we participate actively in national and international work groups for the standardization of devices and procedures for dose measurement and quality control in radiation medicine.

## Our History

In 1922, twenty-seven years after Röntgen discovered the X-rays, Professor Hammer from the Physics Institute of Freiburg University founded PTW to produce and market his development of an X-ray dosimeter based on the electrostatic relais, a revolutionary new electromechanical component for measuring very small electrical charges. In 1927, Dr. Herbert Pychlau took over the company and developed it during four decades into an internationally recognized manufacturer of quality dosimeters for medical radiology. PTW has developed and manufactured many generations of up-to-date products over the years, based on the newest technology. The company has grown continuously. Today, more than 230 employees worldwide achieve an annual turnover of 35 Million EUR.

## The evolvement of radiation detectors

1922 Compact chambers with fixed preamplifier	<i>Hammer Dosimeter</i>
1927 Barrel type chambers as secondary transfer standards	<i>Küstner Dosimeter</i>
1928 Shadow-free chambers	<i>Schattenfreie Kammer</i>
1930 Pressurized radiation protection chambers	<i>Streustrahlenkammer</i>
1932 Continuous monitoring therapy chambers	<i>Tubusrelais</i>
1933 Water protected chambers for water phantom use	<i>Wasserphantom</i>
1933 Capacitor chambers for „wireless“ measurement	<i>Ionognom</i>
1936 Waterproof sealed chambers for brachytherapy	<i>Mikrokammern</i>
1950 Flat chambers for diagnostic radiology and mammography	<i>Flachkammern</i>
1959 Transparent chambers for dose area product measurement	<i>DIAMENTOR®</i>
1971 Pressurized well type chambers for nuclear medicine	<i>CURIEMENTOR®</i>
1977 Parallel plate low energy chambers	<i>Soft X-ray Chambers</i>
1980 Dedicated electron chamber	<i>Markus Chamber</i>
1985 Single and multiple detectors for brachytherapy	<i>AM6 Detectors</i>
1989 Pencil chamber for computed tomography	<i>CT Chamber</i>
1993 Diamond detector for water phantom use	<i>Diamond Detector</i>
1995 Liquid filled ionization chamber linear array	<i>LA 48 Array</i>
1995 Diode detectors for diagnostic radiology	<i>DIADOS Detectors</i>
1996 Well type chambers for brachytherapy source measurement	<i>HDR Chambers</i>
1997 Ultracompact ionization chambers	<i>PinPoint Chambers</i>
1999 Dosimetry diodes for water phantom use	<i>Dosimetry Diodes</i>
2002 4 $\pi$ flat chamber for seed measurement	<i>SourceCheck</i>
2003 2D ionization chamber array	<i>2D-ARRAY seven29</i>
2005 Ultracompact chamber with 3D characteristics	<i>PinPoint 3D Chamber</i>
2005 Dedicated proton chamber	<i>Bragg Peak Chamber</i>
2007 Liquid filled low volume chamber	<i>microLion Chamber</i>
2008 High resolution chamber matrix	<i>STARCHECK</i>

# General Remarks

- All detectors described in this catalog are shipped with a PTW calibration certificate for one measuring quantity (please specify), valid for the stated reference radiation quality.
- An instruction manual in English is included with every detector.
- The cable length of the detectors is 1 m, if not stated otherwise.
- All detectors in this catalog can be operated with a PTW extension cable up to 100 m in length.
- For very accurate measurements a pre-irradiation dose of (1 ... 3) Gy is recommended for all therapy ionization chambers, even if the data sheet does not specify a mandatory pre-irradiation dose.
- In case a detector is not used together with a PTW electrometer, the user must ensure that the polarizing voltage is applied by a current-limiting device with a maximum current of 0.5 mA.
- Most detectors in this catalog are available with 3 different connecting systems (BNT, TNC and M type).
- All technical data published in this catalog are typical data for the various detector types. Certain data of individual detectors may vary slightly within the ranges of tolerance.
- Some former detector types are not included in this catalogue as they have been replaced by new types. The following table shows discontinued chamber types and their replacements. The technical data for the discontinued chambers listed in the table are mainly identical to those of their replacement types.

Chamber name	Discontinued type	New type	Chamber name	Discontinued type	New type
Farmer, PMMA/Al	30001	30010	0.3 cm <sup>3</sup> flexible	31003	31013
Farmer, all graphite	30002	30011	0.3 cm <sup>3</sup> rigid stem	23332	30016
Farmer graphite/Al	30004	30012	1 cm <sup>3</sup> rigid stem	23331	30015
Farmer, waterproof	30006	30013	PinPoint 0.015 cm <sup>3</sup>	31006	31014
0.125 cm <sup>3</sup> flexible	31002	31010	PinPoint 0.03 cm <sup>3</sup>	31009	31015

# Contents

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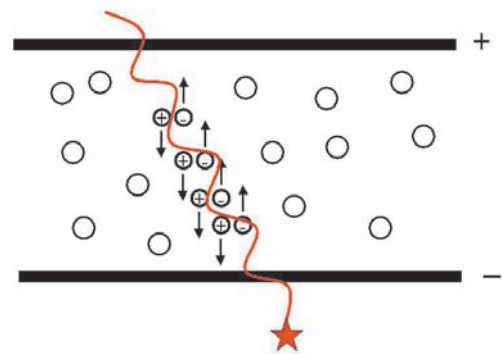
# The Physics

## General Aspects

Radiation detectors convert radiation energy into electrical energy. The electrical signal of a detector when irradiated is measured by an electrometer connected to the detector. By applying a certain detector specific calibration factor (e.g. Gy/C), the detector signal is related to a radiation dose value. Further correction factors depending on the detector characteristics and the beam quality may be used. A variety of detector types with different design for intensity measurements of ionizing radiation is available. The radiation detection for dosimetric purposes in the medical field of diagnostic radiology, radiotherapy and nuclear medicine is mainly based on three principles of measurement, realized by three different detector types: the ionization chamber, the semiconductor detector and the diamond detector.

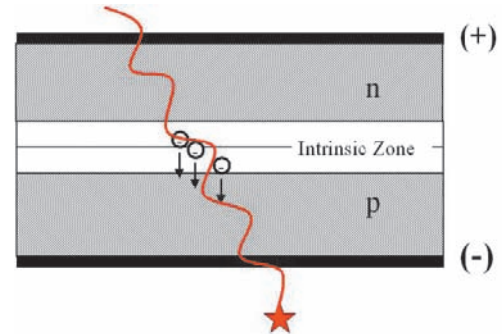
## Ionization Chamber

An ionization chamber basically consists of a gas volume between two electrodes connected to a high voltage supply of typically 100 V to 1000 V. In this gas volume ionizing radiation creates ion pairs. These, being positive and negative charge carriers, are attracted by the electrodes thus creating a current which can be measured by an electrometer. Gas (air) volumes vary from 0.01 cm<sup>3</sup> to 10,000 cm<sup>3</sup>, corresponding currents can be between 10<sup>-14</sup> A and 10<sup>-7</sup> A. Using non-polar fluids, liquid-filled ionization chambers can be realized.



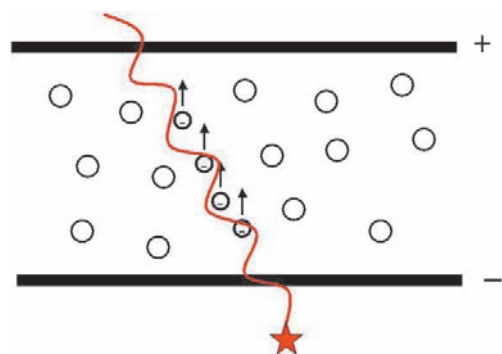
## Semiconductor Detector

In silicon semiconductors a layer of n-type silicon is brought into contact with a layer of p-type silicon, allowing electrons to drift from the n to the p region of the detector thus creating an insulating intrinsic zone. Incident radiation frees electrons in the intrinsic zone (sensitive layer of the detector) which move to the positively charged p region, generating a current. This solar cell principle does not need an external bias voltage.



## Diamond Detector

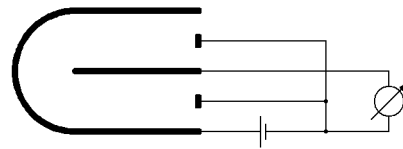
A high purity diamond can operate as a solid state ionization detector. Ionizing radiation can push electrons from the valence band to higher energy levels thereby first filling electron traps caused by impurities and then bringing electrons to the conductivity band. An external bias is needed to produce an ionization current very much like in an ionization chamber. A stable current can only be measured though after sufficient pre-irradiation to fill the traps.



# The Detector Design

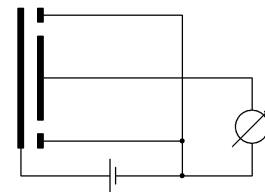
## Thimble Ionization Chamber

A thimble chamber (also known as compact chamber) consists of a central electrode and a cylindrical chamber wall with a spherical or conical end mounted on a cylindrical stem. A guard on central electrode potential leading up to the sensitive volume limits dark currents and stem effects.



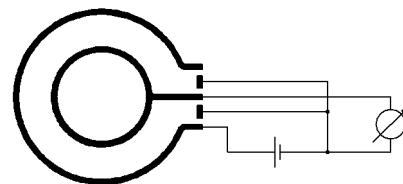
## Parallel Plate Ionization Chamber

A parallel plate chamber (also known as flat chamber) consists of a high voltage electrode plate and a measuring electrode plate confining the sensitive volume. A guard on central electrode potential around the measuring electrode plate limits dark current and perturbation effect.



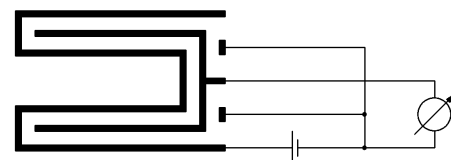
## Spherical Ionization Chamber

A spherical chamber consists of two concentric balls representing the central measuring electrode and the chamber wall and confining the sensitive volume. A guard on central electrode potential around the measuring electrode stem limits the dark current.



## Well Type Ionization Chamber

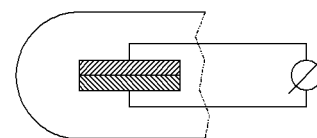
A well type chamber consists of an outer housing with an inset cylindrical cavity - representing the chamber wall - to receive the measuring object. The measuring electrode also surrounds this cavity. A guard on central electrode potential around the measuring electrode stem limits the dark current.



## Semiconductor Detector

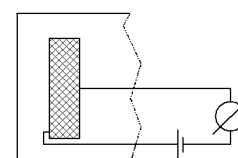
A silicon semiconductor detector consists of a layered silicon disk with contact wires to the measuring instrument. This is embedded horizontally or vertically in protective and / or build-up material depending on the intended application to form a useful probe.

This detector does not need an external bias voltage nor a guard.



## Diamond Detector

A diamond detector consists of a diamond disk with contact wires to the measuring instrument. This is embedded vertically in water-equivalent protective material to produce a probe with the highest possible spatial resolution in axial direction for use in therapy beam analysis. A guard is lead up to the detector stem.



# PTW Calibration Laboratory

As both the oldest and the largest manufacturer of ionization chambers and medical dosimetry equipment, PTW-Freiburg has always maintained a calibration laboratory for dosimetric measuring quantities. While being an integral part of the company and a key component of the PTW-Freiburg comprehensive quality assurance system, the calibration laboratory is also proud of its very own traditions and achievements. The PTW Calibration Laboratory as an independent functional unit today is recognized internationally as one of the leading Secondary Standard Dosimetry Laboratories of the world.



Front view of the PTW-Freiburg factory, building with calibration laboratory to the left. Chamber assembly building in the background

## Origin and tradition

PTW-Freiburg was founded on May 9, 1922 for the purpose of manufacturing radiation therapy dosimeters based on the electrostatic relay invented by one of the founders, Prof. Hammer. Early photographs of the calibration laboratory show Hammer and Küstner dosimeters and their ionization chambers facing X-ray tubes supplied by open high-voltage leads. Calibration traceability to the National Laboratory (first PTR, now PTB) always was of prime importance. Original and



Detail of the calibration laboratory approx. 1957

improved versions of the Küstner Transfer Standard instrument in the PTW museum bear witness of that tradition. Internal traceability is proudly extended to the point of preserving the original measurement notes to every calibration performed since 1937. This traditional approach to quality today gives the laboratory the advantage of access to what is probably the largest database on calibrations of clinical dosimetry in the world.

## Calibration facilities and instrumentation

Our facility is one of the largest, most modern commercial ionizing radiation calibration lab and repair facility in the world. In 2008 the space for the calibration lab is enlarged up to 900 sq. meters. Today the PTW calibration laboratory operates nine separate calibration benches for radiological and radiotherapy measurements ranging from small mammography and soft X-ray facilities up to  $^{137}\text{Cs}$  and the 74 TBq (2000 Ci)  $^{60}\text{Co}$  radiotherapy standard. Work at all these single calibration places is coordinated using a custom-made laboratory software for process control, data acquisition from the calibration monitors (UNIDOS instruments)



The building with the calibration laboratory (with solar panels) seen from above (Photo: Bavaria Luftbild Verlags GmbH)

and calibration calculation for the department office writing the calibration certificates. As far as possible (for connector compatibility) the reference class UNIDOS electrometers are also used for the measurement of the customer chambers. The calibration in electrical measuring quantities of all electrometers used is also traceable to the PTB primary standard. Besides the dose and dose rate ranges the laboratory maintains facilities for the calibration of non-invasive kV-meters and nuclear medicine isotope calibrators.

## Quality and regulatory compliance

Both as part of PTW-Freiburg and as Secondary Standard Dosimetry Laboratory the PTW Calibration Laboratory is qualified by adherence to the most stringent QA standards. Current certifications comprise ISO 9001-2000, ISO 13485-2003, ISO 17025, and Annex II, Section 3 of the Directive 93/42/EEC (Medical Device Directive).

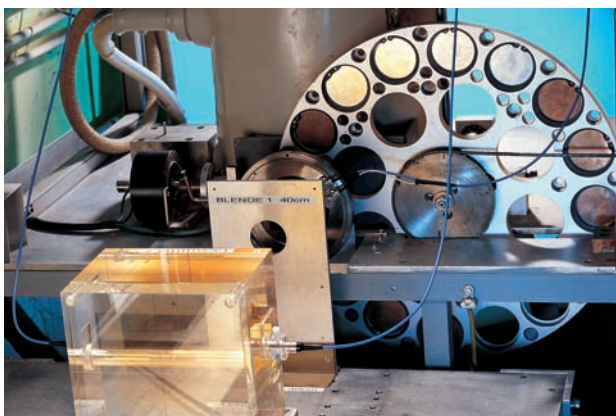
Customers have the choice of Factory Calibration Certificate or Secondary Standard Calibration Certificate (DAkkS) for dose / dose rate calibrations.

## Scope of work

Repair and electrical calibration of measuring instruments are mainly done for PTW dosimeters. This includes complete electrical recalibration of the modern electrometers through all their measuring ranges as well as early fault elimination by burn-in and comprehensive electrical safety tests.

Whenever possible radiological calibrations include the adjustment of the instrument to directly display dose at the reference quality. Radiological calibrations are performed in the measuring quantities and radiation quality ranges as shown on page 8.

For these calibrations every instrument from every manufacturer is accepted (as long as it works and physically fits within the beam). Special radiological calibrations are available upon request. In consequence the PTW laboratory is one of the busiest radiological calibration laboratories worldwide with over 10000 instruments calibrated every year.



300 kV X-ray installation with filter wheel

## Comparison measurements

Comparison measurements both in the form of direct comparisons in the calibration chain and ring comparisons between laboratories of equal rank are essential in documenting and maintaining traceability for any calibration laboratory. At the PTW Calibration Laboratory comparisons both with primary laboratories and with

other secondary standard dosimetry laboratories are done on a regular basis. Traceability to PTB is maintained by calibration of six sets of dosimetry equipment every two years with comparative measurements and reports every three months. Comparison with IAEA is done by exchange of mailed TLD every year and occasional comparative measurements with



Setting up a chamber

ionization chambers. Deviations are always minimal.

Participation in European Ring Comparisons (mostly also supplied with PTW equipment) continuously shows very successful results.

TLD comparison measurements between IAEA and PTW both using the IAEA system and the PTW TLD audit probes have shown only minimal differences.

## Secondary Standard Laboratory/ Cooperation with IAEA and PTB

Having successfully participated in the regular comparisons for some years, since the year 2000 the PTW calibration laboratory is formally recognized as a Secondary Standard Dosimetry Laboratory in the IAEA/WHO SSDL network<sup>[1]</sup>.

This so far is the latest expression of the extremely good and fruitful cooperation PTW has enjoyed with the IAEA Dosimetry Laboratory. (Since 1996 PTW has qualified and thrice requalified as preferred supplier of clinical dosimetry equipment to IAEA.) Another positive aspect of this cooperation is in the mutual discussion of procedures and equipment which has led to the design or continued development of several dosimetry components as for example the PTW Farmer chambers. A similar close cooperation is traditionally maintained with the German National Laboratory, PTB. Joint development has led to such successful results as the Böhm extrapolation chamber and the Roos electron chamber. In the German DKD service of secondary standard laboratories PTW was the first and only laboratory for dosimetric quantities<sup>[2]</sup>. PTW is also one of the oldest members of this service (since 1980).

[1] IAEA /WHO SSDL Newsletter No. 43 July 2000 page 43

([http://www.iaea.or.at/programmes/nahunet/e3/dmtp\\_e3\\_pub.html](http://www.iaea.or.at/programmes/nahunet/e3/dmtp_e3_pub.html))

[2] Physikalisch-Technische Bundesanstalt, DKD Deutscher Kalibrierdienst, Verzeichnis der Kalibrierlaboratorien, Ausgabe 3/2001: DKD-K-01501 (<http://www.dkd.ptb.de>)

# Calibration Service - Radiation Qualities

## Radiation Therapy Dosemeters

- X-rays 10, 15, 30, 50, 70 kV  
(T qualities according to DIN 6817)
- X-rays 70, 100, 140, 200, 280 kV  
(T qualities according to DIN 6817)
- <sup>137</sup>Cs 662 keV
- <sup>60</sup>Co 1.3 MeV

## Diagnostic Radiology Dosemeters

- X-rays 50, 70, 90, 120, 150 kV Conventional  
(RQR and RQA qualities according to IEC 61267)
- X-rays 70, 90, 120, 150 kV CT  
(RQR and RQA qualities according to IEC 61267)
- X-rays 100, 120, 150 kV CT  
(RQT qualities according to IEC 61267)
- X-rays 50, 70, 90 kV Dental
- X-rays 25, 28, 30, 35 kV Mammography  
(RQR-M and RQA-M qualities according to IEC 61267)  
Mo/Al, Mo/Rh, Rh/Rh, W/Ag, W/Al, W/Mo, W/Rh

## Radiation Protection Dosemeters

- X-rays 20, 30, 40 kV  
(Narrow Spectrum Series (N) qualities acc ISO 4037-1)
- X-rays 60, 80, 100, 150, 200, 250 kV  
(Narrow Spectrum Series (N) qualities acc ISO 4037-1)
- <sup>137</sup>Cs 662 keV
- <sup>60</sup>Co 1.3 MeV

## Miscellaneous Calibrations

- Source strength (cGym<sup>2</sup>h<sup>-1</sup>) of brachytherapy sources measured by well-type chambers
- Diagnostic X-ray generator high voltage of all types of X-ray equipment measured non-invasively by kV-meters: Different ranges from 20 to 150 kV
- Nuclide activity in nuclear medicine measured by isotope calibrators (only CURIEMENTOR instruments)
- Electrical measuring quantities charge (C) and current (A) measured by highly sensitive electrometers

## General Information

According to the PTW definition, each such set of beam qualities represents one calibration point for a certain application and can be ordered with a single order number. For more detailed information please refer to "Calibrations at PTW – A Short Guide" which you will find in the section Services-Calibrations on our website [www.ptw.de](http://www.ptw.de).



# Therapy Detectors

## ► Therapy Detectors

Farmer Chamber (PMMA/Aluminum)	▶	10
Farmer Chamber (Graphite/Graphite)	▶	11
Farmer Chamber (Graphite/Aluminum)	▶	12
Farmer Chamber, waterproof	▶	13
Semiflex Chamber 0.125 cm <sup>3</sup>	▶	14
Semiflex Chamber 0.3 cm <sup>3</sup>	▶	15
Rigid Stem Chamber 0.3 cm <sup>3</sup>	▶	16
Rigid Stem Chamber 1.0 cm <sup>3</sup>	▶	17
Advanced Markus Chamber	▶	18
Markus Chamber	▶	19
Roos Chamber	▶	20
Bragg Peak Chamber	▶	21
PinPoint Chambers	▶	22
PinPoint 3D Chamber	▶	23
microLion Chamber	▶	24
Diamond Detector	▶	25
Dosimetry Diode P	▶	26
Dosimetry Diode E	▶	27
Soft X-Ray Chamber 0.02 cm <sup>3</sup>	▶	28
Soft X-Ray Chamber 0.2 cm <sup>3</sup>	▶	29
Soft X-Ray Chamber 0.005 cm <sup>3</sup>	▶	30
SOURCECHECK	▶	31
Well-Type Chamber	▶	32
System Incorporated Detectors	▶	33
Radioactive Check Devices	▶	34



# Farmer Chamber

## Type 30010

*Classical therapy chamber for absolute dosimetry in high-energy photon, electron and proton beams*

### Features

- ▶ Fully guarded chamber
- ▶ Sensitive volume 0.6 cm<sup>3</sup>, vented to air
- ▶ Acrylic wall, graphited
- ▶ Aluminum central electrode
- ▶ Radioactive check device (option)

The 30010 Farmer chamber is a wide spread ionization chamber for absolute dose measurements in radiation therapy. Correction factors needed to determine absorbed dose to water or air kerma are published in the pertinent dosimetry protocols. The acrylic chamber wall ensures the ruggedness of the chamber. The chamber is designed for the use in solid state phantoms and therefore not water-proof.

### Specification

Type of product	vented cylindrical ionization chamber acc. IEC 60731
Application	absolute dosimetry in radiotherapy beams
Measuring quantities	absorbed dose to water, air kerma, exposure
Reference radiation quality	<sup>60</sup> Co
Nominal sensitive volume	0.6 cm <sup>3</sup>
Design	not waterproof, vented, fully guarded
Reference point	on chamber axis, 13 mm from chamber tip
Direction of incidence	radial
Nominal response	20 nC/Gy
Long-term stability	≤ 0.5 % per year
Chamber voltage	400 V nominal ± 500 V maximal
Polarity effect at <sup>60</sup> Co	< 0.5 %
Photon energy response	≤ ± 2 % (70 kV ... 280 kV) ≤ ± 4 % (200 kV ... <sup>60</sup> Co)
Directional response in solid state phantom	≤ ± 0.5 % for rotation around the chamber axis and for tilting of the axis up to ± 5°
Leakage current	≤ ± 4 fA
Cable leakage	≤ 1 pC/(Gy·cm)

### Materials and measures:

Wall of sensitive volume	0.335 mm PMMA, 1.19 g/cm <sup>3</sup> 0.09 mm graphite, 1.85 g/cm <sup>3</sup>
Total wall area density	56.5 mg/cm <sup>2</sup>
Dimension of sensitive volume	radius 3.05 mm length 23.0 mm
Central electrode	Al 99.98, diameter 1.1 mm
Build-up cap	PMMA, thickness 4.55 mm

### Ion collection efficiency at nominal voltage:

Ion collection time	140 μs
Max. dose rate for ≥ 99.5 % saturation	5 Gy/s
≥ 99.0 % saturation	10 Gy/s
Max. dose per pulse for ≥ 99.5 % saturation	0.46 mGy
≥ 99.0 % saturation	0.91 mGy

### Useful ranges:

Chamber voltage	± (100 ... 400) V
Radiation quality	30 kV ... 50 MV photons (10 ... 45) MeV electrons (50 ... 270) MeV protons
Field size	(5 x 5) cm <sup>2</sup> ... (40 x 40) cm <sup>2</sup>
Temperature	(10 ... 40) °C (50 ... 104) °F
Humidity	(10 ... 80) %, max 20 g/m <sup>3</sup>
Air pressure	(700 ... 1060) hPa

### Ordering Information

- TN30010-1 Farmer type chamber 0.6 cm<sup>3</sup>, PMMA/Al, connecting system BNT
- TW30010-1 Farmer type chamber 0.6 cm<sup>3</sup>, PMMA/Al, connecting system TNC
- TM30010-1 Farmer type chamber 0.6 cm<sup>3</sup>, PMMA/Al, connecting system M

### Options

- T48012 Radioactive check device <sup>90</sup>Sr
- T48002.3.003 Chamber holding device for check device



# Farmer Chamber

## Type 30011

*Pure graphite therapy chamber for absolute dosimetry in high-energy photon, electron and proton beams*

### Features

- ▶ Fully guarded chamber
- ▶ Sensitive volume 0.6 cm<sup>3</sup>, vented to air
- ▶ Graphite wall
- ▶ Graphite central electrode
- ▶ Radioactive check device (option)

The 30011 all graphite Farmer chamber is used for absolute dose measurements in radiation therapy in cases where a minimum of different materials in the radiation field is desired. Correction factors needed to determine absorbed dose to water or air kerma are published in the pertinent dosimetry protocols. Due to the sole use of graphite the energy response of the chamber at energies below <sup>60</sup>Co varies stronger than that of chambers with an aluminum electrode. The chamber is designed for the use in solid state phantoms and therefore not waterproof.

### Specification

Type of product	vented cylindrical ionization chamber acc. IEC 60731
Application	absolute therapy dosimetry in solid state phantoms and air
Measuring quantities	absorbed dose to water, air kerma, exposure
Reference radiation quality	<sup>60</sup> Co
Nominal sensitive volume	0.6 cm <sup>3</sup>
Design	not waterproof, vented, fully guarded
Reference point	on chamber axis, 13 mm from chamber tip
Direction of incidence	radial
Nominal response	20 nC/Gy
Long-term stability	≤ 0.5 % per year
Chamber voltage	400 V nominal ± 500 V maximal
Polarity effect at <sup>60</sup> Co	< 0.5 %
Photon energy response	≤ ± 12 % (280 kV ... <sup>60</sup> Co)
Directional response in solid state phantom	≤ ± 0.5 % for rotation around the chamber axis and for tilting of the axis up to ± 5°
Leakage current	≤ ± 4 fA
Cable leakage	≤ 1 pC/(Gy·cm)

### Materials and measures:

Wall of sensitive volume	0.425 mm graphite, 1.85 g/cm <sup>3</sup>
Total wall area density	79 mg/cm <sup>2</sup>
Dimension of sensitive volume	radius 3.05 mm length 23.0 mm
Central electrode	graphite, diameter 1.0 mm
Build-up cap	PMMA, thickness 4.55 mm

### Ion collection efficiency at nominal voltage:

Ion collection time	140 μs
Max. dose rate for ≥ 99.5 % saturation	5 Gy/s
≥ 99.0 % saturation	10 Gy/s
Max. dose per pulse for ≥ 99.5 % saturation	0.46 mGy
≥ 99.0 % saturation	0.91 mGy

### Useful ranges:

Chamber voltage	± (100 ... 400) V
Radiation quality	140 kV ... 50 MV photons (10 ... 45) MeV electrons (50 ... 270) MeV protons
Field size	(5 x 5) cm <sup>2</sup> ... (40 x 40) cm <sup>2</sup>
Temperature	(10 ... 40) °C (50 ... 104) °F
Humidity	(10 ... 80) %, max 20 g/m <sup>3</sup>
Air pressure	(700 ... 1060) hPa

### Ordering Information

TN30011-1 Farmer type chamber 0.6 cm<sup>3</sup>, C/C, connecting system BNT  
 TW30011-1 Farmer type chamber 0.6 cm<sup>3</sup>, C/C, connecting system TNC

### Options

T48012 Radioactive check device <sup>90</sup>Sr  
 T48002.3.003 Chamber holding device for check device



# Farmer Chamber

## Type 30012

*Farmer chamber with graphite wall for absolute dosimetry in high-energy photon, electron and proton beams*

### Features

- ▶ Fully guarded chamber
- ▶ Sensitive volume 0.6 cm<sup>3</sup>, vented to air
- ▶ Graphite wall
- ▶ Aluminum central electrode
- ▶ Radioactive check device (option)

The 30012 Farmer chamber is intended for absolute dose measurements in radiation therapy. Correction factors needed to determine absorbed dose to water or air kerma are published in the pertinent dosimetry protocols. The graphite wall makes the chamber almost water-equivalent, the aluminum central electrode improves the energy response at energies below <sup>60</sup>Co. The chamber is intended for the use in solid state phantoms and therefore not waterproof.

### Specification

Type of product	vented cylindrical ionization chamber acc. IEC 60731
Application	absolute therapy dosimetry in solid state phantoms and air
Measuring quantities	absorbed dose to water, air kerma, exposure
Reference radiation quality	<sup>60</sup> Co
Nominal sensitive volume	0.6 cm <sup>3</sup>
Design	not waterproof, vented, fully guarded
Reference point	on chamber axis, 13 mm from chamber tip
Direction of incidence	radial
Nominal response	20 nC/Gy
Long-term stability	≤ 0.5 % per year
Chamber voltage	400 V nominal ± 500 V maximal
Polarity effect at <sup>60</sup> Co	< 0.5 %
Photon energy response	≤ ± 2 % (70 kV ... 280 kV) ≤ ± 4 % (200 kV ... <sup>60</sup> Co)
Directional response in solid state phantom	≤ ± 0.5 % for rotation around the chamber axis and for tilting of the axis up to ± 5°
Leakage current	≤ ± 4 fA
Cable leakage	≤ 1 pC/(Gy·cm)

### Materials and measures:

Wall of sensitive volume	0.425 mm graphite, 1.85 g/cm <sup>3</sup>
Total wall area density	79 mg/cm <sup>2</sup>
Dimension of sensitive volume	radius 3.05 mm length 23.0 mm
Central electrode	Al 99.98, diameter 1.1 mm
Build-up cap	PMMA, thickness 4.55 mm

### Ion collection efficiency at nominal voltage:

Ion collection time	140 μs
Max. dose rate for ≥ 99.5 % saturation	5 Gy/s
≥ 99.0 % saturation	10 Gy/s
Max. dose per pulse for ≥ 99.5 % saturation	0.46 mGy
≥ 99.0 % saturation	0.91 mGy

### Useful ranges:

Chamber voltage	± (100 ... 400) V
Radiation quality	60 kV ... 50 MV photons (10 ... 45) MeV electrons (50 ... 270) MeV protons
Field size	(5 x 5) cm <sup>2</sup> ... (40 x 40) cm <sup>2</sup>
Temperature	(10 ... 40) °C (50 ... 104) °F
Humidity	(10 ... 80) %, max 20 g/m <sup>3</sup>
Air pressure	(700 ... 1060) hPa

### Ordering Information

TN30012-1 Farmer type chamber 0.6 cm<sup>3</sup>, C/Al, connecting system BNT  
 TW30012-1 Farmer type chamber 0.6 cm<sup>3</sup>, C/Al, connecting system TNC

### Options

T48012 Radioactive check device <sup>90</sup>Sr  
 T48002.3.003 Chamber holding device for check device



# Farmer Chamber

## Type 30013

*Waterproof therapy chamber for absolute dosimetry in high-energy photon, electron and proton beams*

### Features

- ▶ Waterproof, fully guarded chamber
- ▶ Sensitive volume 0.6 cm<sup>3</sup>, vented to air
- ▶ Acrylic wall, graphited
- ▶ Aluminum central electrode
- ▶ Radioactive check device (option)

The 30013 Farmer chamber is the standard ionization chamber for absolute dose measurements in radiation therapy. Correction factors needed to determine absorbed dose to water or air kerma are published in the pertinent dosimetry protocols. Its waterproof design allows the chamber to be used in water or in solid state phantoms. The acrylic chamber wall ensures the ruggedness of the chamber.

### Specification

Type of product	vented cylindrical ionization chamber acc. IEC 60731
Application	absolute therapy dosimetry in water, solid state phantoms and air
Measuring quantities	absorbed dose to water, air kerma, exposure
Reference radiation quality	<sup>60</sup> Co
Nominal sensitive volume	0.6 cm <sup>3</sup>
Design	waterproof, vented, fully guarded
Reference point	on chamber axis, 13 mm from chamber tip
Direction of incidence	radial
Nominal response	20 nC/Gy
Long-term stability	≤ 0.5 % per year
Chamber voltage	400 V nominal ± 500 V maximal
Polarity effect at <sup>60</sup> Co	< 0.5 %
Photon energy response	≤ ± 2 % (70 kV ... 280 kV) ≤ ± 4 % (200 kV ... <sup>60</sup> Co)
Directional response in water	≤ ± 0.5 % for rotation around the chamber axis and for tilting of the axis up to ± 5°
Leakage current	≤ ± 4 fA
Cable leakage	≤ 1 pC/(Gy·cm)

### Materials and measures:

Wall of sensitive volume	0.335 mm PMMA, 1.19 g/cm <sup>3</sup> 0.09 mm graphite, 1.85 g/cm <sup>3</sup>
Total wall area density	56.5 mg/cm <sup>2</sup>
Dimension of sensitive volume	radius 3.05 mm length 23.0 mm
Central electrode	Al 99.98, diameter 1.1 mm
Build-up cap	PMMA, thickness 4.55 mm

### Ion collection efficiency at nominal voltage:

Ion collection time	140 μs
Max. dose rate for ≥ 99.5 % saturation	5 Gy/s
≥ 99.0 % saturation	10 Gy/s
Max. dose per pulse for ≥ 99.5 % saturation	0.46 mGy
≥ 99.0 % saturation	0.91 mGy

### Useful ranges:

Chamber voltage	± (100 ... 400) V
Radiation quality	30 kV ... 50 MV photons (10 ... 45) MeV electrons (50 ... 270) MeV protons
Field size	(5 x 5) cm <sup>2</sup> ... (40 x 40) cm <sup>2</sup>
Temperature	(10 ... 40) °C (50 ... 104) °F
Humidity	(10 ... 80) %, max 20 g/m <sup>3</sup>
Air pressure	(700 ... 1060) hPa

### Ordering Information

- TN30013 Farmer type chamber 0.6 cm<sup>3</sup>, waterproof, connecting system BNT
- TW30013 Farmer type chamber 0.6 cm<sup>3</sup>, waterproof, connecting system TNC
- TM30013 Farmer type chamber 0.6 cm<sup>3</sup>, waterproof, connecting system M

### Options

- T48012 Radioactive check device <sup>90</sup>Sr
- T48002.3.003 Chamber holding device for check device



### Features

- ▶ Waterproof, semiflexible design for easy mounting in scanning water phantoms
- ▶ Minimized directional response
- ▶ Sensitive volume 0.125 cm<sup>3</sup>, vented to air
- ▶ Radioactive check device (option)

The 31010 semiflexible chamber is the ideal compromise between small size for reasonable spatial resolution and large sensitive volume for precise dose measurements. This makes the 31010 chamber to one of the most commonly used chambers in scanning water phantom systems. The chamber volume of 0.125 cm<sup>3</sup> gives enough signal to use the chamber also for high precision absolute dose measurements. The sensitive volume is approximately spherical resulting in a flat angular response and a uniform spatial resolution along all three axes of a water phantom.

### Specification

Type of product	vented cylindrical ionization chamber
Application	absolute dosimetry in radiotherapy beams
Measuring quantities	absorbed dose to water, air kerma, exposure
Reference radiation quality	<sup>60</sup> Co
Nominal sensitive volume	0.125 cm <sup>3</sup>
Design	waterproof, vented, fully guarded
Reference point	on chamber axis, 4.5 mm from chamber tip
Direction of incidence	radial
Nominal response	3.3 nC/Gy
Long-term stability	≤ 1 % per year
Chamber voltage	400 V nominal ± 500 V maximal
Polarity effect at <sup>60</sup> Co	< 1 %
Photon energy response	≤ ± 2 % (140 kV ... 280 kV) ≤ ± 4 % (140 kV ... <sup>60</sup> Co)
Directional response in water	≤ ± 0.5 % for rotation around the chamber axis and for tilting of the axis up to ± 10°
Leakage current	≤ ± 4 fA
Cable leakage	≤ 1 pC/(Gy·cm)

# 0.125 cm<sup>3</sup> Semiflex Chamber

## Type 31010

*Standard therapy chamber for scanning systems and for absolute dosimetry*

### Materials and measures:

Wall of sensitive volume	0.55 mm PMMA, 1.19 g/cm <sup>3</sup> 0.15 mm graphite, 0.82 g/cm <sup>3</sup>
Total wall area density	78 mg/cm <sup>2</sup>
Dimension of sensitive volume	radius 2.75 mm length 6.5 mm
Central electrode	Al 99.98, diameter 1.1 mm
Build-up cap	PMMA, thickness 3 mm

### Ion collection efficiency at nominal voltage:

Ion collection time	100 μs
Max. dose rate for ≥ 99.5 % saturation	6 Gy/s
≥ 99.0 % saturation	12 Gy/s
Max. dose per pulse for ≥ 99.5 % saturation	0.5 mGy
≥ 99.0 % saturation	1.0 mGy

### Useful ranges:

Chamber voltage	± (100 ... 400) V
Radiation quality	66 kV ... 50 MV photons (10 ... 45) MeV electrons (50 ... 270) MeV protons
Field size	(3 x 3) cm <sup>2</sup> ... (40 x 40) cm <sup>2</sup>
Temperature	(10 ... 40) °C (50 ... 104) °F
Humidity	(10 ... 80) %, max 20 g/m <sup>3</sup>
Air pressure	(700 - 1060) hPa

### Ordering Information

TN31010 Semiflex chamber 0.125 cm<sup>3</sup>,  
connecting system BNT

TW31010 Semiflex chamber 0.125 cm<sup>3</sup>,  
connecting system TNC

TM31010 Semiflex chamber 0.125 cm<sup>3</sup>,  
connecting system M

### Options

T48012 Radioactive check device <sup>90</sup>Sr

T48002.1.004 Chamber holding device for check device



# 0.3 cm<sup>3</sup> Semiflex Chamber

## Type 31013

*Therapy chamber for scanning systems and for absolute dosimetry*

### Features

- ▶ Waterproof, semiflexible design for easy mounting in scanning water phantoms
- ▶ Increased sensitive volume for low level measurements
- ▶ Sensitive volume 0.3 cm<sup>3</sup>, vented to air
- ▶ Radioactive check device (option)

The 31013 semiflexible chamber is ideal for precise dose measurements and for the measurement of dose distributions in scanning water phantom systems. The chamber is used as an alternative for the 31010 chamber in cases where increased signal levels are required and spatial resolution along the axis of the chamber can be compromised.

### Specification

Type of product	vented cylindrical ionization chamber
Application	absolute dosimetry in radiotherapy beams
Measuring quantities	absorbed dose to water, air kerma, exposure
Reference radiation quality	<sup>60</sup> Co
Nominal sensitive volume	0.3 cm <sup>3</sup>
Design	waterproof, vented, fully guarded
Reference point	on chamber axis, 9.5 mm from chamber tip
Direction of incidence	radial
Nominal response	10 nC/Gy
Long-term stability	≤ 1 % per year
Chamber voltage	400 V nominal ± 500 V maximal
Polarity effect at <sup>60</sup> Co	< 1 %
Photon energy response	≤ ± 2 % (140 kV ... 280 kV) ≤ ± 4 % (100 kV ... <sup>60</sup> Co)
Directional response in water	≤ ± 0.5 % for rotation around the chamber axis and for tilting of the axis up to ± 10°
Leakage current	≤ ± 4 fA
Cable leakage	≤ 1 pC/(Gy·cm)

### Materials and measures:

Wall of sensitive volume	0.55 mm PMMA, 1.19 g/cm <sup>3</sup> 0.15 mm graphite, 0.82 g/cm <sup>3</sup>
Total wall area density	78 mg/cm <sup>2</sup>
Dimension of sensitive volume	radius 2.75 mm length 16.25 mm
Central electrode	Al 99.98, diameter 0.9 mm
Build-up cap	PMMA, thickness 3 mm

### Ion collection efficiency at nominal voltage:

Ion collection time	80 μs
Max. dose rate for ≥ 99.5 % saturation	14 Gy/s
≥ 99.0 % saturation	28 Gy/s
Max. dose per pulse for ≥ 99.5 % saturation	0.8 mGy
≥ 99.0 % saturation	1.5 mGy

### Useful ranges:

Chamber voltage	± (100 ... 400) V
Radiation quality	40 kV ... 50 MV photons (10 ... 45) MeV electrons (50 ... 270) MeV protons
Field size	(4 x 4) cm <sup>2</sup> ... (40 x 40) cm <sup>2</sup>
Temperature	(10 ... 40) °C (50 ... 104) °F
Humidity	(10 ... 80) %, max 20 g/m <sup>3</sup>
Air pressure	(700 ... 1060) hPa

### Ordering Information

- TN31013 Semiflex chamber 0.3 cm<sup>3</sup>,  
connecting system BNT
- TW31013 Semiflex chamber 0.3 cm<sup>3</sup>,  
connecting system TNC
- TM31013 Semiflex chamber 0.3 cm<sup>3</sup>,  
connecting system M

### Options

- T48012 Radioactive check device <sup>90</sup>Sr
- T48002.1.004 Chamber holding device for check device



## 0.3 cm<sup>3</sup> Rigid Stem Chamber

### Type 30016

*Therapy chamber for absolute dosimetry in high-energy photon and electron beams*

#### Features

- ▶ Fully guarded chamber
- ▶ Sensitive volume 0.3 cm<sup>3</sup>, vented to air
- ▶ Acrylic wall, graphited
- ▶ Aluminum central electrode
- ▶ Radioactive check device (option)

The 30016 chamber is used for absolute dose measurements in radiation therapy in cases where the high volume of the 30015 chamber is not needed and a higher spatial resolution is needed. Correction factors needed to determine absorbed dose to water or air kerma are published in the pertinent dosimetry protocols. The acrylic chamber wall ensures the ruggedness of the chamber. The chamber is designed for the use in solid state phantoms and is therefore not waterproof.

#### Specification

Type of product	vented cylindrical ionization chamber
Application	absolute dosimetry in radiotherapy beams
Measuring quantities	absorbed dose to water, air kerma, exposure
Reference radiation quality	<sup>60</sup> Co
Nominal sensitive volume	0.3 cm <sup>3</sup>
Design	not waterproof, vented, fully guarded
Reference point	on chamber axis, 9.5 mm from chamber tip
Direction of incidence	radial
Nominal response	10.5 nC/Gy
Long-term stability	≤ 1 % per year
Chamber voltage	400 V nominal ± 600 V maximal
Polarity effect	≤ 1 %
Photon energy response	≤ ± 2 % (70 kV ... 250 kV) ≤ ± 4 % (200 kV ... <sup>60</sup> Co)
Directional response in solid state phantom	≤ ± 0.5 % for rotation around the chamber axis, ≤ ± 1 % for tilting of the axis up to ± 20°
Leakage current	≤ ± 4 fA
Cable leakage	≤ 1 pC/(Gy·cm)

#### Materials and measures:

Wall of sensitive volume	0.35 mm PMMA, 1.19 g/cm <sup>3</sup> 0.135 mm graphite, 1.85 g/cm <sup>3</sup>
Total wall area density	67 mg/cm <sup>2</sup>
Dimension of sensitive volume	radius 2.5 mm length 18 mm
Central electrode	Al 99.98, diameter 0.85 mm
Build-up cap	PMMA, thickness 3 mm

#### Ion collection efficiency at nominal voltage:

Ion collection time	84 μs
Max. dose rate for ≥ 99.5 % saturation	11.5 Gy/s
≥ 99.0 % saturation	23.1 Gy/s
Max. dose per pulse for ≥ 99.5 % saturation	0.69 mGy
≥ 99.0 % saturation	1.38 mGy

#### Useful ranges:

Chamber voltage	± (100 ... 600) V
Radiation quality	70 kV ... 50 MV photons (6 ... 25) MeV electrons
Field size	(5 x 5) cm <sup>2</sup> ... (40 x 40) cm <sup>2</sup>
Temperature	(10 ... 40) °C (50 ... 104) °F
Humidity	(20 ... 80) %, max 20 g/m <sup>3</sup>
Air pressure	(700 ... 1060) hPa

#### Ordering Information

TN30016 Rigid stem chamber 0.3 cm<sup>3</sup>,  
connecting system BNT  
TW30016 Rigid stem chamber 0.3 cm<sup>3</sup>,  
connecting system TNC  
TM30016 Rigid stem chamber 0.3 cm<sup>3</sup>,  
connecting system M

#### Options

T48012 Radioactive check device <sup>90</sup>Sr  
T48002.3.004 Chamber holding device for check device





# 1.0 cm<sup>3</sup> Rigid Stem Chamber

## Type 30015

*High-volume therapy chamber for absolute dosimetry in high-energy photon and electron beams*

### Features

- ▶ Fully guarded chamber
- ▶ Sensitive volume 1.0 cm<sup>3</sup>, vented to air
- ▶ Acrylic wall, graphited
- ▶ Aluminum central electrode
- ▶ Radioactive check device (option)

The 30015 rigid stem chamber is used for absolute dose measurements in radiation therapy. Correction factors needed to determine absorbed dose to water or air kerma are published in the pertinent dosimetry protocols. The acrylic chamber wall ensures the ruggedness of the chamber. The chamber is designed for the use in solid state phantoms and is therefore not waterproof.

### Specification

Type of product	vented cylindrical ionization chamber
Application	absolute dosimetry in radiotherapy beams
Measuring quantities	absorbed dose to water, air kerma, exposure
Reference radiation quality	<sup>60</sup> Co
Nominal sensitive volume	1.0 cm <sup>3</sup>
Design	not waterproof, vented, fully guarded
Reference point	on chamber axis, 11.5 mm from chamber tip
Direction of incidence	radial
Nominal response	31.9 nC/Gy
Long-term stability	≤ 1 % per year
Chamber voltage	400 V nominal ± 600 V maximal
Polarity effect	≤ 1 %
Photon energy response	≤ ± 2 % (70 kV ... 250 kV) ≤ ± 4 % (200 kV ... <sup>60</sup> Co)
Directional response in solid state phantom	≤ ± 0.5 % for rotation around the chamber axis, ≤ ± 1 % for tilting of the axis up to ± 20°
Leakage current	≤ ± 4 fA
Cable leakage	≤ 1 pC/(Gy·cm)

### Materials and measures:

Wall of sensitive volume    0.4 mm PMMA,  
1.19 g/cm<sup>3</sup>  
0.135 mm graphite,  
1.85 g/cm<sup>3</sup>

Total wall area density	73 mg/cm <sup>2</sup>
Dimension of sensitive volume	radius 3.95 mm length 22 mm
Central electrode	Al 99.98, diameter 1.1 mm
Build-up cap	PMMA, thickness 3 mm

### Ion collection efficiency at nominal voltage:

Ion collection time	236 μs
Max. dose rate for ≥ 99.5 % saturation	1.5 Gy/s
≥ 99.0 % saturation	2.9 Gy/s
Max. dose per pulse for ≥ 99.5 % saturation	0.25 mGy
≥ 99.0 % saturation	0.49 mGy

### Useful ranges:

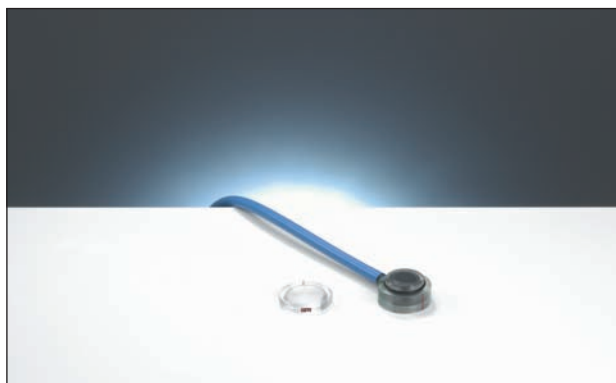
Chamber voltage	± (100 ... 600) V
Radiation quality	70 keV ... 50 MV photons (10 ... 45) MeV electrons
Field size	(5 x 5) cm <sup>2</sup> ... (40 x 40) cm <sup>2</sup>
Temperature	(10 ... 40) °C (50 ... 104) °F
Humidity	(20 ... 80) %, max 20 g/m <sup>3</sup>
Air pressure	(700 ... 1060) hPa

### Ordering Information

TN30015 Rigid stem chamber 1.0 cm<sup>3</sup>,  
connecting system BNT  
TW30015 Rigid stem chamber 1.0 cm<sup>3</sup>,  
connecting system TNC  
TM30015 Rigid stem chamber 1.0 cm<sup>3</sup>,  
connecting system M

### Options

T48012 Radioactive check device <sup>90</sup>Sr  
T48002.3.004 Chamber holding device for check device



### Features

- ▶ Perturbation-free electron chamber
- ▶ Thin entrance window and waterproof protection cap
- ▶ Small-sized for high spatial resolution
- ▶ Sensitive volume 0.02 cm<sup>3</sup>, vented to air
- ▶ Radioactive check device (option)

The 34045 Advanced Markus chamber is the successor of the well-known classic Markus electron chamber, equipped with a wide guard ring for perturbation-free measurements. The thin entrance window allows measurements in solid state phantoms up to the surface. The protection cap makes the chamber waterproof for measurements in water phantoms.

### Specification

Type of product	vented plane parallel ionization chamber
Application	absolute dosimetry in high-energy electron beams
Measuring quantity	absorbed dose to water
Reference radiation quality	<sup>60</sup> Co
Nominal sensitive volume	0.02 cm <sup>3</sup>
Design	waterproof with protection cap, vented
Reference point	in chamber center on entrance foil, or 1.3 mm below surface of protection cap
Direction of incidence	perpendicular to chamber plane
Nominal response	0.67 nC/Gy
Long-term stability	≤ 1 % per year
Chamber voltage	300 V nominal ± 400 V maximal
Polarity effect	≤ 1 % for electrons ≥ 9 MeV
Directional response in water	≤ ± 0.1 % for chamber tilting ≤ ± 10°
Leakage current	≤ ± 4 fA
Cable leakage	≤ 1 pC/(Gy·cm)

# Advanced Markus Chamber

## Type 34045

*Perturbation-free version of the famous classic Markus chamber for absolute dosimetry in high-energy electron beams*

### Materials and measures:

Entrance foil	0.03 mm PE (polyethylene CH <sub>2</sub> ), 2.76 mg/cm <sup>2</sup>
Protection cap	0.87 mm PMMA, 1.19 g/cm <sup>3</sup> , 0.4 mm air
Total window area density	106 mg/cm <sup>2</sup> , 1.3 mm (protection cap included)
Water-equivalent window thickness	1.06 mm (protection cap included)
Sensitive volume	radius 2.5 mm depth 1 mm
Guard ring width	2 mm

### Ion collection efficiency at nominal voltage:

Ion collection time	22 μs
Max. dose rate for ≥ 99.5 % saturation	187 Gy/s
≥ 99.0 % saturation	375 Gy/s
Max. dose per pulse for ≥ 99.5 % saturation	2.78 mGy
≥ 99.0 % saturation	5.56 mGy

### Useful ranges:

Chamber voltage	± (50 ... 300) V
Radiation quality	(2 ... 45) MeV electrons
Field size	(3 x 3) cm <sup>2</sup> ... (40 x 40) cm <sup>2</sup>
Temperature	(10 ... 40) °C (50 ... 104) °F
Humidity	(10 ... 80) %, max 20 g/m <sup>3</sup>
Air pressure	(700 ... 1060) hPa

### Ordering Information

TN34045 Advanced Markus electron chamber, 0.02 cm<sup>3</sup>, connecting system BNT  
 TW34045 Advanced Markus electron chamber, 0.02 cm<sup>3</sup>, connecting system TNC  
 TM34045 Advanced Markus electron chamber, 0.02 cm<sup>3</sup>, connecting system M

### Options

T48010 Radioactive check device <sup>90</sup>Sr  
 T23343/11 Chamber holding device for check device



# Markus Chamber

## Type 23343

*Classic plane parallel chamber for absolute dosimetry in high-energy electron beams*

### Features

- ▶ Thin entrance window and waterproof protection cap
- ▶ Small-sized for high spatial resolution
- ▶ Sensitive volume 0.055 cm<sup>3</sup>, vented to air
- ▶ Radioactive check device (option)

The 23343 Markus chamber is manufactured in the original famous Markus design. Absorbed dose to water can be measured by applying correction factors for perturbation effects as published in pertinent dosimetry protocols. The thin entrance window allows measurements in solid state phantoms up to the surface. The protection cap makes the chamber waterproof for measurements in water phantoms.

### Specification

Type of product	vented plane parallel ionization chamber
Application	absolute dosimetry in high-energy electron beams
Measuring quantity	absorbed dose to water
Reference radiation quality	<sup>60</sup> Co
Nominal sensitive volume	0.055 cm <sup>3</sup>
Design	waterproof with protection cap, vented
Reference point	in chamber center on entrance foil, or 1.3 mm below surface of protection cap
Direction of incidence	perpendicular to chamber plane
Nominal response	2 nC/Gy
Long-term stability	≤ 1 % per year
Chamber voltage	300 V nominal ± 400 V maximal
Polarity effect	≤ 1 % for electrons ≥ 9 MeV
Directional response in water	≤ ± 0.1 % for chamber tilting ≤ ± 10°
Leakage current	≤ ± 4 fA
Cable leakage	≤ 3.5 pC/(Gy·cm)

### Materials and measures:

Entrance foil	0.03 mm PE (polyethylene CH <sub>2</sub> ), 2.76 mg/cm <sup>2</sup>
Protection cap	0.87 mm PMMA, 1.19 g/cm <sup>3</sup> , 0.4 mm air
Total window area density	106 mg/cm <sup>2</sup> , 1.3 mm (protection cap included)
Water-equivalent window thickness	1.06 mm (protection cap included)
Sensitive volume	radius 2.65 mm depth 2 mm
Guard ring width	< 0.2 mm

### Ion collection efficiency at nominal voltage:

Ion collection time	90 μs
Max. dose rate for ≥ 99.5 % saturation	12 Gy/s
≥ 99.0 % saturation	24 Gy/s
Max. dose per pulse for ≥ 99.5 % saturation	0.7 mGy
≥ 99.0 % saturation	1.4 mGy

### Useful ranges:

Chamber voltage	± (100 ... 300) V
Radiation quality	(2 ... 45) MeV electrons
Field size	(3 x 3) cm <sup>2</sup> ... (40 x 40) cm <sup>2</sup>
Temperature	(10 ... 40) °C (50 ... 104) °F
Humidity	(10 ... 80) %, max 20 g/m <sup>3</sup>
Air pressure	(700 ... 1060) hPa

### Ordering Information

TN23343 Markus electron chamber 0.055 cm<sup>3</sup>,  
connecting system BNT  
TW23343 Markus electron chamber 0.055 cm<sup>3</sup>,  
connecting system TNC  
TM23343 Markus electron chamber 0.055 cm<sup>3</sup>,  
connecting system M

### Options

T48010 Radioactive check device <sup>90</sup>Sr  
T23343/11 Chamber holding device for check device



# Roos Chamber

## Type 34001

*Waterproof plane parallel chamber for absolute dosimetry in high-energy electron and proton beams*

### Features

- ▶ Perturbation-free, minimized polarity effect
- ▶ Waterproof, wide guard ring design
- ▶ Sensitive volume 0.35 cm<sup>3</sup>, vented to air
- ▶ Radioactive check device (option)

The 34001 Roos chamber is the golden standard for absolute dose measurements in high-energy electron beams. Modern dosimetry protocols refer to the chamber's design and provide dosimetric correction factors. Its waterproof design allows the chamber to be used in water or in solid state phantoms. The Roos chamber is also well suited for the measurement of high-energy photon depth dose curves up to 2.5 mm below the water surface. The chamber can be used for dose measurements of proton beams.

### Specification

Type of product	vented plane parallel ionization chamber acc. IEC 60731
Application	absolute dosimetry in high-energy electron and proton beams
Measuring quantity	absorbed dose to water
Reference radiation quality	<sup>60</sup> Co
Nominal sensitive volume	0.35 cm <sup>3</sup>
Design	waterproof, vented
Reference point	in chamber center, 1.12 mm below surface
Direction of incidence	perpendicular to chamber plane, see label FOCUS
Nominal response	12 nC/Gy
Long-term stability	≤ 0.5 % per year
Chamber voltage	200 V nominal ± 400 V maximal
Polarity effect	< 0.5 %
Directional response in water	≤ ± 0.1 % for chamber tilting ≤ ± 10°
Leakage current	≤ ± 4 fA
Cable leakage	≤ 1 pC/(Gy·cm)

### Materials and measures:

Entrance window	1 mm PMMA, 1.19 g/cm <sup>3</sup> 0.02 mm graphite, 0.82 g/cm <sup>3</sup> 0.1 mm varnish, 1.19 g/cm <sup>3</sup>
Total window area density	132 mg/cm <sup>2</sup>
Water-equivalent window thickness	1.3 mm
Sensitive volume	radius 7.5 mm depth 2 mm
Guard ring width	4 mm

### Ion collection efficiency at nominal voltage:

Ion collection time	125 μs
Max. dose rate for ≥ 99.5 % saturation	5.2 Gy/s
≥ 99.0 % saturation	10.4 Gy/s
Max. dose per pulse for ≥ 99.5 % saturation	0.46 mGy
≥ 99.0 % saturation	0.93 mGy

### Useful ranges:

Chamber voltage	± (50 ... 300) V
Radiation quality	(2 ... 45) MeV electrons <sup>60</sup> Co ... 25 MV photons (70 ... 250) MeV protons
Field size	(4 x 4) cm <sup>2</sup> ... (40 x 40) cm <sup>2</sup>
Temperature	(10 ... 40) °C (50 ... 104) °F
Humidity	(10 ... 80) %, max 20 g/m <sup>3</sup>
Air pressure	(700 ... 1060) hPa

### Ordering Information

- TN34001 Roos electron chamber 0.35 cm<sup>3</sup>,  
connecting system BNT
- TW34001 Roos electron chamber 0.35 cm<sup>3</sup>,  
connecting system TNC
- TM34001 Roos electron chamber 0.35 cm<sup>3</sup>,  
connecting system M

### Options

- T48010 Radioactive check device <sup>90</sup>Sr
- T48004 Chamber holding device for check device



# Bragg Peak Chambers

## Types 34070, 34073

*Waterproof plane-parallel chambers for dosimetry in proton beams*

### Features

- ▶ Waterproof, wide guard ring design
- ▶ Sensitive volumes 10.5 cm<sup>3</sup> and 2.5 cm<sup>3</sup>, vented to air

The Bragg peak chambers are designed to measure the exact location of the Bragg peak in therapy proton beams. The large diameters of the chambers allow the measurement of the complete proton beam diameter (non-scanned) including the scattered protons. The chambers are waterproof and consequently can either be used in air behind a water column or in a water phantom.

In water, both Bragg Peak chambers can be used for measurements of horizontal beams. Due to the thicker entrance and exit windows, the 34070 Bragg Peak chamber can additionally be used in vertical beams where measurements are performed in different water depths.

### Specification

Type of products	vented plane parallel ionization chambers
Application	relative dosimetry in high-energy proton beams
Nominal sensitive volumes	10.5 cm <sup>3</sup> , 2.5 cm <sup>3</sup> (34070, 34073)
Design	waterproof, vented
Reference point	in chamber center, 3.47 mm, 1.13 mm from chamber surface
Direction of incidence	perpendicular to chamber plane, see label 'Focus'
Nominal response	325 nC/Gy, 78 nC/Gy (at <sup>60</sup> Co free in air)
Chamber voltage	400 V nominal ± 500 V maximal
Polarity effect	≤ 1 %
Leakage current	≤ ± 100 fA
Cable leakage	≤ 1 pC/(Gy·cm)
Cable length	2.5 m

### Materials and measures:

Entrance window	3.35 mm, 1.01 mm PMMA 0.02 mm graphite 0.1 mm varnish
Total window area density	411 mg/cm <sup>2</sup> , 133 mg/cm <sup>2</sup>
Water-equivalent window thickness	4 mm, 1.3 mm
Sensitive volume	radius 40.8 mm, 19.8 mm depth 2 mm
Guard ring width	1.1 mm, 4 mm

### Ion collection efficiency at nominal voltage:

Ion collection time	67 μs
Max. dose rate for ≥ 99.5 % saturation	21 Gy/s
≥ 99.0 % saturation	42 Gy/s
Max. dose per pulse for ≥ 99.5 % saturation	0.9 mGy
≥ 99.0 % saturation	1.8 mGy

### Useful ranges:

Chamber voltage	(300 ... 500) V
Radiation quality	(70 ... 250) MeV protons
Field size	diameter (3 ... 10) mm valid for both chamber types
Temperature	(10 ... 40) °C (50 ... 104) °F
Humidity	(10 ... 80) %, max 20 g/m <sup>3</sup>
Air pressure	(700 ... 1060) hPa

### Ordering Information

- TN34070-2,5 Bragg peak chamber 10.5 cm<sup>3</sup>, connecting system BNT
- TW34070-2,5 Bragg peak chamber 10.5 cm<sup>3</sup>, connecting system TNC
- TM34070-2,5 Bragg peak chamber 10.5 cm<sup>3</sup>, connecting system M
- TN34073-2,5 Bragg peak chamber 2.5 cm<sup>3</sup>, connecting system BNT
- TW34073-2,5 Bragg peak chamber 2.5 cm<sup>3</sup>, connecting system TNC
- TM34073-2,5 Bragg peak chamber 2.5 cm<sup>3</sup>, connecting system M



# PinPoint Chambers

## Type 31014, 31015

*Ultra small-sized therapy chambers for dosimetry in high-energy photon beams*

### Features

- ▶ Small-sized sensitive volumes of only 0.015 cm<sup>3</sup> and 0.03 cm<sup>3</sup>, 2 mm and 2.9 mm in diameter, vented to air
- ▶ Very high spatial resolution when used for scans perpendicular to the chamber axis
- ▶ Aluminum central electrode
- ▶ Radioactive check device (option)

The PinPoint chambers are ideal for dose measurements in small fields as encountered e.g. in IORT, IMRT and stereotactic beams. Relative dose distributions can be measured with very high spatial resolution when the chambers are moved perpendicular to the chamber axis. The waterproof, fully guarded chambers can be used in air, solid state phantoms and in water.

### Specification

Type of products	vented cylindrical ionization chambers
Application	dosimetry in high-energy photon beams with high spatial resolution
Measuring quantities	absorbed dose to water, air kerma, exposure
Reference radiation quality	<sup>60</sup> Co
Nominal sensitive volume	0.015 cm <sup>3</sup> , 0.03 cm <sup>3</sup>
Design	waterproof, vented, fully guarded
Reference point	on chamber axis, 3.4 mm from chamber tip
Direction of incidence	radial, axial (31014)
Pre-irradiation dose	2 Gy
Nominal response	400 pC/Gy, 800 pC/Gy
Long-term stability	≤ 1 % per year
Chamber voltage	400 V nominal ± 500 V maximal
Polarity effect	≤ ± 2 %
Directional response in water	≤ ± 0.5 % for rotation around the chamber axis, ≤ ± 1 % for tilting of the axis up to ± 20° (radial incidence) ± 15° (axial incidence)
Leakage current	≤ ± 4 fA
Cable leakage	≤ 1 pC/(Gy·cm)

### Materials and measures:

Wall of sensitive volume	0.57 mm PMMA, 1.19 g/cm <sup>3</sup> 0.09 mm graphite, 1.85 g/cm <sup>3</sup>
Total wall area density	85 mg/cm <sup>2</sup>
Dimensions of sensitive volume	radius 1 mm, 1.45 mm length 5 mm
Central electrode	Al 99.98, diameter 0.3 mm
Build-up cap	PMMA, thickness 3 mm

### Ion collection efficiency at nominal voltage:

Ion collection time	20 μs, 50 μs
Max. dose rate for ≥ 99.5 % saturation	265 Gy/s, 29 Gy/s
≥ 99.0 % saturation	580 Gy/s, 55 Gy/s
Max. dose per pulse for ≥ 99.5 % saturation	3.5 mGy, 1.2 mGy
≥ 99.0 % saturation	7 mGy, 2.3 mGy

### Useful ranges:

Chamber voltage	± (100 ... 400) V
Radiation quality	<sup>60</sup> Co ... 50 MV photons
Field size	(2 x 2) cm <sup>2</sup> ... (30 x 30) cm <sup>2</sup>
Temperature	(10 ... 40) °C (50 ... 104) °F
Humidity	(10 ... 80) %, max 20 g/m <sup>3</sup>
Air pressure	(700 ... 1060) hPa

### Ordering Information

- TN31014 PinPoint chamber 0.015 cm<sup>3</sup>,  
connecting system BNT
- TW31014 PinPoint chamber 0.015 cm<sup>3</sup>,  
connecting system TNC
- TM31014 PinPoint chamber 0.015 cm<sup>3</sup>,  
connecting system M
- TN31015 PinPoint chamber 0.03 cm<sup>3</sup>,  
connecting system BNT
- TW31015 PinPoint chamber 0.03 cm<sup>3</sup>,  
connecting system TNC
- TM31015 PinPoint chamber 0.03 cm<sup>3</sup>,  
connecting system M

### Options

- T48012 Radioactive check device <sup>90</sup>Sr
- T48002.1.007 Chamber holding device for check device



## PinPoint 3D Chamber Type 31016

*Ultra small-sized therapy chamber  
with 3D characteristics for dosimetry  
in high-energy photon beams*

### Features

- ▶ Small-sized sensitive volume 0.016 cm<sup>3</sup>, vented to air
- ▶ Minimized directional response
- ▶ Aluminum central electrode
- ▶ Radioactive check device (option)

The 31016 PinPoint 3D chamber is ideal for dose measurements in small fields as encountered e.g. in IORT, IMRT and stereotactic beams. Relative dose distributions can be measured with high spatial resolution in any direction. The waterproof, fully guarded chamber can be used in air, solid state phantoms and in water.

### Specification

Type of product	vented cylindrical ionization chamber
Application	dosimetry in high-energy photon beams
Measuring quantities	absorbed dose to water, air kerma, exposure
Reference radiation quality	<sup>60</sup> Co
Nominal sensitive volume	0.016 cm <sup>3</sup>
Design	waterproof, vented, fully guarded
Reference point	on chamber axis, 2.4 mm from chamber tip
Direction of incidence	radial
Pre-irradiation dose	2 Gy
Nominal response	400 pC/Gy
Long-term stability	≤ 1 % per year
Chamber voltage	400 V nominal ± 500 V maximal
Polarity effect	≤ ± 2 %
Directional response in water	≤ ± 0.5 % for rotation around the chamber axis, ≤ ± 1 % for tilting of the axis up to ± 110°
Leakage current	≤ ± 4 fA
Cable leakage	≤ 1 pC/(Gy·cm)

### Materials and measures:

Wall of sensitive volume	0.57 mm PMMA, 1.19 g/cm <sup>3</sup> 0.09 mm graphite, 1.85 g/cm <sup>3</sup>
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Total wall area density	85 mg/cm <sup>2</sup>
Dimensions of sensitive volume	radius 1.45 mm length 2.9 mm
Central electrode	Al 99.98, diameter 0.3 mm
Build-up cap	PMMA, thickness 3 mm

### Ion collection efficiency at nominal voltage:

Ion collection time	60 μs
Max. dose rate for ≥ 99.5 % saturation	19 Gy/s
≥ 99.0 % saturation	38 Gy/s
Max. dose per pulse for ≥ 99.5 % saturation	1.0 mGy
≥ 99.0 % saturation	1.9 mGy

### Useful ranges:

Chamber voltage	± (100 ... 400) V
Radiation quality	<sup>60</sup> Co ... 50 MV photons
Field size	(2 x 2) cm <sup>2</sup> ... (30 x 30) cm <sup>2</sup>
Temperature	(10 ... 40) °C (50 ... 104) °F
Humidity	(10 ... 80) %, max 20 g/m <sup>3</sup>
Air pressure	(700 ... 1060) hPa

### Ordering Information

- TN31016 PinPoint 3D chamber 0.016 cm<sup>3</sup>,  
connecting system BNT
- TW31016 PinPoint 3D chamber 0.016 cm<sup>3</sup>,  
connecting system TNC
- TM31016 PinPoint 3D chamber 0.016 cm<sup>3</sup>,  
connecting system M

### Options

- T48012 Radioactive check device <sup>90</sup>Sr
- T48002.1.008 Chamber holding device for check device



# microLion Chamber

## Type 31018

*Liquid filled ion chamber for dose distribution measurements in radiotherapy with high spatial resolution*

### Features

- ▶ Liquid filled sensitive volume of 0.002 cm<sup>3</sup>
- ▶ Suitable for dose scanning in radiotherapy beams with a superior spatial resolution
- ▶ Suitable for use in water
- ▶ Connector types: BNT, TNC or M

The waterproof micro liquid ion chamber<sup>1</sup> (microLion) has been specially designed for relative beam profile and depth dose curve measurements in a motorized water phantom. It is used for characterization of LINAC radiation fields where superior spatial resolution is desired, like stereotactic fields. Due to the liquid filling, the microLion chamber delivers a high signal in relation to its very small sensitive volume.

The recommended chamber voltage of 800 V is delivered by an additional HV-Supply. The HV-Supply can be connected to the UNIDOS<sup>webline</sup> or the latest version of the TANDEM dosimeters.

### Specification

Type of product	liquid filled ionization chamber
Application	dose distribution measurements in high-energy photon beams with high spatial resolution
Measuring quantity	absorbed dose to water
Reference radiation quality	<sup>60</sup> Co
Nominal sensitive volume	0.002 cm <sup>3</sup> (exactly 1.7 mm <sup>3</sup> )
Design	liquid filled, waterproof
Reference point	on chamber axis, 0.975 mm from entrance window
Direction of incidence	axial
Pre-irradiation dose	≥ 3 Gy
Nominal response	9.8 nC/Gy
Long-term stability	≤ 1 % per year
Chamber voltage	800 V nominal ± 1000 V maximal
Polarity effect	< 1 %
Directional response in water	≤ ± 0.5 % for rotation around the chamber axis, ≤ ± 1 % for tilting of the axis up to ± 40°
Leakage current	≤ ± 1 pA

Cable leakage	≤ 1 pC/(Gy·cm)
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Cable length	1.3 m
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### Materials and measures:

Entrance window	0.5 mm polystyrene 0.28 mm graphite 0.02 mm varnish
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Total window area density	107 mg/cm <sup>2</sup>
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Dimensions of sensitive volume	radius 1.25 mm depth 0.35 mm
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Central electrode	graphite
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### Ion collection efficiency at nominal voltage:

Ion collection time	5.3 ms
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Max. dose rate at f ≤ 190 Hz for	
≥ 99.5 % saturation	13.1 Gy/min
≥ 99.0 % saturation	26.4 Gy/min

Max. dose per pulse at f ≤ 190 Hz for	
≥ 99.5 % saturation	1.36 mGy
≥ 99.0 % saturation	2.73 mGy

### Useful ranges:

Chamber voltage	± (400 ... 1000) V
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Radiation quality	<sup>60</sup> Co ... 25 MV photons
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Field size	(1 x 1) cm <sup>2</sup> ... (20 x 20) cm <sup>2</sup>
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Temperature	(10 ... 35) °C (50 ... 95) °F
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Humidity	(10 ... 80) %, max 20 g/m <sup>3</sup>
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Air pressure	(700 ... 1060) hPa
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### Ordering Information

TN31018-1,3 microLion chamber 0.002 cm<sup>3</sup>,  
connecting system BNT

TW31018-1,3 microLion chamber 0.002 cm<sup>3</sup>,  
connecting system TNC

TM31018-1,3 microLion chamber 0.002 cm<sup>3</sup>,  
connecting system M

T16036 HV-Supply for ionization chambers,  
range ± 950 V

T4316/U331 TBA detector holder

<sup>1</sup> The microLion chamber was designed in collaboration with Göran Wickman and Thord Holmstroem, University of Umeå, Sweden and is based on a well-tested and patented LIC concept.





# Diamond Detector

## Type 60003

*Waterproof diamond detector for dose measurements in high-energy photon and electron beams*

### Features

- ▶ Very small sensitive volume of 1 to 6 mm<sup>3</sup> and typically 0.3 mm thickness
- ▶ Good tissue-equivalence
- ▶ Suitable for dose scanning in IMRT and stereotactic fields because of its excellent spatial resolution

The Diamond Detector, based on a naturally grown diamond, is a nearly tissue-equivalent radiation detector. It is designed for dose distribution measurements in high-energy photon and electron beams, featuring a favorable signal-to-noise ratio. Because of its small sensitive volume, the detector is applied for IMRT, stereotactic beams, brachytherapy and water phantom scanning, and is especially well suited for beams with very small field sizes or steep fluence gradients. The Diamond Detector responds with an excellent spatial resolution, low energy and temperature dependence, high sensitivity, nearly no directional dependence and high resistance to radiation damage. The cable length is 1.5 m.

### Specification

Type of product	diamond detector
Application	dosimetry in radiotherapy beams
Measuring quantity	absorbed dose to water
Reference radiation quality	<sup>60</sup> Co
Nominal sensitive volume	(1 ... 6) mm <sup>3</sup>
Design	waterproof, disk-shaped sensitive volume perpendicular to detector axis
Reference point	on detector axis, 1 mm from detector tip
Direction of incidence	radial or axial
Pre-irradiation dose	(5 ... 15) Gy
Nominal response	(50 ... 500) nC/Gy
Energy response	at higher depths than $d_{\max}$ , the percentage depth dose curves match curves measured with ionization chambers within $\pm 0.5$ %
Detector bias voltage	+ 100 V ( $\pm 1$ %)
Directional response	$\leq \pm 2$ % for tilting $\leq \pm 170^\circ$

Leakage current	$\leq 5$ pA
Cable leakage	$\leq 1$ pC/(Gy·cm)
Charge collection time	$\leq 10$ ns

### Measures:

Sensitive area	(3 ... 15) mm <sup>2</sup>
Thickness of sensitive area	(0.1 ... 0.4) mm
Water-equivalent window thickness	1.15 mm
Outer dimensions	diameter 7.3 mm

### Useful ranges:

Dose rate	(0.05 ... 30) Gy/min
Radiation quality	80 keV ... 20 MV photons (4 ... 20) MeV electrons
Temperature	(10 ... 40) °C (50 ... 104) °F
Humidity	(10 ... 80) %, max 20 g/m <sup>3</sup>
Air pressure	(700 ... 1060) hPa

### Ordering Information

TM60003 Diamond Detector, connecting system M, cable length 1.5 m



## Dosimetry Diode P Type 60016

*Waterproof silicon detector for dosimetry in high-energy photon beams up to field size 40 cm x 40 cm*

### Features

- ▶ Useful for measurements in small and large photon fields
- ▶ Excellent spatial resolution
- ▶ Minimized energy response for field size independent measurements up to 40 cm x 40 cm

The 60016 Dosimetry Diode P is ideal for dose measurements in small photon fields as encountered in IORT, IMRT and stereotactic beams. The excellent spatial resolution makes it possible to measure very precisely beam profiles even in the penumbra region of small fields. The superior energy response enables the user to perform accurate percentage depth dose measurements which are field size independent up to field sizes of (40 x 40) cm<sup>2</sup>. The waterproof detector can be used in air, solid state phantoms and in water.

### Specification

Type of product	p-type silicon diode
Application	dosimetry in radiotherapy beams
Measuring quantity	absorbed dose to water
Reference radiation quality	<sup>60</sup> Co
Nominal sensitive volume	0.03 mm <sup>3</sup>
Design	waterproof, disk-shaped sensitive volume perpendicular to detector axis
Reference point	on detector axis, 2 mm from detector tip
Direction of incidence	axial
Nominal response	9 nC/Gy
Dose stability	≤ 0.5 %/kGy at 6 MV ≤ 1 %/kGy at 15 MV ≤ 0.5 %/kGy at 5 MeV ≤ 4 %/kGy at 21 MeV
Temperature response	≤ 0.4 %/K
Energy response	at higher depths than $d_{max}$ , the percentage depth dose curves match curves measured with ionization chambers within ± 0.5 %
Detector bias voltage	0 V
Signal polarity	negative

Directional response in water	≤ ± 0.5 % for rotation around the chamber axis, ≤ ± 1 % for tilting ≤ ± 40°
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Leakage current	≤ ± 50 fA
Cable leakage	≤ 1 pC/(Gy·cm)

### Materials and measures:

Entrance window	1 mm RW3, 1.045 g/cm <sup>3</sup> 1 mm epoxy
Total window area density	220 mg/cm <sup>2</sup>
Water-equivalent window thickness	2.21 mm
Sensitive volume	1 mm <sup>2</sup> circular 30 μm thick
Outer dimensions	diameter 7 mm, length 47 mm

### Useful ranges:

Radiation quality	<sup>60</sup> Co ... 25 MV photons
Field size	(1 x 1) cm <sup>2</sup> ... (40 x 40) cm <sup>2</sup>
Temperature	(10 ... 40) °C (50 ... 104) °F
Humidity	(10 ... 80) %, max 20 g/m <sup>3</sup>

### Ordering Information

TN60016 Dosimetry Diode P, connecting system BNT  
 TW60016 Dosimetry Diode P, connecting system TNC  
 TM60016 Dosimetry Diode P, connecting system M



## Dosimetry Diode E

### Type 60017

*Waterproof silicon detector for dosimetry in high-energy electron and photon beams*

#### Features

- ▶ Useful for measurements in all electron fields and for small photon fields
- ▶ Excellent spatial resolution
- ▶ Minimized energy response
- ▶ Thin entrance window for measurements in the vicinity of surfaces and interfaces

The 60017 Dosimetry Diode E is ideal for dose measurements in small electron and photon fields as encountered in IORT, IMRT and stereotactic beams. The excellent spatial resolution makes it possible to measure very precisely beam profiles even in the penumbra region of small fields. The superior energy response enables the user to perform accurate percentage depth dose measurements which are field size independent up to field sizes of (40 x 40) cm<sup>2</sup>. The waterproof detector can be used in air, solid state phantoms and in water.

#### Specification

Type of product	p-type silicon diode
Application	dosimetry in radiotherapy beams
Measuring quantity	absorbed dose to water
Reference radiation quality	<sup>60</sup> Co
Nominal sensitive volume	0.03 mm <sup>3</sup>
Design	waterproof, disk-shaped sensitive volume perpendicular to detector axis
Reference point	on detector axis, 0.77 mm from detector tip
Direction of incidence	axial
Nominal response	9 nC/Gy
Dose stability	≤ 0.5 %/kGy at 6 MV ≤ 1 %/kGy at 15 MV ≤ 0.5 %/kGy at 5 MeV ≤ 4 %/kGy at 21 MeV
Temperature response	≤ 0.4 %/K
Energy response	at higher depths than d <sub>max</sub> , the percentage depth dose curves match curves measured with ionization chambers within ± 0.5 %
Detector bias voltage	0 V
Signal polarity	negative

Directional response in water	≤ ± 0.5 % for rotation around the chamber axis, ≤ ± 1 % for tilting ≤ ± 20°
Leakage current	≤ ± 50 fA
Cable leakage	≤ 1 pC/(Gy·cm)

#### Materials and measures:

Entrance window	0.3 mm RW3, 1.045 g/cm <sup>3</sup> 0.4 mm epoxy
Total window area density	140 mg/cm <sup>2</sup>
Water-equivalent window thickness	1,33 mm
Sensitive volume	1 mm <sup>2</sup> circular 30 μm thick
Outer dimensions	diameter 7 mm, length 45.5 mm

#### Useful ranges:

Radiation quality	(6 ... 25) MeV electrons <sup>60</sup> Co ... 25 MV photons
Field size	(1 x 1) cm <sup>2</sup> ... (40 x 40) cm <sup>2</sup> for electrons (1 x 1) cm <sup>2</sup> ... (10 x 10) cm <sup>2</sup> for photons
Temperature	(10 ... 40) °C (50 ... 104) °F
Humidity	(10 ... 80) %, max 20 g/m <sup>3</sup>

#### Ordering Information

TN60017 Dosimetry Diode E, connecting system BNT  
 TW60017 Dosimetry Diode E, connecting system TNC  
 TM60017 Dosimetry Diode E, connecting system M



# 0.02 cm<sup>3</sup> Soft X-Ray Chamber

## Type 23342

*Thin window plane parallel chamber for dose measurements in superficial radiation therapy*

### Features

- ▶ Ultra thin entrance window
- ▶ For low-energy photons from 8 keV to 35 keV
- ▶ Sensitive volume 0.02 cm<sup>3</sup>, vented to air
- ▶ Radioactive check device (option)

The 23342 soft X-ray chamber is the golden standard for absolute dose measurements in low-energy photon beams as used in superficial radiation therapy. Correction factors needed for the determination of absorbed dose to water are available. The chamber is designed for the use in solid state phantoms.

### Specification

Type of product	vented plane parallel ionization chamber acc. IEC 60731
Application	absolute dosimetry in low-energy photon beams
Measuring quantities	absorbed dose to water, air kerma, exposure
Reference radiation quality	30 kV, HVL 0.37 mm Al (T30)
Nominal sensitive volume	0.02 cm <sup>3</sup>
Design	not waterproof, vented
Reference point	in chamber center of entrance foil underside
Direction of incidence	perpendicular to chamber plane
Nominal response	1 nC/Gy
Long-term stability	≤ 1 % per year
Chamber voltage	300 V nominal ± 500 V maximal
Directional response	≤ ± 1 % for chamber tilting up to ± 20°
Leakage current	≤ ± 10 fA
Cable leakage	≤ 1 pC/(Gy·cm)

### Materials and measures:

Entrance foil	0.03 mm PE
Total window area density	2.76 mg/cm <sup>2</sup>
Sensitive volume	radius 1.5 mm depth 1 mm

### Ion collection efficiency at nominal voltage:

Ion collection time	30 μs
Max. dose rate for ≥ 99.5 % saturation	175 Gy/s
≥ 99.0 % saturation	350 Gy/s
Max. dose per pulse for ≥ 99.5 % saturation	1.8 mGy
≥ 99.0 % saturation	4.5 mGy

### Useful ranges:

Chamber voltage	± (100 ... 400) V
Radiation quality	(8 ... 35) keV X-rays
Field size	(1 x 1) cm <sup>2</sup> ... (40 x 40) cm <sup>2</sup>
Temperature	(10 ... 40) °C (50 ... 104) °F
Humidity	(20 ... 80) %, max 20 g/m <sup>3</sup>
Air pressure	(700 ... 1060) hPa

### Ordering Information

TN23342 Soft X-ray chamber 0.02 cm<sup>3</sup>,  
connecting system BNT

TW23342 Soft X-ray chamber 0.02 cm<sup>3</sup>,  
connecting system TNC

TM23342 Soft X-ray chamber 0.02 cm<sup>3</sup>,  
connecting system M

### Options

T48010 Radioactive check device <sup>90</sup>Sr

T23238 Chamber holding device for check device



# 0.2 cm<sup>3</sup> Soft X-Ray Chamber

## Type 23344

*Thin window plane parallel chamber for dose measurements in superficial radiation therapy*

### Features

- ▶ Ultra thin entrance window
- ▶ For low-energy photons from 8 keV to 35 keV
- ▶ Sensitive volume 0.2 cm<sup>3</sup>, vented to air
- ▶ Radioactive check device (option)

The 23344 soft X-ray chamber is used for absolute dose measurements in low-energy photon beams as used in superficial radiation therapy. The sensitive volume is larger than that of the 23342 chamber, giving a higher signal at the cost of a lower spatial resolution. Correction factors needed for the determination of absorbed dose to water are available. The chamber is designed for the use in solid state phantoms.

### Specification

Type of product	vented plane parallel ionization chamber acc. IEC 60731
Application	absolute dosimetry in low-energy photon beams
Measuring quantities	absorbed dose to water, air kerma, exposure
Reference radiation quality	30 kV, HVL 0.37 mm Al (T30)
Nominal sensitive volume	0.2 cm <sup>3</sup>
Design	not waterproof, vented
Reference point	in chamber center of entrance foil underside
Direction of incidence	perpendicular to chamber plane
Nominal response	7 nC/Gy
Long-term stability	≤ 1 % per year
Chamber voltage	400 V nominal ± 500 V maximal
Directional response	≤ ± 1 % for chamber tilting up to ± 20°
Leakage current	≤ ± 10 fA
Cable leakage	≤ 1 pC/(Gy·cm)

### Materials and measures:

Entrance foil	0.03 mm PE
Total window area density	2.76 mg/cm <sup>2</sup>
Sensitive volume	radius 6.5 mm depth 1.5 mm

### Ion collection efficiency at nominal voltage:

Ion collection time	30 μs
Max. dose rate for ≥ 99.5 % saturation	60 Gy/s
≥ 99.0 % saturation	120 Gy/s
Max. dose per pulse for ≥ 99.5 % saturation	1.1 mGy
≥ 99.0 % saturation	2.7 mGy

### Useful ranges:

Chamber voltage	± (100 ... 400) V
Radiation quality	(8 ... 35) keV X-rays
Field size	(2 x 2) cm <sup>2</sup> ... (40 x 40) cm <sup>2</sup>
Temperature	(10 ... 40) °C (50 ... 104) °F
Humidity	(20 ... 80) %, max 20 g/m <sup>3</sup>
Air pressure	(700 ... 1060) hPa

### Ordering Information

TN23344 Soft X-ray chamber 0.2 cm<sup>3</sup>,  
connecting system BNT

TW23344 Soft X-ray chamber 0.2 cm<sup>3</sup>,  
connecting system TNC

TM23344 Soft X-ray chamber 0.2 cm<sup>3</sup>,  
connecting system M

### Options

T48010 Radioactive check device <sup>90</sup>Sr

T23236 Chamber holding device for check device



## 0.005 cm<sup>3</sup> Soft X-Ray Chamber Type 34013

*Thin window plane parallel chamber for dose measurements in superficial radiation therapy*

### Features

- ▶ Ultra thin entrance window
- ▶ For low-energy photons from 8 keV to 35 keV
- ▶ Extremely small size
- ▶ Sensitive volume 0.005 cm<sup>3</sup>, vented to air

The 34013 soft X-ray chamber is used for absolute dose measurements in low-energy photon beams as used in superficial radiation therapy. The chamber's small size enables the user to perform measurements with excellent spatial resolution. Correction factors needed for the determination of absorbed dose to water are available. The chamber is designed for the use in solid state phantoms.

### Specification

Type of product	vented plane parallel ionization chamber
Application	absolute dosimetry in low-energy photon beams
Measuring quantities	absorbed dose to water, air kerma, exposure
Reference radiation quality	30 kV, HVL 0.37 mm Al (T30)
Nominal sensitive volume	0.005 cm <sup>3</sup>
Design	not waterproof, vented
Reference point	in chamber center of entrance foil underside
Direction of incidence	perpendicular to chamber plane
Nominal response	200 pC/Gy
Long-term stability	≤ 1 % per year
Chamber voltage	400 V nominal ± 400 V maximal
Directional response	≤ 5 % for chamber tilting up to ± 10°
Leakage current	≤ ± 10 fA
Cable leakage	≤ 1 pC/(Gy·cm)

### Materials and measures:

Entrance foil	25 μm PE
Total window area density	2.3 mg/cm <sup>2</sup>
Sensitive volume	radius 0.85 mm depth 0.75 mm

### Ion collection efficiency at nominal voltage:

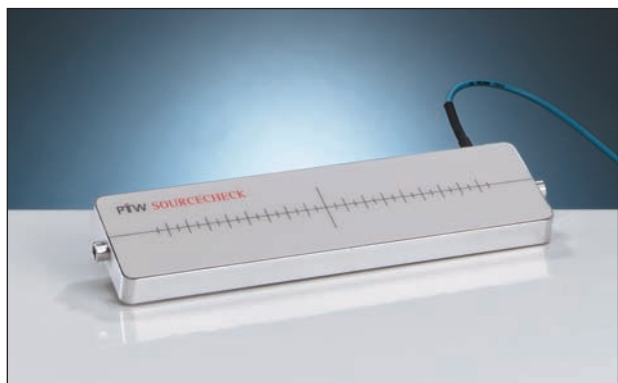
Ion collection time	0.03 ms
Max. dose rate for ≥ 99.5 % saturation	0.99 kGy/s
≥ 99.0 % saturation	1.9 kGy/s
Max. dose per pulse for ≥ 99.5 % saturation	4 mGy
≥ 99.0 % saturation	10 mGy

### Useful ranges:

Chamber voltage	± (100 ... 400) V
Radiation quality	(8 ... 35) keV X-rays
Field size	(0.5 x 0.5) cm <sup>2</sup> ... (40 x 40) cm <sup>2</sup>
Temperature	(10 ... 40) °C (50 ... 104) °F
Humidity	(20 ... 80) %, max 20 g/m <sup>3</sup>
Air pressure	(700 ... 1060) hPa

### Ordering Information

- TN34013 Soft X-ray chamber 0.005 cm<sup>3</sup>,  
connecting system BNT
- TW34013 Soft X-ray chamber 0.005 cm<sup>3</sup>,  
connecting system TNC
- TM34013 Soft X-ray chamber 0.005 cm<sup>3</sup>,  
connecting system M



# SOURCECHECK

## Type 34051

*Flat ionization chamber for measuring the source strength of radioactive seeds and intravascular brachytherapy sources*

### Features

- ▶ Measures the source strength with  $4\pi$  geometry
- ▶ Accommodates the source inside the chamber volume
- ▶ Vented sensitive volume of 55 cm<sup>3</sup>

The SOURCECHECK ionization chamber is the ideal device for measuring the source strength of radioactive seeds, which are used in radiation therapy for permanent implantation into cancer tissue and of sources used in intravascular brachytherapy (IVB). It is specially designed to feature a full  $4\pi$  geometry for high precision source strength measurements. A polystyrol guide tube is located in the center of the chamber to accommodate the radioactive source to be measured. The SOURCECHECK chamber makes it possible to measure single seeds or seed trains of up to 130 mm length. A wide guard ring reduces the influence of scattered radiation from the housing to improve the measuring accuracy. Since the sensitive volume is vented, air density corrections are required. For measurements, the SOURCECHECK chamber is connected to an electrometer like UNIDOS, UNIDOS<sup>webline</sup> or UNIDOS E.

### Specification

Type of product	vented flat ionization chamber
Application	source strength measurement of brachytherapy sources
Measuring quantities	air kerma strength, apparent activity, exposure strength
Calibration	<sup>125</sup> I, others upon request
Nominal sensitive volume	55 cm <sup>3</sup>
Design	vented; $4\pi$ geometry
Reference point	center of longitudinal chamber axis
Chamber voltage	400 V
Nominal response	28.3 fA/MBq for <sup>125</sup> I
Leakage current	$\leq \pm 5$ fA
Cable leakage	$\leq 1$ pC/(Gy·cm)

### Materials and measures:

Guiding tube	Polystyrol, inner diameter 3.4 mm (minimum)
Outer dimensions	width 220 mm depth 60 mm height 15 mm
Weight	200 g

### Useful ranges:

Temperature	(10 ... 40) °C (50 ... 104) °F
Humidity	(10 ... 80) %, max 20 g/m <sup>3</sup>
Air pressure	(700 ... 1060) hPa

### Ordering Information

TN34051 SOURCECHECK, connecting system BNT  
 TW34051 SOURCECHECK, connecting system TNC  
 TM34051 SOURCECHECK, connecting system M

### Options

Adapters for single seeds  
 Adapters for strands



## Well-Type Chamber Type 33004

*Well-type ionization chamber for afterloading source strength measurements*

### Features

- ▶ Vented sensitive volume of 200 cm<sup>3</sup>
- ▶ Makes it possible to measure the source strength of afterloading sources according to AAPM TG-56
- ▶ Accommodates suitable applicator adapters for commercial afterloading brachytherapy systems

According to AAPM TG-56, the well-type chamber is required for the source strength measurement of radioactive afterloading sources. The recommended calibration factor is the air kerma strength (cGy m<sup>2</sup>/h). The PTW calibration certificate also includes factors for apparent activity (GBq or Ci) and exposure strength (R m<sup>2</sup>/h). Suitable applicator adapters and calibrations are available for the commercial standard afterloading systems. The calibration of the well-type chamber is traceable to NIST, USA, and PTB, Germany. For measurements, the chamber is connected to a sensitive electrometer (e.g. UNIDOS, UNIDOS E, MULTIDOS, TANDEM), which has a reading in pA, a wide dynamic range and an interval time function. The well-type chamber is suitable for the calibration of high dose rate (HDR) and pulsed dose rate (PDR) sources such as <sup>192</sup>Ir. Calibrations for low dose rate sources (LDR) such as <sup>137</sup>Cs are available upon request.

### Specification

Type of product	vented well-type chamber
Application	calibration of afterloading sources
Measuring quantities	air kerma strength, apparent activity, exposure strength
Calibration	<sup>192</sup> Ir, others upon request
Nominal sensitive volume	200 cm <sup>3</sup>
Design	vented sensitive volume
Reference point	84.5 mm below chamber top
Chamber voltage	400 V nominal 500 V maximal
Change of response with source positioning change of ± 1 cm	< 1 %
Leakage current	≤ 0.5 pA

Measuring range	1.7 MBq ... 8.5 TBq for <sup>192</sup> Ir with UNIDOS (the upper limit of the measuring range at 400 V for a saturation of 99.5 % is 4 TBq)
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### Measures:

Inner well diameter	32 mm
Outer dimensions	height 190.5 mm base diameter 178 mm outer well diameter 93 mm
Weight	2.4 kg

### Useful ranges:

Temperature	(10 ... 40) °C (50 ... 104) °F
Humidity	(10 ... 80) %, max 20 g/m <sup>3</sup>
Air pressure	(700 ... 1060) hPa

### Ordering Information

TN33004 Well-type chamber, connecting system BNT  
 TW33004 Well-type chamber, connecting system TNC  
 TM33004 Well-type chamber, connecting system M

### Options

Universal adapters for catheters with diameters between 0.7 and 7.2 mm  
 Adapter for Nucletron microSelectron afterloaders (type 077.095)



# System Incorporated Detectors for Radiotherapy

Besides the radiation detectors presented in this chapter, there are available a number of further detectors which are incorporated components of therapy dosimeters. Firstly there are detectors used for in-vivo dosimetry during therapeutic treatments to control the radiation load given to patients. Secondly state-of-the-art linear and planar detector matrices for dose distribution measurements of intensity modulated therapy beams (IMRT) are part of the PTW detector range.



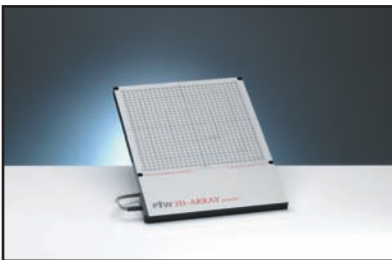
## Patient in-vivo Detectors

Semiconductor probes for in-vivo dosimetry are fixed to the patient's body to measure the patient skin, entrance or exit dose during external radiation treatments. Three different detector types for photon energies and one type for electron measurements are available. Additionally a risk organ diode with increased sensitivity and homogeneous directional response is available.



## LA48 Linear Chamber Array

The LA48 linear chamber array is designed specially for fast, accurate and reliable dynamic field dosimetry measurements of virtual wedges and multileaf collimators. It incorporates the latest development in fluid-filled ion chamber technology into an advanced ion chamber array. The combination of speed, accuracy and spatial resolution is simply not possible with other systems.



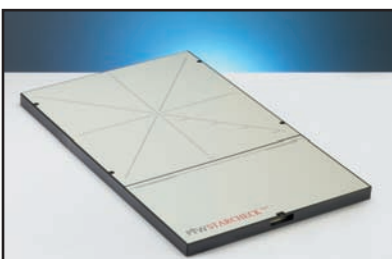
## 2D-Array *seven29* Planar Chamber Array

The 2D-ARRAY *seven29* is a new concept of an ion chamber matrix in a plane for IMRT verification and quality control in radiation therapy. There are 729 vented plane-parallel ion chambers located in a matrix of 27 x 27. Utilizing ion chambers avoids radiation defects, the major drawback of solid-state detectors.



## STARCHECK Planar Chamber Array

STARCHECK is a precise and reliable tool for fast measurements in radiation therapy beams. Typical applications are quality control and LINAC beam adjustment. The 527 ionization chambers feature an excellent relative response stability, avoiding the need of frequent recalibration. The excellent spatial resolution of only 3 mm ensures precise measurements even in penumbra regions.



## STARCHECK<sup>maxi</sup> Planar Chamber Array

STARCHECK<sup>maxi</sup> is a precise and reliable tool for fast measurements in radiation therapy beams. Typical applications are quality control and LINAC beam adjustment. The 707 ionization chambers feature an excellent relative response stability, avoiding the need of frequent recalibration. It combines the high-resolution of 3 mm as known from the STARCHECK with the ability to cover fields up to a size of 40 cm x 40 cm.

Details upon request

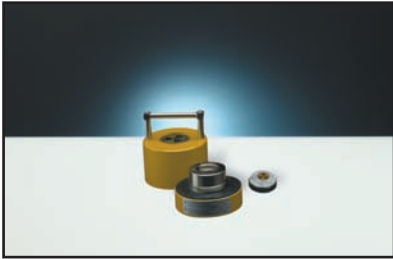
# Radioactive $^{90}\text{Sr}$ Check Devices

Radioactive check devices are used for air density corrections of vented ionization chambers and for constancy checks of the complete dosimeters including chamber. Appropriate holding devices to reproducibly adapt the various ion chambers to the radioactive check devices are available.



## T48012 Check Device for Thimble Chambers

The check device type T48012 is specially designed for thimble chambers and includes an encapsulated  $^{90}\text{Sr}$  source with a low activity of 33 MBq. The sensitive volume of the inserted chamber is irradiated from all directions. The check device is supplemented by a thermometer for controlling its inside temperature. The source is equivalent to ISO class C64444.



## T48010 Check Device for Flat Chambers

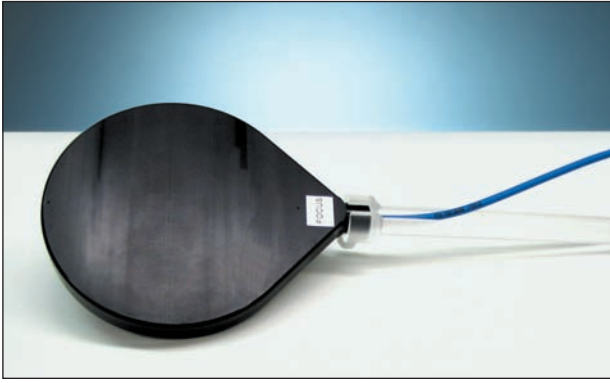
The check device type T48010 is specially designed for flat chambers and includes an encapsulated  $^{90}\text{Sr}$  source with a low activity of 20 MBq. The cylindrical source of the check device is placed near to the entrance window of the ion chamber by means of the appropriate holding device. The source is equivalent to ISO class C6X444.

Details upon request

# Diagnostic Detectors

## ▶ Diagnostic Detectors

SFD Chamber 75 cm <sup>3</sup>	▶	36
SFD Chamber 6 cm <sup>3</sup>	▶	37
CT Chambers	▶	38
Flat Chamber 30 cm <sup>3</sup>	▶	39
System Incorporated Detectors	▶	40



## 75 cm<sup>3</sup> SFD Diagnostic Chamber Type 34060

*Shadow-free plane parallel chamber  
for absolute dosimetry in diagnostic  
radiology*

### Features

- ▶ Shadow-free design for use with automatic exposure control / brightness control
- ▶ Sensitive volume 75 cm<sup>3</sup>, vented to air
- ▶ Suitable for measurements in front of and behind a phantom

The 34060 SFD diagnostic chamber is a general purpose, high precision chamber for measurements in diagnostic radiology. The chamber complies with the standard IEC 61674. Its shadow-free design makes it possible to use the chamber even while the automatic exposure control or brightness control is activated. Together with an adequate diagnostic dosimeter the chamber features a wide dynamic range for measurements either in front of or behind a patient-equivalent phantom. The length of the mounted connection cable is 2.5 m.

### Specification

Type of product	vented plane parallel ionization chamber acc. IEC 61674
Application	absolute dosimetry in diagnostic radiology
Measuring quantities	air kerma, exposure
Reference radiation quality	70 kV, HVL 2.58 mm Al (RQR5)
Nominal sensitive volume	75 cm <sup>3</sup>
Design	not waterproof, vented
Reference point	in chamber center
Direction of incidence	perpendicular to chamber plane, see label 'Focus'
Nominal response	2.8 µC/Gy
Long-term stability	≤ 0.5 % per year
Chamber voltage	200 V nominal ± 400 V maximal
Energy response	≤ ± 2 % (50 ... 150) kV
Polarity effect at RQR/RQA5	≤ 1 %
Directional response	≤ 3 % for chamber tilting up to ≤ ± 15°
Leakage current	≤ ± 5 fA
Cable leakage	≤ 1 pC/(Gy·cm)

### Materials and measures:

Entrance window	0.6 mm polycarbonate, 1.55 g/cm <sup>3</sup> 0.002 mm graphite 0.32 g/cm <sup>3</sup>
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Total window area density	93 mg/cm <sup>2</sup>
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Water-equivalent window thickness	0.9 mm
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Sensitive volume	radius 45.7 mm depth 2 x 5.71 mm
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### Ion collection efficiency at nominal voltage:

Ion collection time	1 ms
---------------------	------

Max. dose rate for ≥ 99 % saturation	0.16 Gy/s
≥ 95 % saturation	0.78 Gy/s

### Useful ranges:

Chamber voltage	± (100 ... 400) V
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Radiation quality	(25 ... 150) kV X-rays
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Field size	(11 x 11) cm <sup>2</sup> ... (40 x 40) cm <sup>2</sup>
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Temperature	(10 ... 40) °C (50 ... 104) °F
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Humidity	(10 ... 80) %, max 20 g/m <sup>3</sup>
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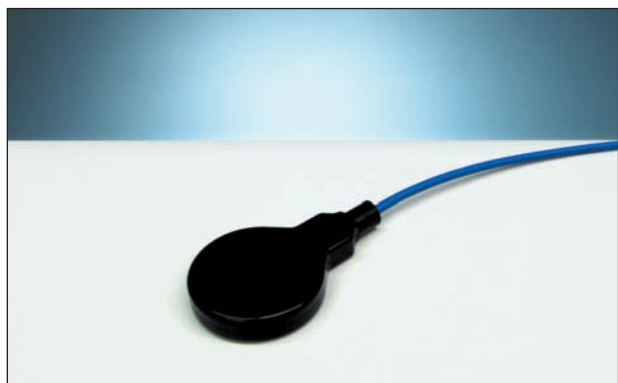
Air pressure	(700 ... 1060) hPa
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### Ordering Information

TN34060-2,5 SFD diagnostic chamber 75 cm<sup>3</sup>,  
connecting system BNT

TW34060-2,5 SFD diagnostic chamber 75 cm<sup>3</sup>,  
connecting system TNC

TM34060-2,5 SFD diagnostic chamber 75 cm<sup>3</sup>,  
connecting system M



## 6 cm<sup>3</sup> SFD Mammo Chamber Type 34069

*Shadow-free plane parallel chamber for absolute dosimetry in diagnostic radiology and mammography*

### Features

- ▶ Shadow-free design for use with automatic exposure control
- ▶ Sensitive volume 6 cm<sup>3</sup>, vented to air
- ▶ Suitable for measurements in front of and behind a phantom

The 34069 SFD mammo chamber is a high precision chamber for measurements in diagnostic radiology at high dose rates and in mammography. The chamber complies with the standard IEC 61674. Its shadow-free design makes it possible to use the chamber even while the automatic exposure control is activated. Together with an adequate diagnostic dosimeter the chamber features a wide dynamic range for measurements either in front of or behind a patient-equivalent phantom. The length of the mounted connection cable is 2.5 m.

### Specification

Type of product	vented plane parallel ionization chamber acc. IEC 61674
Application	absolute dosimetry in diagnostic radiology
Measuring quantities	air kerma, exposure
Reference radiation quality	30 kV, HVL 0.337 mm Al (RQR-M3) 70 kV, HVL 2.58 mm Al (RQR5)
Nominal sensitive volume	6 cm <sup>3</sup>
Design	not waterproof, vented
Reference point	in chamber center
Direction of incidence	perpendicular to chamber plane, see label 'Focus'
Nominal response	230 nC/Gy
Long-term stability	≤ 2 % per year
Chamber voltage	200 V nominal ± 400 V maximal
Energy response	≤ ± 2 % (25 ... 35) kV
Polarity effect at RQR-M3 (RQA-M3)	≤ 1 % (≤ 2 %)
Directional response	≤ 3 % for chamber tilting up to ≤ ± 15°
Leakage current	≤ 5 fA
Cable leakage	≤ 1 pC/(Gy·cm)

### Materials and measures:

Entrance window	0.32 mm PMMA, 1.19 g/cm <sup>3</sup> 0.002 mm graphite 0.32 g/cm <sup>3</sup>
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Total window area density	38 mg/cm <sup>2</sup>
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Water-equivalent window thickness	0.4 mm
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Sensitive volume	radius 15.2 mm depth 2 x 4.21mm
------------------	------------------------------------

### Ion collection efficiency at nominal voltage:

Ion collection time	550 μs
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Max. dose rate for ≥ 99 % saturation	0.53 Gy/s
≥ 95 % saturation	2.65 Gy/s

### Useful ranges:

Chamber voltage	± (100 ... 400) V
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Radiation quality	(25 ... 150) kV X-rays
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Field size	(5 x 5) cm <sup>2</sup> ... (40 x 40) cm <sup>2</sup>
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Temperature	(10 ... 40) °C (50 ... 104) °F
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Humidity	(10 ... 80) %, max 20 g/m <sup>3</sup>
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Air pressure	(700 ... 1060) hPa
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### Ordering Information

TN34069-2,5 SFD mammo chamber 6 cm<sup>3</sup>,  
connecting system BNT

TW34069-2,5 SFD mammo chamber 6 cm<sup>3</sup>,  
connecting system TNC

TM34069-2,5 SFD mammo chamber 6 cm<sup>3</sup>,  
connecting system M



## CT Chambers

### Types 30009, 30017

*Vented cylindrical pencil chambers for dose length product measurements in computed tomography*

#### Features

- ▶ Pencil type chambers for measurements within a CT head or body phantom (type 30009) or free in air (both types)
- ▶ Provide sensitive measuring lengths of 10 cm (type 30009) and 30 cm (type 30017)
- ▶ Show a homogeneous response over the whole chamber length

The CT chambers are vented cylinder chambers designed for dose length product and dose length product rate measurements in computed tomography. The chamber type 30009 allows the determination of the  $CTDI_{100}^1$ ,  $CTDI_W^2$  and  $CTDI_{Vol}^3$  according to IEC 61223-2-6 and IEC 61223-3-5.

#### Specification

Type of product	vented pencil type chambers
Application	dosimetry in computed tomography
Measuring quantities	air kerma length product, exposure length product
Reference radiation quality	120 kV, HVL 8.4 mm Al (RQT9)
Nominal sensitive volume	3.14 cm <sup>3</sup> , 9.3 cm <sup>3</sup> (30009, 30017)
Design	not waterproof, vented, pencil type
Reference point	chamber center
Direction of incidence	radial
Nominal response	14 nC/(Gy·cm), 13 nC/(Gy·cm)
Chamber voltage	- 100 V nominal ± 500 V maximal high voltage to be connected only with active current-limiting device ( $I_{max} < 0.5$ mA)
Energy response	≤ ± 5 % for (70 ... 150) kV (30009) (50 ... 150) kV (30017)
Leakage current	≤ ± 10 fA
Cable leakage	≤ 1 pC/(Gy·cm)

#### Materials and measures:

Wall material	1 mm PMMA, graphite coated
Wall area density	119 mg/cm <sup>2</sup>
Dimension of sensitive volume	radius 3.5 mm length 100 mm, 300 mm
Electrode	Al tube, graphited outer diameter 3 mm

#### Ion collection efficiency at nominal voltage:

Ion collection time	300 μs, 274 μs
Max. dose rate for ≥ 95.0 % saturation	12.4 Gy/s
Max. dose per pulse for ≥ 95.0 % saturation	2.26 mGy

#### Useful ranges:

Chamber voltage	± (100 ... 400) V
Radiation quality	(50 ... 150) kV
Temperature	(10 ... 40) °C (50 ... 104) °F
Humidity	(10 ... 80) %, max 20 g/m <sup>3</sup>
Air pressure	(700 ... 1060) hPa

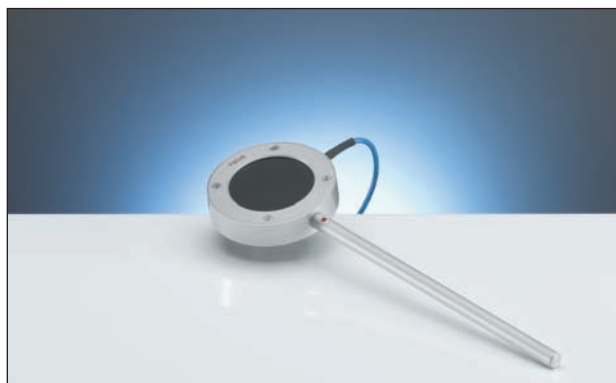
#### Ordering Information

TN30009 CT chamber 3.14 cm<sup>3</sup>, connecting system BNT  
 TW30009 CT chamber 3.14 cm<sup>3</sup>, connecting system TNC  
 TM30009 CT chamber 3.14 cm<sup>3</sup>, connecting system M  
 TN30017 CT chamber 9.3 cm<sup>3</sup>, connecting system BNT  
 TW30017 CT chamber 9.3 cm<sup>3</sup>, connecting system TNC  
 TM30017 CT chamber 9.3 cm<sup>3</sup>, connecting system M

<sup>1</sup> $CTDI_{100}$  = Computed Tomography Dose Index 100

<sup>2</sup> $CTDI_W$  = Weighted  $CTDI_{100}$

<sup>3</sup> $CTDI_{Vol}$  = Volume  $CTDI_W$



## 30 cm<sup>3</sup> Flat Chamber Type 233612

*Flat ionization chamber for precise dose measurements in the useful X-ray beam*

### Features

- ▶ Suitable for dose measurements of diagnostic X-ray qualities in air
- ▶ Can be used down to 35 keV radiation energy
- ▶ Comes with a holding stem for mounting in the radiation field

The 30 cm<sup>3</sup> flat chamber is especially designed for X-ray dose measurements in air down to 35 keV radiation energy. The maximal polarizing voltage is 500 V. The area density of the entrance window is 90 mg/cm<sup>2</sup>. A radioactive check device including check source and shielding is available to correct air density and carry out function tests. Using the appropriate holder, the check source can always be positioned and oriented at the same place on the chamber.

### Specification

Type of product	vented plane-parallel ionization chamber
Application	absolute dosimetry in diagnostic radiology
Measuring quantities	air kerma, exposure
Reference radiation quality	70 kV, HVL 2.58 mm Al (RQR5)
Nominal sensitive volume	30 cm <sup>3</sup>
Design	not waterproof, vented
Reference point	in chamber center
Direction of incidence plane	perpendicular to chamber plane
Nominal response	1 μC/Gy
Chamber voltage	400 V nominal ± 500 V maximal high voltage to be connected only with active current-limiting device ( $I_{\max} < 0.5$ mA)
Energy response	≤ ± 6 % (35 ... 75) keV
Directional response in water	≤ 5% for chamber tilting up to 5°
Leakage current	≤ 10 fA
Cable leakage	≤ 1 pC/(Gy·cm)

### Materials and measures:

Entrance window	0.75 mm PMMA, graphite coated
Total window area density	90 mg/cm <sup>2</sup>
Electrode	0.05 mm graphite coated polyimide foil
Dimension of sensitive volume	radius 23.5 mm depth 2 x 5.98 mm

### Ion collection efficiency at nominal voltage:

Ion collection time	0.6 ms
Max. dose rate for ≥ 99.5 % saturation	0.26 Gy/s
≥ 99.0 % saturation	0.52 Gy/s

### Useful ranges:

Chamber voltage	(300 ... 500) V
Radiation quality	(35 ... 75) keV X-rays
Temperature	(10 ... 40) °C (50 ... 104) °F
Humidity	(10 ... 80) %, max 20 g/m <sup>3</sup>
Air pressure	(700 ... 1060) hPa

### Ordering Information

TN233612 Flat chamber 30 cm<sup>3</sup>,  
connecting system BNT

TW233612 Flat chamber 30 cm<sup>3</sup>,  
connecting system TNC

TM233612 Flat chamber 30 cm<sup>3</sup>,  
connecting system M

## System Incorporated Detectors for Diagnostic Radiology

Besides the radiation detectors presented in this chapter, there are available a number of further detectors which are incorporated components of diagnostic dosimeters. There are detectors for patient dosimetry (DIAMENTOR) measuring the dose area product or semiconductor detectors for absolute dosimetry (DIADOS). Special ionization chambers for radiation leakage measurements amend the PTW detector range.



### DIAMENTOR Patient Dosimetry Chambers

DIAMENTOR chambers for dose area product measurements are available in different sizes and types to cover a wide range of diagnostic X-ray installations. The chambers can easily be mounted to the X-ray collimator or are firmly installed parts of the X-ray installation. The transparent models do not interfere with the collimators light field diaphragm.



### DIADOS Absolute Dosimetry Detectors

The DIADOS detectors are sturdy semiconductor detectors designed to withstand tough handling. They do not need air density correction or high voltage supply like ion chambers do and are suitable for acceptance tests and service quality checks as well. Two types are available, covering the conventional diagnostic or the mammography X-ray range.



### XLS X-Ray Leakage Chamber

This rectangular plane parallel XLS ionization chamber is used as part of the XLS X-ray leakage system for radiation leakage measurements of diagnostic X-ray installations. Up to 18 of these chambers can be arranged for radiation leakage detection around X-ray tubes.

## System Incorporated Detectors for Nuclear Medicine

Besides detectors used in nuclear medicine presented in other chapters, e.g. for radiation protection measurements, a special chamber as an incorporated component of the CURIEMENTOR system is available.



### Well-type Chamber for CURIEMENTOR Isotope Calibrator

The CURIEMENTOR chamber is a pressurized well-type ionization chamber with nearly  $4\pi$  measuring geometry. It is part of the CURIEMENTOR system which measures the activity of radioactive isotopes as used in diagnostic and therapeutic nuclear medicine and in intravascular brachytherapy.



# Health Physics Detectors

## ► Health Physics Detectors

<u>Radiation Monitoring Chamber 0.1 l</u>	▶	42
<u>Radiation Monitoring Chamber 3 l</u>	▶	43
<u>Radiation Monitoring Chamber 50 l</u>	▶	44
<u>Spherical Chambers 1 and 10 l</u>	▶	45
<u>Spherical Chambers PS-10 and PS-50</u>	▶	46
<u>Spherical Chamber TK-30</u>	▶	47
<u>Cylinder Stem Chamber 30 cm<sup>3</sup></u>	▶	48
<u>H<sub>p</sub>(10) Secondary Standard Chamber</u>	▶	49
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<u>Böhm Extrapolation Chamber</u>	▶	53



# 0.1 Liter Radiation Monitoring Chamber Type 32001

*Cylindrical Al chamber for stationary and mobile radiation monitoring of high level gamma radiation*

## Features

- ▶ Vented sensitive volume of 102 cm<sup>3</sup>
- ▶ Suitable as radiation monitoring chamber
- ▶ Rigid construction for wall mounting
- ▶ Gamma energy range 80 keV to 1.3 MeV

The 0.1 liter chamber is used for environmental radiation monitoring. The rigid and compact construction makes the chamber suitable for stationary radiation monitoring as well as for mobile operation in vehicles. The chamber is designed to measure very high dose rates of up to 4000 Sv/h (90 % saturation) as they may occur after nuclear accidents. Since the sensitive volume is open to the surroundings, air density correction is required for precise measurement. The chamber is fully guarded up to the sensitive volume. The cylindrical chamber is made of aluminum with 4 mm wall thickness. The ion-collecting electrode is made of aluminum too. The external chamber diameter is 60 mm and the length is approx. 150 mm. For the transfer of the measuring signal and the polarizing voltage, the chamber is supplied with two coaxial Fischer connectors. Via an optional adapter cable of 1.5 m length, the chamber can be connected to a dosimeter with M connector, which has input circuits on ground potential.

## Specification

Type of product	vented cylindrical ionization chamber
Application	radiation monitoring
Measuring quantity	photon equivalent dose
Nominal sensitive volume	102 cm <sup>3</sup>
Design	not waterproof, vented
Reference point	chamber center
Direction of incidence	radial
Nominal response	3 µC/Sv
Chamber voltage	500 V nominal
Energy response	≤ ± 10 % (E <sub>photon</sub> ≥ 80 keV)
Directional response in air	≤ ± 10 % for tilting perpendicular to the axis up to ± 20°
Leakage current	≤ ± 50 fA

## Materials and measures:

Wall of sensitive volume	4 mm Al, 2.85 g/cm <sup>3</sup>
Total wall area density	1.14 g/cm <sup>2</sup>
Dimension of sensitive volume	radius 22.5 mm length 88 mm
Central electrode	Al, diameter 25 mm
Outer dimensions	diameter 60 mm length 150 mm

## Ion collection efficiency at nominal range:

Ion collection time	1.3 ms
Max. dose rate for ≥ 99 % saturation	355 Sv/h
≥ 90 % saturation	3550 Sv/h

## Useful ranges:

Radiation quality	80 keV ... 1.3 MeV
Temperature	(10 ... 40) °C (50 ... 104) °F
Humidity	(10 ... 80) %, max 20 g/m <sup>3</sup>
Air pressure	(700 ... 1060) hPa

## Ordering Information

T32001 Radiation monitoring chamber 0.1 l,  
Fischer coax connectors

## Option

T7262/U10-1.5 Connection cable with M connector,  
length 1.5 m



## 3 Liter Radiation Monitoring Chambers

### Types 34031, 32004

*Cylindrical polyethylene ionization chambers for stationary radiation monitoring of gamma radiation*

#### Features

- ▶ Vented sensitive volume of 3 liters
- ▶ Suitable as radiation monitoring chambers
- ▶ Gamma energy range 80 keV to 1.3 MeV

The 3 liter chambers are used as stationary surveillance devices for environmental radiation monitoring. The chambers are designed to measure protection level dose rates. The chambers are fully guarded up to the sensitive volume. Since the sensitive volume is open to the surroundings, air density correction is required for precise measurement. The cylindrical chambers are made of graphite coated polyethylene with 4 mm wall thickness. The ion-collecting electrode is made of graphite coated polyethylene too. The external chamber diameter is 150 mm and the length is approx. 200 mm. For the transfer of the measuring signal and the polarizing voltage, the chambers are supplied with two coaxial connectors (model 34031) or one triaxial connector (model 32004). The maximal chamber polarizing voltage is 1000 V. The chamber model 34031 is supplied with an integrated adapter for positioning a radioactive check source of type T48010, which makes it possible to check the proper performance of the entire measuring system.

#### Specification

Type of product	vented cylindrical ionization chamber
Application	radiation monitoring
Measuring quantity	photon equivalent dose
Nominal sensitive volume	3 l
Design	not waterproof, vented
Reference point	chamber center
Direction of incidence	radial
Nominal response	100 $\mu\text{C}/\text{Sv}$
Chamber voltage	1000 V nominal
Energy response	$\leq \pm 10\%$ ( $E_{\text{photon}} \geq 80\text{ keV}$ )
Directional response in air	$\leq \pm 10\%$ for tilting perpendicular to the axis up to $\pm 20^\circ$
Leakage current	$\leq \pm 50\text{ fA}$

#### Materials and measures:

Wall of sensitive volume	4 mm PE graphite coated, $0.95\text{ g}/\text{cm}^3$
Total wall area density	$0.38\text{ g}/\text{cm}^2$
Dimension of sensitive volume	radius 71.25 mm length 200 mm
Central electrode	graphite coated PE, diameter 28 mm
Outer dimensions	diameter 150 mm length 200 mm

#### Ion collection efficiency at nominal range:

Ion collection time	25 ms
Max. dose rate for $\geq 99\%$ saturation	$0.95\text{ Sv}/\text{h}$
$\geq 90\%$ saturation	$9.5\text{ Sv}/\text{h}$

#### Useful ranges:

Radiation quality	80 keV ... 1.3 MeV
Temperature	(10 ... 40) $^\circ\text{C}$ (50 ... 104) $^\circ\text{F}$
Humidity	(10 ... 80) %, max 20 $\text{g}/\text{m}^3$
Air pressure	(700 ... 1060) hPa

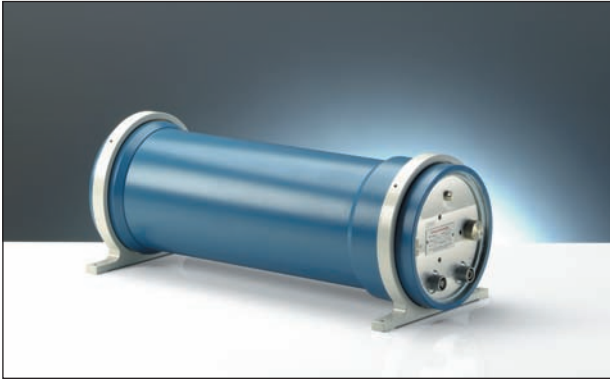
#### Ordering Information

T34031 Radiation monitoring chamber 3 l,  
Fischer coax connectors

T32004 Radiation monitoring chamber 3 l,  
LEMO triax connector

#### Option

T7262/U10-1.5 Connection cable with M connector,  
length 1.5 m



# 50 Liter Radiation Monitoring Chamber Type 7262

*Cylindrical pressurized steel ionization chamber for stationary gamma radiation monitoring*

## Features

- ▶ Sealed sensitive volume of 50 liters
- ▶ Suitable as stationary radiation monitoring chamber
- ▶ Gamma energy range 80 keV to 1.3 MeV

The ionization chamber T7262 has a constructive volume of 5 liters filled with Argon gas at the pressure of 10 bar, resulting in an effective sensitive volume of 50 liters. This superior design makes the chamber very sensitive and enables performing low level gamma radiation measurements down to the natural radiation background. The chamber is used as highly sensitive stationary surveillance device for environmental radiation monitoring. The chamber is fully guarded up to the sensitive volume. Since the sensitive volume is sealed, no air density correction is required. The cylindrical 50 liter chamber is made of steel with 3.25 mm wall thickness and a 3 mm aluminum cover. The ion-collecting electrode is made of brass. The external chamber diameter is 195 mm and the length is 538 mm. The chamber is supplied with two coaxial Fischer connectors for the transfer of the measuring signal and the polarizing voltage. Via an optional adapter cable of 1.5 m length, the chamber can be connected to a dosimeter with M connector, which has input circuits on ground potential. The maximal chamber polarizing voltage is 1000 V.

## Specification

Type of product	pressurized cylindrical ionization chamber
Application	radiation monitoring
Measuring quantity	photon equivalent dose
Nominal sensitive volume	50 l
Design	sealed and pressurized, filled with Ar (10 bar)
Reference point	chamber center
Direction of incidence	radial
Nominal response	2 mC/Sv.
Chamber voltage	1000 V nominal
Energy response	$\leq \pm 10 \%$ ( $E_{\text{photon}} \geq 80 \text{ keV}$ )
Directional response in air	$\leq \pm 10 \%$ for tilting perpendicular to the axis up to $\pm 20^\circ$
Leakage current	$\leq \pm 50 \text{ fA}$

## Materials and measures:

Wall of sensitive volume	3 mm Al, 2.7 g/cm <sup>3</sup> 3.25 mm steel, 7.85 g/cm <sup>3</sup>
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Total wall area density	3.361 g/cm <sup>2</sup>
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Dimension of sensitive volume	radius 66.75 mm length 360 mm
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Central electrode	brass, diameter 17.5 mm
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Outer dimensions	diameter 195 mm length 538 mm
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## Ion collection efficiency at nominal range:

Ion collection time	30 ms
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Max. dose rate for $\geq 99 \%$ saturation	1 mSv/h
$\geq 90 \%$ saturation	10 mSv/h

## Useful ranges:

Radiation quality	80 keV ... 1.3 MeV
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Temperature	(10 ... 40) °C (50 ... 104) °F
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Humidity	(10 ... 80) %, max 20 g/m <sup>3</sup>
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Air pressure	(700 ... 1060) hPa
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## Ordering Information

T7262 Radiation monitoring chamber 50 l,  
Fischer coax connectors

## Option

T7262/U10-1.5 Connection cable with M connector,  
length 1.5 m



# 1 and 10 Liter Spherical Chambers

## Types 32002, 32003

*Spherical ionization chambers for radiation protection level and low level measurement*

### Features

- ▶ Vented sensitive volumes of 1 liter and 10 liters
- ▶ Suitable for survey meter calibration and low level measurements
- ▶ Superior energy response, reproducibility, directional dependence and long-term stability
- ▶ Radioactive check device (option)

The spherical chambers are designed for the measurement of ionizing radiation in the protection level range from 0.1 mSv/h to 0.3 Sv/h (model 32002) and in the low level range from 10  $\mu$ Sv/h to 30 mSv/h (model 32003). Superior features make the chambers suitable as standard chambers for calibration purposes. They fulfill the requirement for excellent reproducibility and long-term stability of the sensitive volumes. The spherical construction ensures a nearly uniform response to radiation from every direction. The energy response is very flat. This is achieved by the thin layer of aluminum on the inner wall surface, which provides for an increased photoelectric yield to compensate for the absorption of soft X-rays. The outer chamber diameters are 140 mm and 276 mm.

### Specification

Type of product	vented spherical ionization chambers
Application	radiation protection measurements
Measuring quantity	photon equivalent dose
Nominal sensitive volume	1 l (32002) 10 l (32003)
Design	not waterproof, vented
Reference point	chamber center
Nominal response	40 $\mu$ C/Sv (32002) 330 $\mu$ C/Sv (32003)
Chamber voltage	400 V nominal $\pm$ 500 V maximal
Energy response	$\leq \pm$ 4 % (32002) $\leq \pm$ 3 % (32003)
Leakage current	$\leq \pm$ 10 fA

### Materials and measures:

Wall of sensitive volume	3 mm POM (32002) 2.75 mm POM (32003) (polyoxymethylene)
Total wall area density	453 mg/cm <sup>2</sup> (32002) 417 mg/cm <sup>2</sup> (32003)
Central electrode	graphite coated polystyrene, diameter 50 mm (32002) diameter 100 mm (32003)
Outer dimensions	diameter 140 mm (32002) diameter 276 mm (32003)

### Ion collection efficiency at nominal range:

Ion collection time	37 ms (32002) 150 ms (32003)
Max. dose rate for $\geq$ 99.5 % saturation	(32002), (32003) 210 mSv/h, 13 mSv/h
$\geq$ 99.0 % saturation	420 mSv/h, 26 mSv/h
Max. dose per pulse for $\geq$ 99.5 % saturation	(32002), (32003) 1.6 $\mu$ Sv, 0.3 $\mu$ Sv
$\geq$ 99.0 % saturation	3.1 $\mu$ Sv, 0.8 $\mu$ Sv

### Useful ranges:

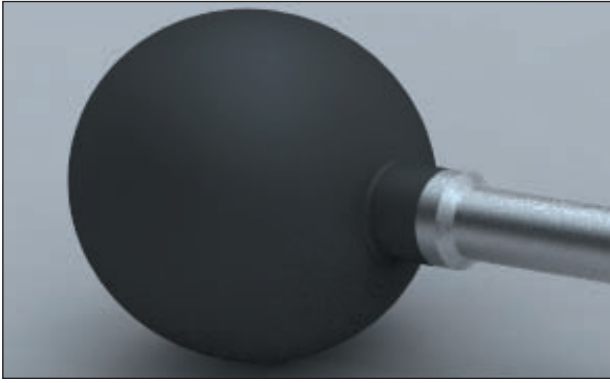
Chamber voltage	$\pm$ (300 ... 500) V
Radiation quality	25 keV ... 50 MeV
Temperature	(10 ... 40) °C (50 ... 104) °F
Humidity	(10 ... 80) %, max 20 g/m <sup>3</sup>
Air pressure	(700 ... 1060) hPa

### Ordering information

TN32002 Spherical chamber 1 l, connecting system BNT  
 TW32002 Spherical chamber 1 l, connecting system TNC  
 TM32002 Spherical chamber 1 l, connecting system M  
 TN32003 Spherical chamber 10 l, connecting system BNT  
 TW32003 Spherical chamber 10 l, connecting system TNC  
 TM32003 Spherical chamber 10 l, connecting system M

### Options

T48010 Radioactive check device <sup>90</sup>Sr  
 T48001 Chamber holding device for check device



### Features

- ▶ Vented sensitive volumes of 50 cm<sup>3</sup> and 10 cm<sup>3</sup>
- ▶ Suitable as primary standard for radiation protection measurements
- ▶ Exact volume individually determined
- ▶ Designed in collaboration with the National Institute of Standards and Technology (NIST)

The spherical graphite chambers PS-50 and PS-10 are vented ionization chambers for the use as primary standard for radiation protection measurements and for absolute dosimetry. The spherical graphite chambers have been designed in collaboration with the Radiation Interactions and Dosimetry Group at the National Institute of Standards and Technology (NIST). The exact volume of each chamber is individually determined. The homogeneity of the walls and electrodes is 0.06 mm. The chambers are constructed with a long rigid stem of approx. 29 cm length for easy mounting in the radiation beam. Air density correction is required for each measurement.

### Specification

Type of product	vented spherical ionization chambers
Application	primary standard for radiation protection measurements
Measuring quantity	air kerma, photon equivalent dose
Nominal sensitive volume	50 cm <sup>3</sup> (32007S) 10 cm <sup>3</sup> (32008S)
Design	not waterproof, vented
Reference point	chamber center
Nominal response	1.73 μC/Gy (32007S) 0.349 μC/Gy (32008S)
Chamber voltage	1000 V nominal (32007S) 500 V nominal (32008S) ± 1000 V maximal
Directional response in air	≤ ± 0.5 % for rotation around the chamber axis and ≤ ± 1 % for tilting the chamber axis up to ± 60° (32007S) ≤ ± 1 % for tilting the chamber axis up to ± 50° (32008S)
Leakage current	≤ ± 5 fA

# PS-50 and PS-10 Spherical Chambers

## Types 32007S, 32008S

*Primary standard spherical ionization chambers for radiation protection measurements*

### Materials and measures:

Wall of sensitive volume	3.5 mm graphite
Total wall area density	647 mg/cm <sup>2</sup>
Central electrode	graphite, diameter 3 mm
Outer dimensions	diameter 53 mm (32007S) diameter 34 mm (32008S)

### Ion collection efficiency at nominal range:

Ion collection time	8.7 ms (32007S) 1.9 ms (32008S)
Max. dose rate for ≥ 99,5 % saturation	(32007S), (32008S) 1.23 mGy/s, 26 mGy/s
≥ 90 % saturation	2.46 mGy/s, 52 mGy/s
Max. dose per pulse for ≥ 99.5 % saturation	(32007S), (32008S) 7.1 μGy, 33 μGy
≥ 99.0 % saturation	14.2 μGy, 65 μGy

### Useful ranges:

Chamber voltage	± (400 ... 1000) V
Radiation quality	<sup>60</sup> Co, <sup>137</sup> Cs
Field size (square field)	≥ (6 x 6) cm <sup>2</sup> (32007S) ≥ (4 x 4) cm <sup>2</sup> (32008S)
Temperature	(10 ... 40) °C (50 ... 104) °F
Humidity	(10 ... 80) %, max 20 g/m <sup>3</sup>
Air pressure	(700 ... 1060) hPa

### Ordering information

TN32007S Spherical chamber PS-50,  
connecting system BNT

TN32008S Spherical chamber PS-10,  
connecting system BNT



# Spherical Ionization Chamber TK-30

## Type 32005

*Spherical ionization chamber with a long rigid stem for radiation protection measurement*

### Features

- ▶ Vented sensitive volume of 28 cm<sup>3</sup>
- ▶ Suitable as high precision reference chamber for radiation protection dosimetry
- ▶ Very flat energy response within a wide range

The spherical chamber TK-30 is designed as a reference chamber for absolute dosimetry to be used by secondary standard dosimetry laboratories (SSDL) and users with high quality requirements. It has very small variations of response with radiation quality from low X-ray energies up to high-energy photon radiation. The guard ring is designed up to the sensitive volume. The chamber is constructed with a long rigid stem of approx. 20 cm length for easy mounting in the radiation beam. Air density correction is required for each measurement.

### Specification

Type of product	vented spherical ionization chamber
Application	radiation protection measurements
Measuring quantity	photon equivalent dose, exposure
Nominal sensitive volume	27.9 cm <sup>3</sup>
Design	not waterproof, vented
Reference point	chamber center
Direction of incidence	radial
Nominal response	900 nC/Sv
Chamber voltage	400 V nominal ± 1000 V maximal
Energy response	≤ ± 5 % (48 keV ... <sup>60</sup> Co)
Directional response in air	≤ ± 0.5 % for rotation around the chamber axis and ≤ ± 3 % for tilting of the axis up to ± 45°
Leakage current	≤ ± 5 fA

### Materials and measures:

Wall of sensitive volume	3 mm POM (polyoxymethylene, graphited)
Total wall area density	453 mg/cm <sup>2</sup>
Dimension of sensitive volume	radius 22 mm
Central electrode	graphite coated PMMA, diameter 4.2 mm

### Ion collection efficiency at nominal range:

Ion collection time	4.5 ms
Max. dose rate for ≥ 99 % saturation	29.4 Sv/h
≥ 90 % saturation	294 Sv/h
Max. dose per pulse for ≥ 99 % saturation	26 μSv

### Useful ranges:

Chamber voltage	± (200 ... 400) V
Radiation quality	25 keV ... 50 MeV
Temperature	(10 ... 40) °C (50 ... 104) °F
Humidity	(10 ... 80) %, max 20 g/m <sup>3</sup>
Air pressure	(700 ... 1060) hPa

### Ordering information

- TN32005 Spherical chamber TK-30, connecting system BNT
- TW32005 Spherical chamber TK-30, connecting system TNC
- TM32005 Spherical chamber TK-30, connecting system M



# 30 cm<sup>3</sup> Cylinder Stem Ionization Chamber

## Type 23361

*Cylindrical PMMA ionization chamber with a long rigid stem for radiation protection measurement*

### Features

- ▶ Vented sensitive volume of 30 cm<sup>3</sup>
- ▶ Suitable as high precision reference chamber for radiation protection dosimetry
- ▶ Very flat energy response within a wide range
- ▶ Radioactive check device (option)

The cylinder stem chamber is designed as a reference chamber for absolute dosimetry to be used by secondary standard dosimetry laboratories (SSDL) and users with high quality requirements. It has very small variations of response with radiation quality from low X-ray energies up to high-energy photon radiation. The guard ring is designed up to the sensitive volume. The chamber is constructed with a long rigid stem of approx. 20 cm length for easy mounting in the radiation beam. An acrylic build-up cap with 3 mm wall thickness for in-air measurement in <sup>60</sup>Co beams is included with each chamber, as well as a calibration certificate. Air density correction is required for each measurement. A radioactive check device and an appropriate holding device are available.

### Specification

Type of product	vented cylindrical ionization chamber
Application	radiation protection measurements
Measuring quantity	photon equivalent dose, exposure
Nominal sensitive volume	30 cm <sup>3</sup>
Design	not waterproof, vented
Reference point	on chamber axis, 27 mm from chamber tip
Direction of incidence	radial
Nominal response	1 µC/Gy
Chamber voltage	400 V nominal ± 500 V maximal
Energy response	≤ ± 4 % (40 keV ... <sup>60</sup> Co)
Directional response in air	≤ ± 0.5 % for rotation around the chamber axis for tilting see diagram page 62
Leakage current	≤ ± 10 fA
Stem leakage	≤ 1 pC/(Gy·cm)

### Materials and measures:

Wall of sensitive volume	1 mm PMMA, graphited
Total wall area density	119 mg/cm <sup>2</sup>
Dimension of sensitive volume	radius 15.5 mm length 51 mm
Central electrode	graphite coated Al, diameter 14 mm
Outer dimensions	diameter 33 mm length 335 mm
Build-up cap	PMMA, thickness 3 mm

### Ion collection efficiency at nominal range:

Ion collection time	1.3 ms
Max. dose rate for ≥ 99.5 % saturation	60 mGy/s
≥ 99.0 % saturation	120 mGy/s
Max. dose per pulse for ≥ 99.5 % saturation	50 µGy
≥ 99.0 % saturation	100 µGy

### Useful ranges:

Radiation quality	30 keV ... 50 MeV
Temperature	(10 ... 40) °C (50 ... 104) °F
Humidity	(10 ... 80) %, max 20 g/m <sup>3</sup>
Air pressure	(700 ... 1060) hPa

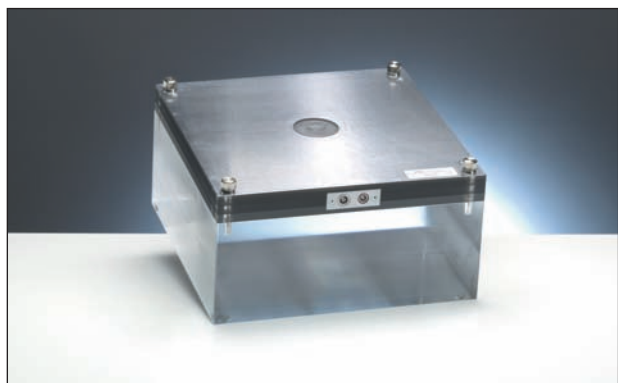
### Ordering information

- TN23361 Cylinder stem chamber 30 cm<sup>3</sup>,  
connecting system BNT
- TW23361 Cylinder stem chamber 30 cm<sup>3</sup>,  
connecting system TNC
- TM23361 Cylinder stem chamber 30 cm<sup>3</sup>,  
connecting system M

### Options

- T48010 Radioactive check device <sup>90</sup>Sr
- T23237 Chamber holding device for check device





## $H_p(10)$ Secondary Standard Chamber Type 34035

*Parallel plate ionization chamber for direct measurement of  $H_p(10)$  personal dose equivalent on a slab phantom*

### Features

- ▶ Vented sensitive volume of 10 cm<sup>3</sup>
- ▶ Measures the  $H_p(10)$  personal dose equivalent directly
- ▶ Suitable as a reference chamber for  $H_p(10)$  calibration

The parallel plate ionization chamber model 34035<sup>1</sup> is integrated into a slab phantom to measure the  $H_p(10)$  radiation protection measuring quantity directly. The high performance chamber is designed to be used as a secondary standard chamber for calibration purposes. The beam calibration with the  $H_p(10)$  chamber makes it unnecessary to precisely determine the spectrum of the X-ray beam. The chamber comes uncalibrated; a primary standard calibration by PTB, the German National Laboratory, is available. The chamber set includes a phantom slab of 31 mm thickness with chamber assembly and an additional PMMA phantom slab of 120 mm thickness. Both sets available include an adapter cable to connect the chamber either to a dosimeter with M connector or with BNC connector and banana pin. The  $H_p(10)$  chamber should be used in connection with a high quality dosimeter such as UNIDOS, UNIDOS E or UNIDOS<sup>webl ine</sup> to ensure best performance.

### Specification

Type of product	vented parallel plate chamber
Application	radiation protection measurements
Measuring quantity	$H_p(10)$ personal dose equivalent
Nominal sensitive volume	10 cm <sup>3</sup>
Design	not waterproof, vented
Reference conditions	20°C, 1013 hPa 65 % rel. humidity
Reference point	chamber center, 13.5 mm below chamber surface or 15.5 mm below surface of integrated step cylinder
Nominal response	285 nC/Sv
Chamber voltage	400 V nominal
Leakage current	≤ ± 10 fA
Cable leakage	≤ 1 pC/(Gy·cm)

### Materials and measures:

Phantom material	PMMA
Outer dimensions	300 mm x 300 mm
chamber assembly	height 31 mm
additional slab phantom	height 120 mm

### Useful ranges:

Chamber voltage	± (300 ... 500) V
Radiation quality	(15 ... 1400) keV
Temperature	(10 ... 40) °C (50 ... 104) °F
Humidity	(10 ... 80) %, max 20 g/m <sup>3</sup>
Air pressure	(700 ... 1060) hPa

### Ordering information

L981937  $H_p(10)$  Secondary standard chamber type 34035, connecting system M

L981938  $H_p(10)$  Secondary standard chamber type 34035, connecting system BNC and banana pin

### Option

PTB Primary standard calibration upon request

<sup>1</sup> Ankerhold, Ambrosi, Eberle – A chamber for determining the conventionally true value of  $H_p(10)$  and  $H^*(10)$  needed by calibration laboratories – Rad. Prot. Dos. Vol. 96, Nos 1-3, pp. 133 - 137 (2001), Nucl. Techn. Publishing



# 100 cm<sup>3</sup> Reference Soft X-Ray Chamber Type 34047

*Calibration grade plane parallel chamber for dose measurements in low-energy photon beams*

## Features

- ▶ Ultra thin entrance window
- ▶ For low-energy photons from 5 keV to 20 keV
- ▶ Sensitive volume 100 cm<sup>3</sup>, vented to air

The 34047 soft X-ray chamber is a reference chamber used in calibration laboratories. Its very thin entrance window makes it possible to measure photon radiation with energies down to 5 keV. Due to the large volume, the chamber gives reasonable and accurate signals. The chamber is designed for measurements free in air.

## Specification

Type of product	vented plane parallel ionization chamber
Application	absolute dosimetry in low-energy photon beams
Measuring quantities	absorbed dose to water, air kerma, exposure
Reference radiation quality	30 kV, HVL 0.37 mm Al (T30)
Nominal sensitive volume	100 cm <sup>3</sup>
Design	not waterproof, vented
Reference point	in chamber center of entrance foil underside
Direction of incidence	perpendicular to chamber plane
Nominal response	4.8 μC/Gy
Long-term stability	≤ 1 % per year
Chamber voltage	400 V nominal ± 500 V maximal
Leakage current	≤ ± 10 fA
Cable leakage	≤ 1 pC/(Gy·cm)

## Materials and measures:

Entrance foil	3.5 μm PET (polyethylenterephthalat), graphite coated
Total window area density	0.5 mg/cm <sup>2</sup>
Sensitive volume	radius 39.9 mm depth 20 mm

## Ion collection efficiency at nominal voltage:

Ion collection time	6.3 ms
Max. dose rate for ≥ 99.5 % saturation	2.1 mGy/s
≥ 99.0 % saturation	4.2 mGy/s

## Useful ranges:

Chamber voltage	± (300 ... 400) V
Radiation quality	(5 ... 20) keV X-rays
Field size	(15 x 15) cm <sup>2</sup> ... (40 x 40) cm <sup>2</sup>
Temperature	(10 ... 40) °C (50 ... 104) °F
Humidity	(20 ... 80) %, max 20 g/m <sup>3</sup>
Air pressure	(700 ... 1060) hPa

## Ordering Information

TN34047 Reference Soft X-ray chamber 100 cm<sup>3</sup>, connecting system BNT

TW34047 Reference Soft X-ray chamber 100 cm<sup>3</sup>, connecting system TNC

TM34047 Reference Soft X-ray chamber 100 cm<sup>3</sup>, connecting system M



# Monitor Ionization Chambers

## Types 34014, 786

*Large size plane parallel transmission chambers for use as dose monitors combined with calibration facilities*

### Features

- ▶ Vented sensitive volumes of 94 cm<sup>3</sup> and 86 cm<sup>3</sup>
- ▶ Include twin-sensitive volumes
- ▶ Shadow-free transmission chambers for dose monitoring with calibration facilities

The circular plane parallel transmission chambers are used for dose monitoring in combination with calibration benches. The sensitive volumes are designed as twin-chambers with 2.5 mm measuring depth each and a diameter of 155 mm (model 786) or 148 mm (model 34014). The chamber walls and the electrodes are made of polyimide (PI) of 0.025 mm thickness each with graphite layer. The chambers are fully guarded. The external diameter of the chamber housing is 230 mm. Two holes with 6 mm threads serve for mechanical chamber fixation.

Two chamber versions are available: model 786 is used together with dosimeters having the input circuits on ground potential, and model 34014 is used together with dosimeters having the input circuits on high voltage.

### Specification

Type of product	vented plane parallel twin-chambers
Application	dose monitoring in calibration facilities
Measuring quantity	exposure
Nominal sensitive volumes	86 cm <sup>3</sup> (34014) 94 cm <sup>3</sup> (786)
Design	not waterproof, vented
Nominal response	depends on field size
Chamber voltage	400 V nominal
Leakage current	≤ 1 pA

### Materials and measures:

Entrance window	3 x 0.025 mm polyimide, graphite coated
Total window area density	3 x 3.55 mg/cm <sup>2</sup>
Electrode	polyimide foil, graphite coated
Outer dimensions	diameter 230 mm

### Ion collection efficiency at nominal voltage:

Max. dose rate for ≥ 99.5 % saturation	8.5 Gy/s
≥ 99.0 % saturation	17 Gy/s (34014) 18 Gy/s (786)

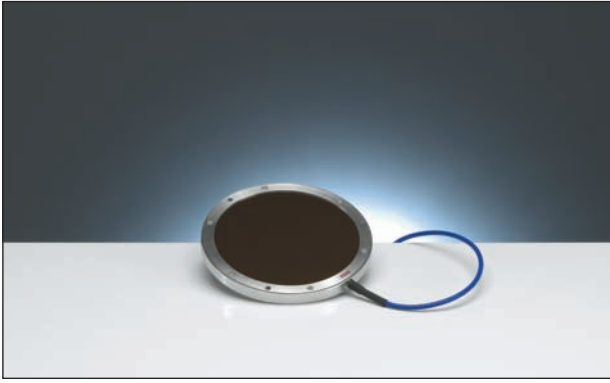
Max. dose per pulse for ≥ 99.5 % saturation	590 μGy
≥ 99.0 % saturation	1.19 mGy

### Useful ranges:

Radiation quality	(7.5 ... 420) kV X-rays
Field size	≤ 148 mm diameter (34014) ≤ 155 mm diameter (786)
Temperature	(10 ... 40) °C (50 ... 104) °F
Humidity	(10 ... 80) %, max 20 g/m <sup>3</sup>
Air pressure	(700 ... 1060) hPa

### Ordering information

TN34014 Monitor chamber, connecting system BNT  
 TW34014 Monitor chamber, connecting system TNC  
 TM786 Monitor chamber, connecting system M  
 TB786 Monitor chamber, connecting system BNC  
 and banana pin  
 Monitor chambers with smaller diameter of sensitive volume upon request



# X-ray Therapy Monitor Chamber

## Type 7862

*Large size plane parallel transmission chamber for use as dose monitor combined with X-ray therapy units*

### Features

- ▶ Vented sensitive volume of 17.6 cm<sup>3</sup>
- ▶ Shadow-free transmission chamber for dose monitoring with radiation therapy X-ray equipment

The circular plane parallel transmission chamber model 7862 is used for dose monitoring in combination with radiotherapy X-ray units. The sensitive volume is designed as a very thin cylinder of 2.4 mm thickness and 96.5 mm diameter. The chamber wall and the electrode are made of polyimide (PI) of 0.05 mm thickness each with graphite layer, mechanically protected by another PI foil of 0.05 mm in front of each wall. The nominal photon energy range is 7.5 kV up to 420 kV and the leakage current is less than 1 pA. The chamber is fully guarded. The external diameter of the chamber housing is 119.5 mm. Three holes with 3.5 mm threads serve for mechanical chamber fixation. The transmission chamber model 7862 is used in connection with dosimeters having the input circuits on ground potential.

### Specification

Type of product	vented plane parallel triple-chamber
Application	dose monitoring in X-ray therapy units
Measuring quantity	exposure
Nominal sensitive volume	17.6 cm <sup>3</sup>
Design	not waterproof, vented
Nominal response	depends on field size
Chamber voltage	400 V nominal
Leakage current	≤ 1 pA

### Materials and measures:

Entrance window	4 x 0.05 mm polyimide, graphite coated
Total window area density	4 x 7.1 mg/cm <sup>2</sup>
Electrode	polyimide foil, graphite coated
Outer dimensions	diameter 119.5 mm

### Ion collection efficiency at nominal voltage:

Max. dose rate for	
≥ 99.5 % saturation	10 Gy/s
≥ 99.0 % saturation	20 Gy/s
Max. dose per pulse for	
≥ 99.5 % saturation	640 μGy
≥ 99.0 % saturation	1.29 mGy

### Useful ranges:

Radiation quality	(7.5 ... 420) kV X-rays
Field size	≤ 95 mm diameter
Temperature	(10 ... 40) °C (50 ... 104) °F
Humidity	(10 ... 80) %, max 20 g/m <sup>3</sup>
Air pressure	(700 ... 1060) hPa

### Ordering information

TM7862 Monitor chamber for X-ray therapy units, connecting system M



# Böhm Extrapolation Chamber

## Type 23392

*Low energy extrapolation chamber with adjustable volume depth for measurements of absorbed dose in soft tissue*

### Features

- ▶ Measures absolute dose of beta radiation and X-rays in soft tissue equivalent material very precisely
- ▶ Includes a micrometer screw for the depth adjustment of the sensitive volume down to zero
- ▶ Suitable for beta calibration at PSDLs and SSDLs

The Böhm extrapolation chamber is a high quality device for absorbed dose measurements of beta and low energy X radiation in certain depths below the surface of the entrance window. Primary standard dosimetry laboratories (PSDL) and secondary standard dosimetry laboratories (SSDL) use it for low energy radiation calibration. The dose is determined from the ionization density in a small air gap, the extrapolation chamber volume, embedded in tissue equivalent material (PMMA). The chamber is supplied with a very thin entrance window of  $0.75 \text{ mg/cm}^2$  and a collecting electrode of 30 mm in diameter. By means of the built-in micrometer screw, the collecting electrode surrounded by a guard ring of 15 mm can be moved to adjust the depth of the sensitive volume between 10.5 mm and 0.5 mm. The zero point of the chamber depth setting can be obtained by measuring the chamber capacitance  $C$  versus the chamber depth  $x$  and extrapolating  $C^{-1}$  towards  $x = 0$ . The chamber is equipped with two BNC sockets for signal and polarizing voltage. A connection cable from both BNC sockets to an electrometer with M type connector is available. An electrometer with the input circuits on ground potential is required. The extrapolation chamber comes in a protective storage case.

### Specification

Type of product	extrapolation chamber according to Böhm
Application	absolute dosimetry of beta radiation and X-rays
Measuring quantity	absorbed dose in soft tissue
Nominal sensitive volume	$(0.353 \dots 7.422) \text{ cm}^3$
Design	not waterproof, vented, fully guarded
Reference point	in chamber center of entrance foil underside
Nominal response	dependent on electrode distance
Chamber voltage	dependent on electrode distance 500 V maximal
Leakage current	$\leq 1 \text{ pA}$
Cable leakage	$\leq 1 \text{ pC}/(\text{Gy}\cdot\text{cm})$

### Materials and measures:

Entrance window	PET, graphite coated
Total window area density	$0.75 \text{ mg/cm}^2$
Measuring electrode	diameter 30 mm
Rear electrode	PMMA, graphite coated diameter 60.5 mm
Distance between electrodes	$(0.5 \dots 10.5) \text{ mm}$

### Ion collection efficiency at nominal voltage:

Ion collection time and max. dose rate	dependent on electrode distance
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### Useful ranges:

Temperature	$(10 \dots 40) \text{ }^\circ\text{C}$ $(50 \dots 104) \text{ }^\circ\text{F}$
Humidity	$(10 \dots 80) \%$ , max $20 \text{ g/m}^3$
Air pressure	$(700 \dots 1060) \text{ hPa}$

### Ordering information

T23392 Böhm extrapolation chamber

T23392/U5 Connection cable for Böhm extrapolation chamber, connecting system M

# Notes

# Quick View

## ▶ Product Family Quick View

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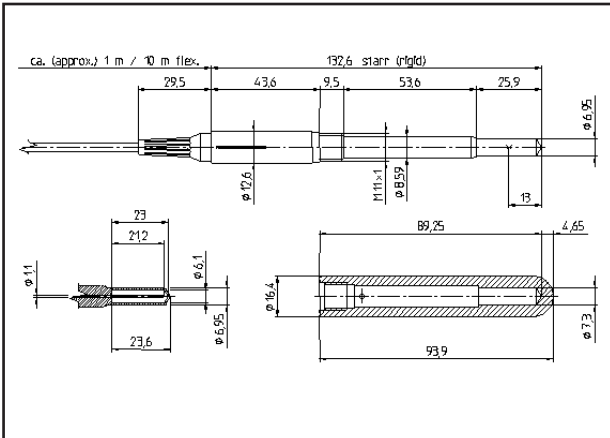
Connector Design	▶	66
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Overview of PTW Detectors	▶	68
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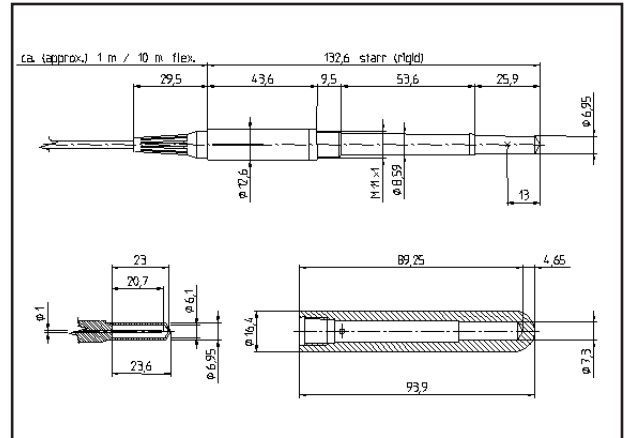
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# Drawings



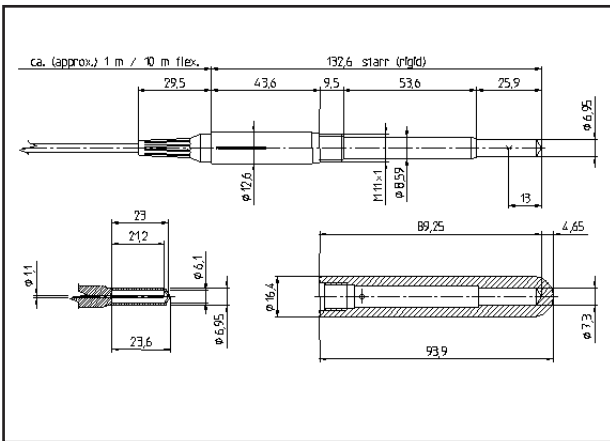
Farmer Chamber

30010



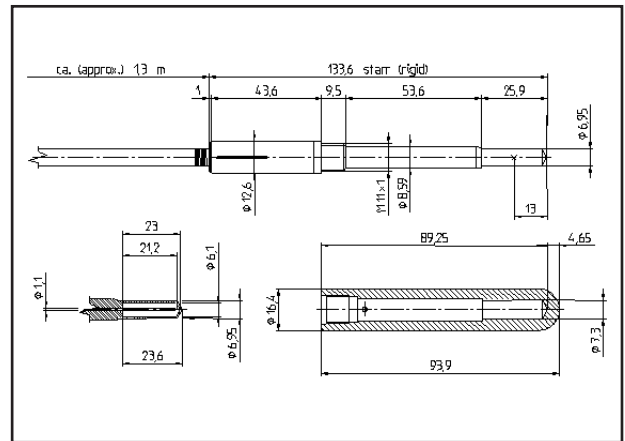
Farmer Chamber

30011



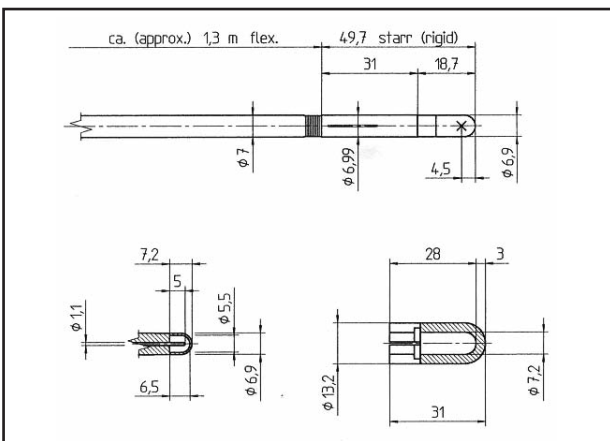
Farmer Chamber

30012



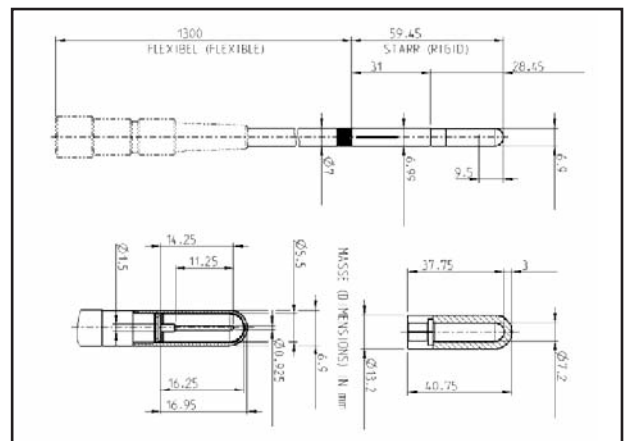
Farmer Chamber

30013



0.125 cm<sup>3</sup> Semiflex Chamber

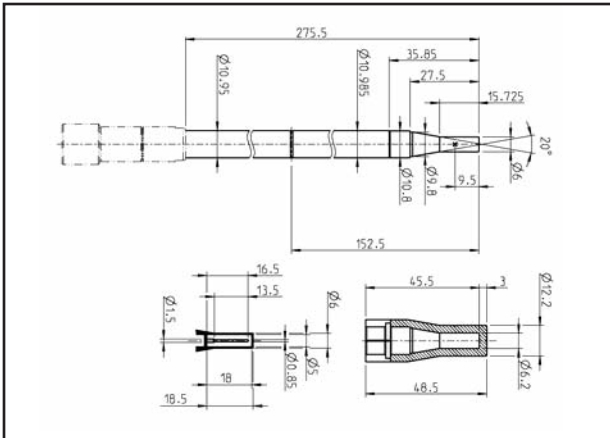
31010



0.3 cm<sup>3</sup> Semiflex Chamber

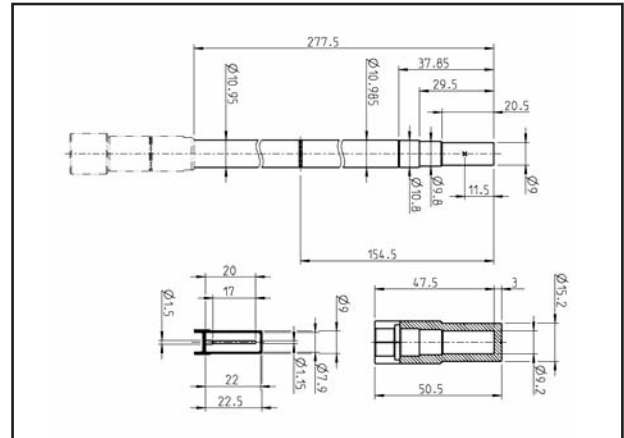
31013





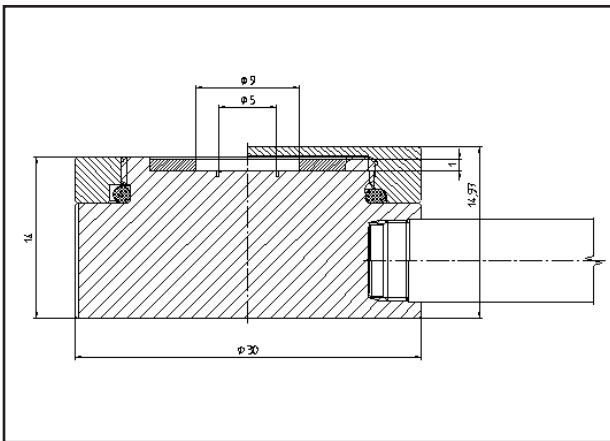
0.3 cm<sup>3</sup> Rigid Stem Chamber

30016



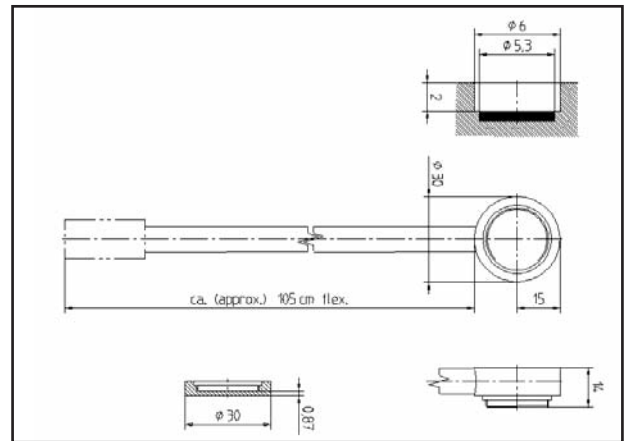
1.0 cm<sup>3</sup> Rigid Stem Chamber

30015



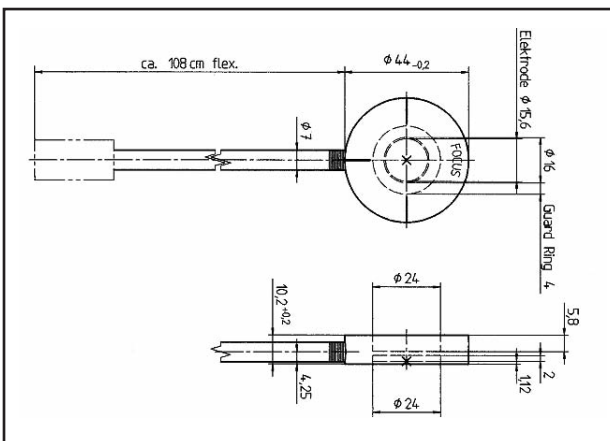
Advanced Markus Chamber

34045



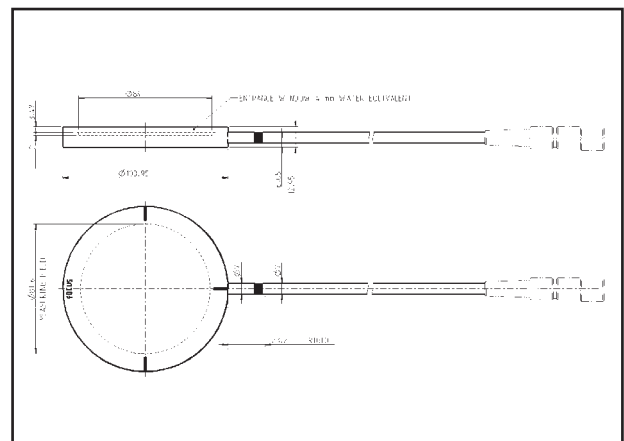
Markus Chamber

23343



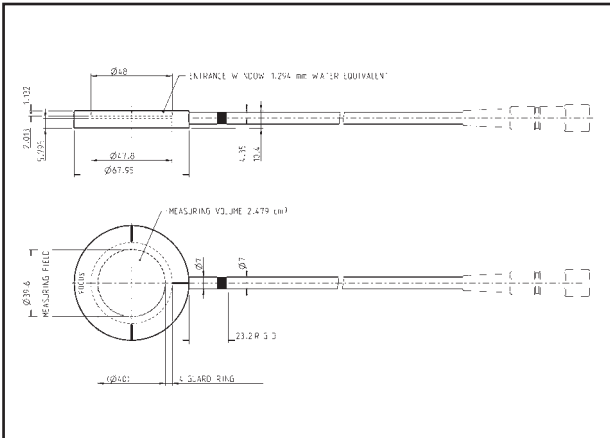
Roos Chamber

34001



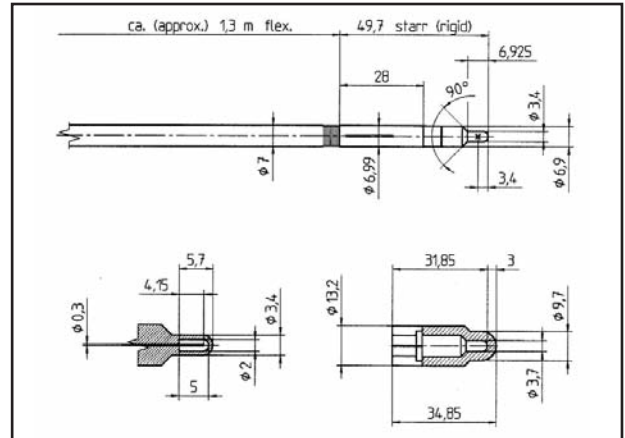
10.5 cm<sup>3</sup> Bragg Peak Chamber

34070



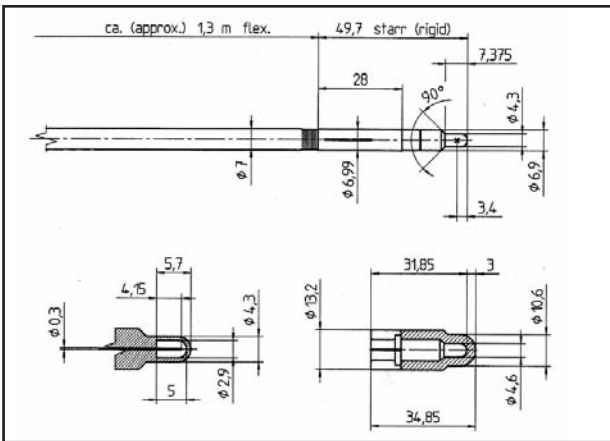
2.5 cm<sup>3</sup> Bragg Peak Chamber

34073



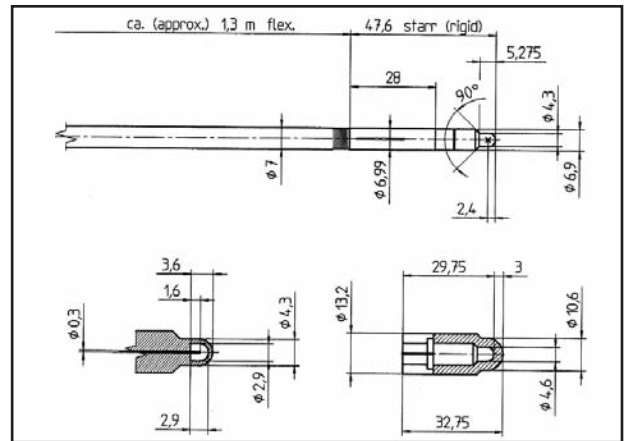
PinPoint Chamber

31014



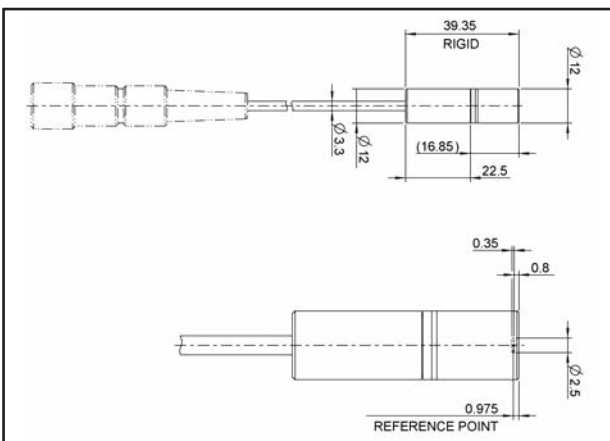
PinPoint Chamber

31015



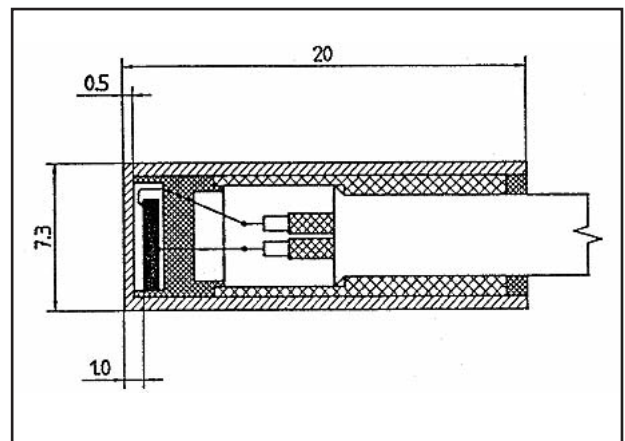
PinPoint 3D Chamber

31016



microLion Chamber

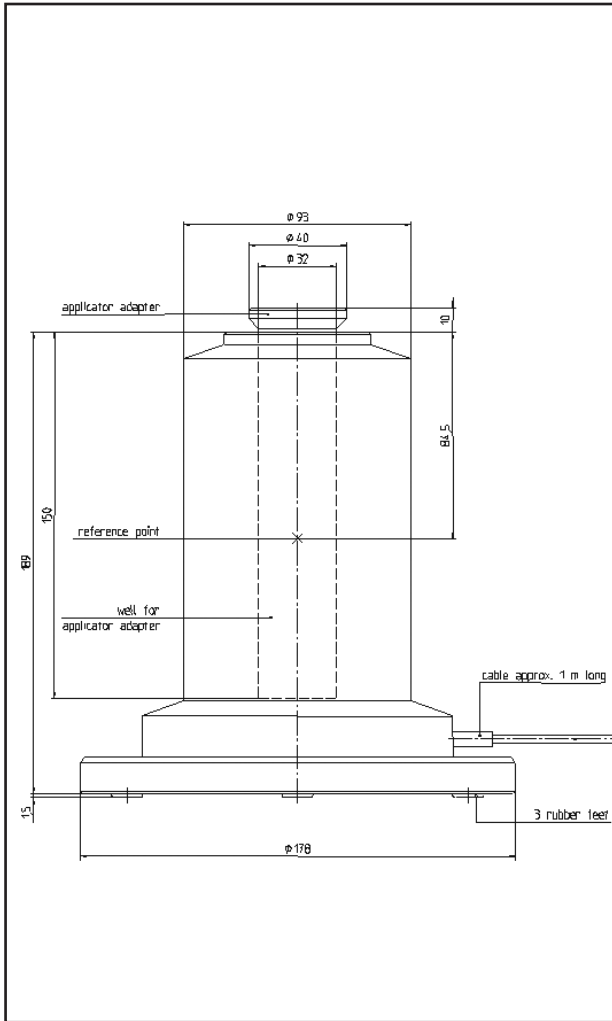
31018



Diamond Detector

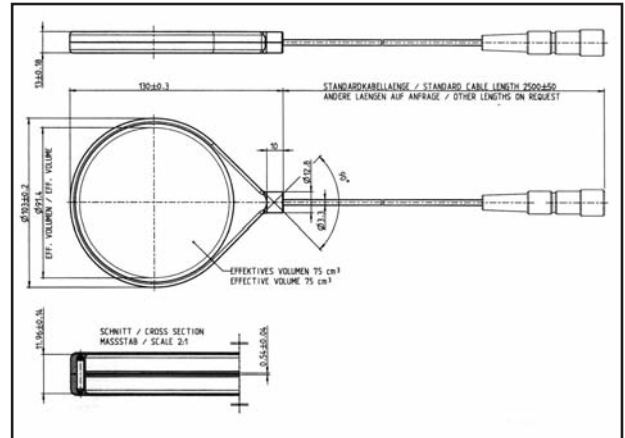
60003





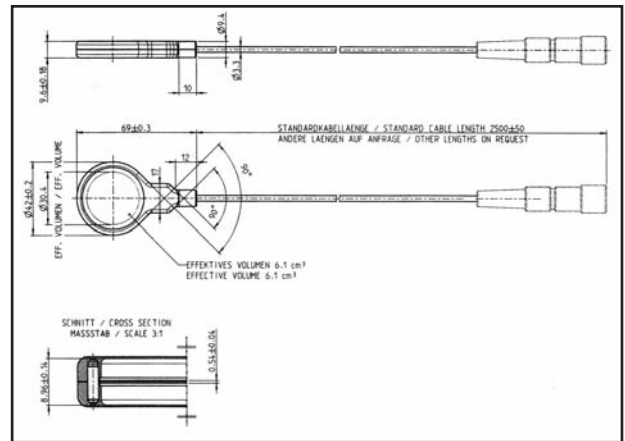
Well-Type Chamber

33004



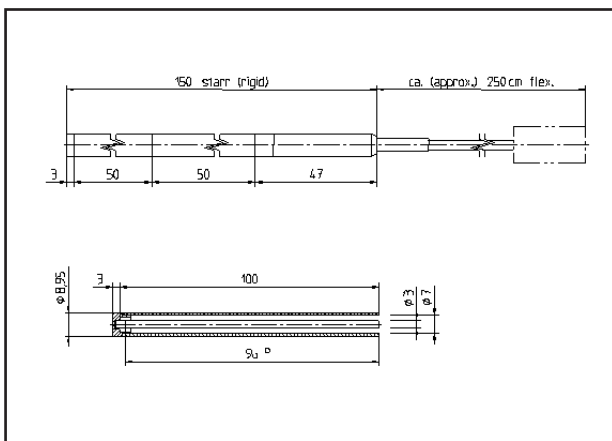
75 cm<sup>3</sup> SFD Diagnostic Chamber

34060



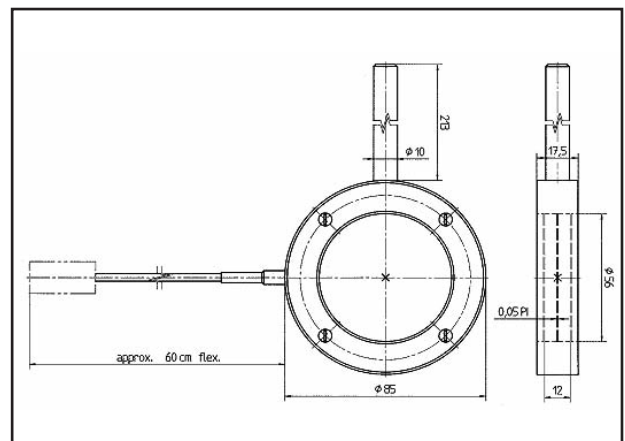
6 cm<sup>3</sup> SFD Diagnostic Chamber

34069



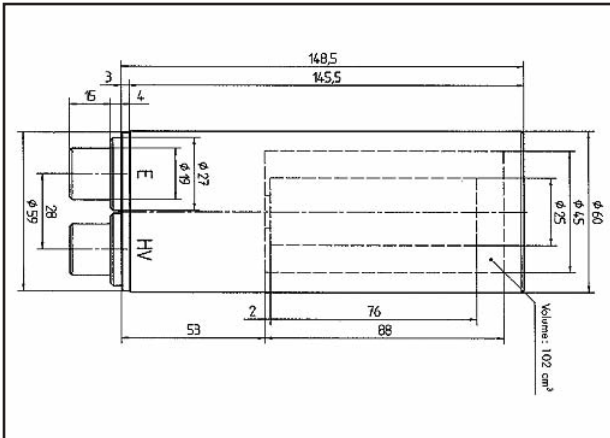
3.14 cm<sup>3</sup> CT Chamber

30009

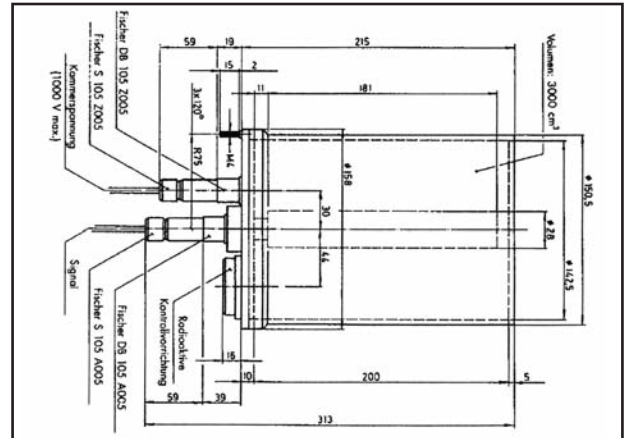


30 cm<sup>3</sup> Flat Chamber

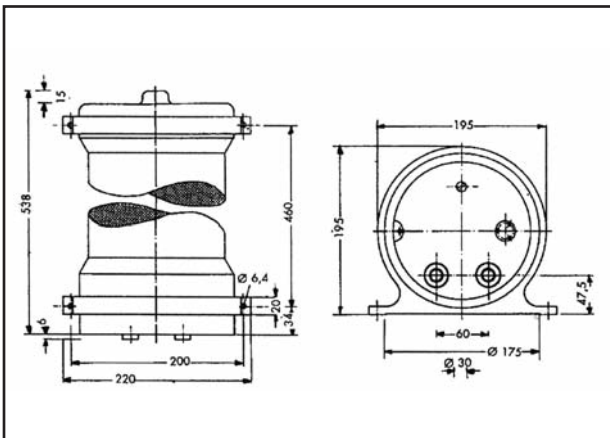
233612



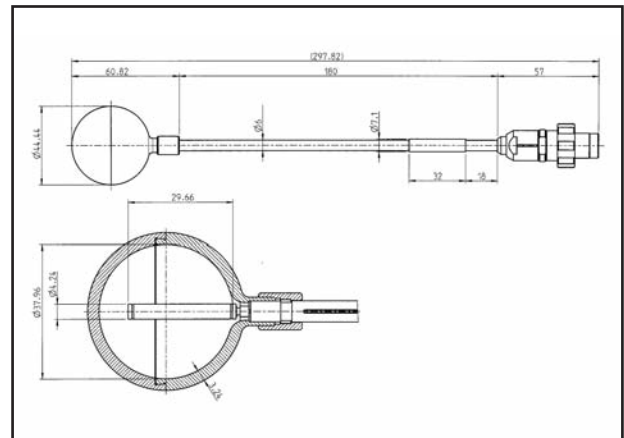
0.1 Liter Radiation Monitoring Chamber 32001



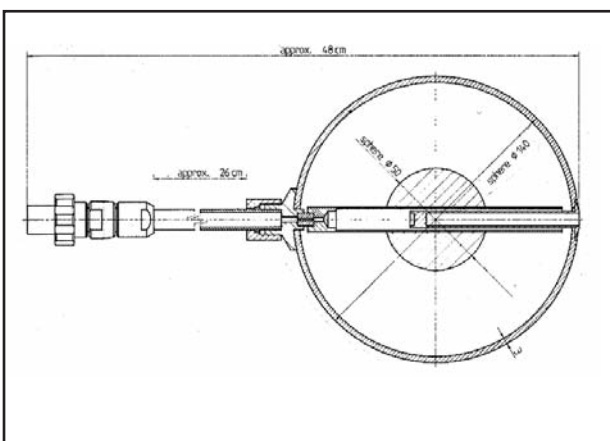
3 Liter Radiation Monitoring Chamber 34031



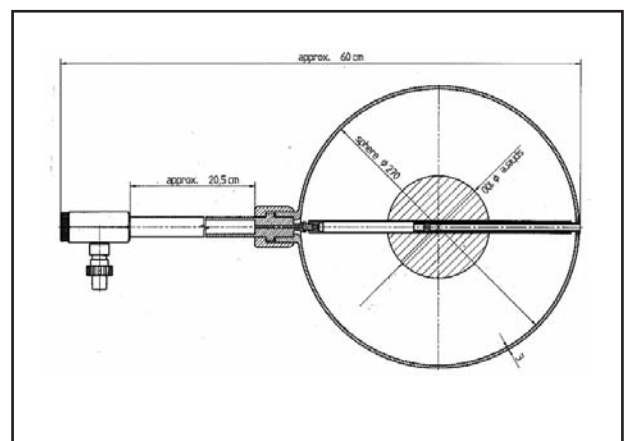
50 Liter Radiation Monitoring Chamber 7262



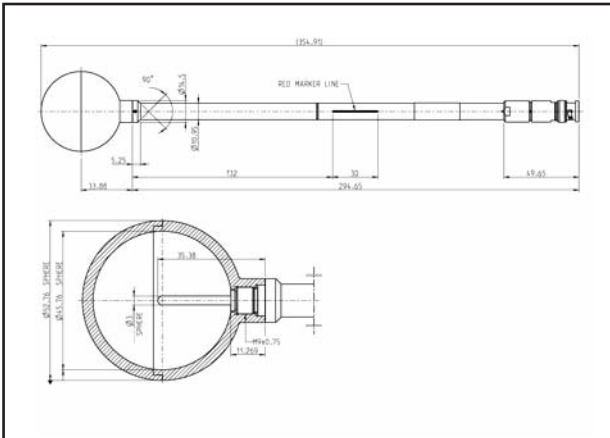
Spherical Ionization Chamber TK-30 32005



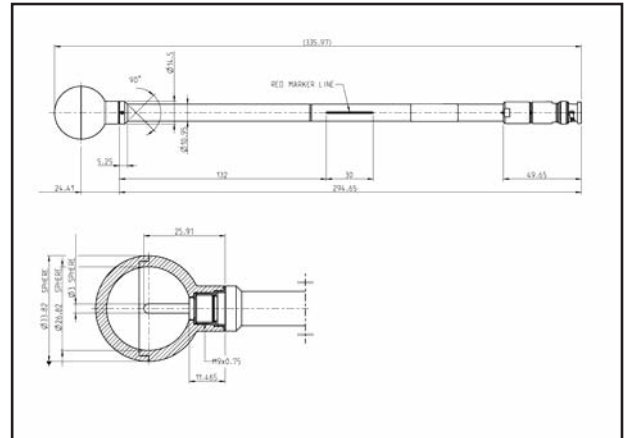
1 Liter Spherical Ionization Chamber 32002



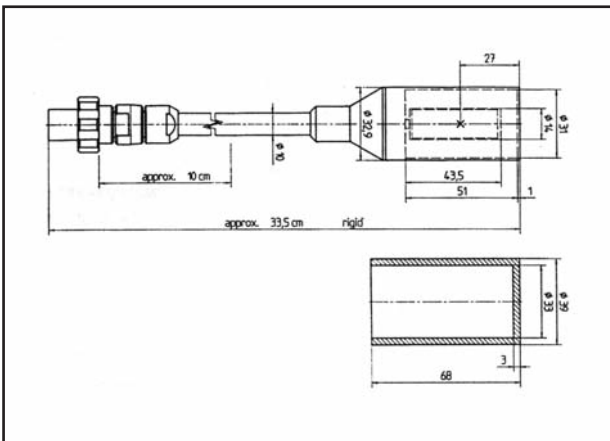
10 Liter Spherical Ionization Chamber 32003



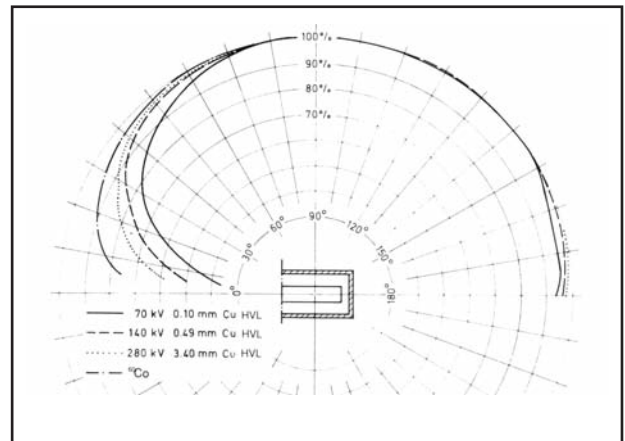
50 cm<sup>3</sup> Spherical Ionization Chamber PS-50 32007S



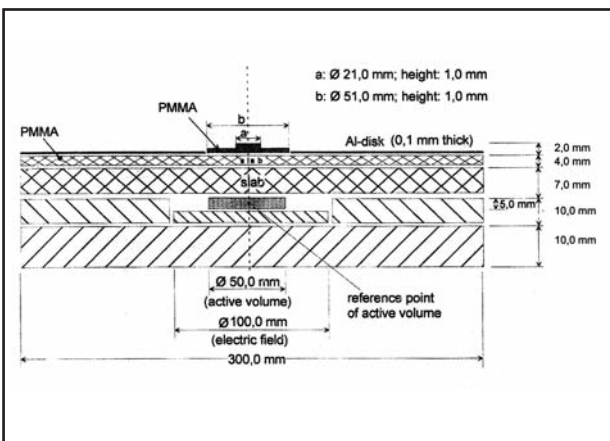
10 cm<sup>3</sup> Spherical Ionization Chamber PS-10 32008S



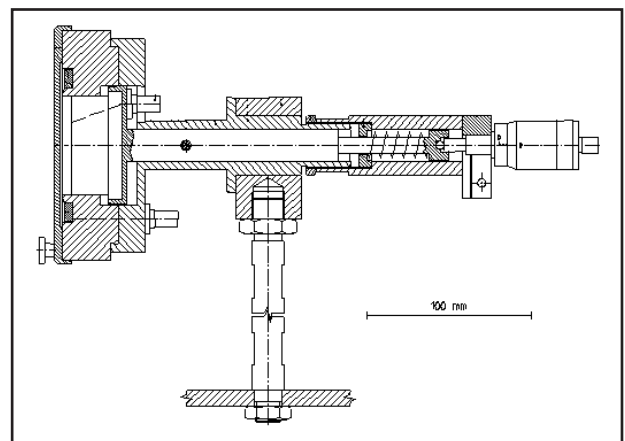
30 cm<sup>3</sup> Cylinder Stem Ionization Chamber 23361



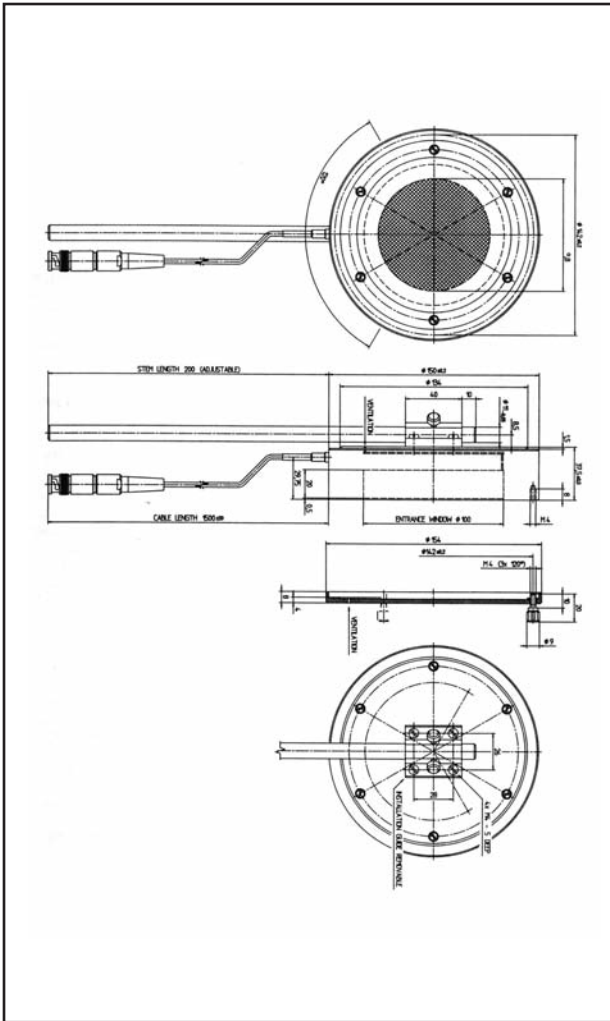
30 cm<sup>3</sup> Cylinder Stem Ionization Chamber 23361  
Directional response in air



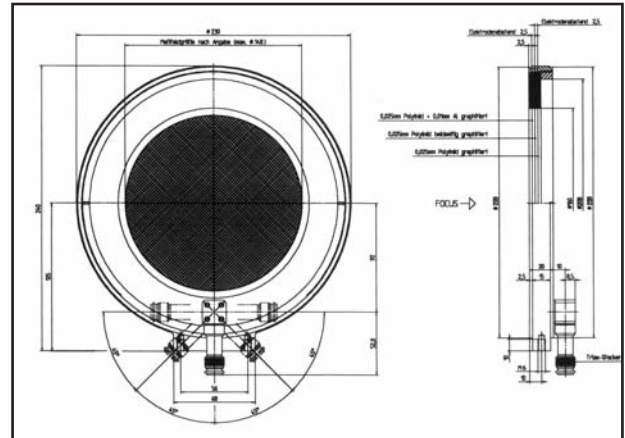
H<sub>0</sub>(10) Secondary Standard Chamber 34035



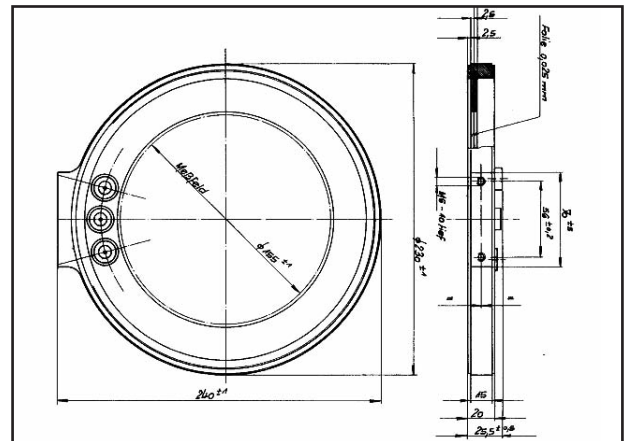
Böhm Extrapolation Chamber 23392



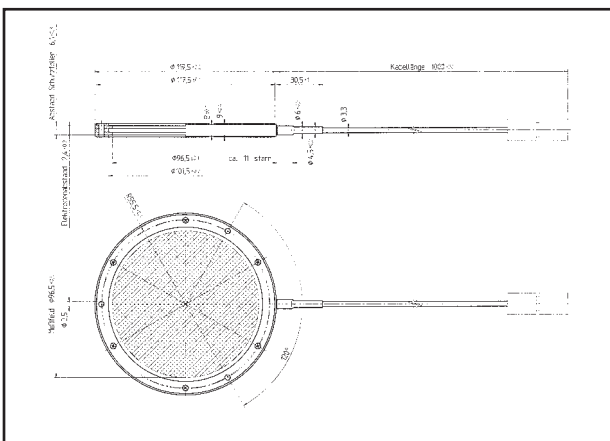
100 cm<sup>3</sup> Reference Soft X-Ray Chamber 34047



Monitor Ionization Chamber 34014



Monitor Ionization Chamber 786



X-Ray Therapy Monitor Chamber 7862

# International Standards

The quality management system of PTW-Freiburg is certified according to the appropriate quality management standards. The medical and electric products are manufactured in strict accordance with valid international standards. The medical products are CE marked in accordance with the European Medical Device Directive MDD and have the 510(k) approval of the FDA, USA, (if applicable). They comply with the valid IEC standards within their defined range of use.

## Quality Management

ISO 9001:2000

Quality management systems - Requirements

ISO 13485:2003

Medical devices - Quality management systems - Requirements for regulatory purposes

ISO/IEC 17025:1999

General requirements for the competence of testing and calibration laboratories

## Safety Requirements for Medical Devices

European Council Directive 93/42/EEC (Medical Device Directive MDD) of 14 June 1993 concerning medical devices

European Council Directive 97/43/EURATOM of 30 June 1997 on health protection of individuals against the danger of ionizing radiation in relation to medical exposure

IEC 60601-1

Medical electrical equipment - General requirements for safety

IEC 6060-1-1

Medical electrical equipment - General requirements for safety - Collateral standard: Safety requirements for medical electrical systems

IEC 60601-2-44

Medical electrical equipment - Particular requirements for the safety of X-ray equipment for computed tomography

## Dosimetry in Medical Radiology

IEC 60731

Medical electrical equipment - Dosimeters with ionization chambers as used in radiotherapy

IEC 61674

Medical electrical equipment - Dosimeters with ionization chambers and/or semiconductor detectors as used in X-ray diagnostic imaging

IAEA Report TRS-381

The Use of Plane Parallel Ionization Chambers in High Energy Electron and Photon Beams  
An International Code of Practice for Dosimetry

IAEA Report TRS-398

Absorbed Dose Determination in External Beam Radiotherapy

An International Code of Practice for Dosimetry based on Standards of Absorbed Dose to Water

AAPM TG-25, Report #32

Clinical electron beam dosimetry

AAPM TG-51, Report #67

Protocol for clinical reference dosimetry of high energy photon and electron beams

AAPM TG-56, Report #59

Code of Practice for Brachytherapy Physics

DIN 6800-2

Dosismessverfahren nach der Sondenmethode für Photonen- und Elektronenstrahlung  
Teil 2: Ionisationsdosimetrie

## Quality Assurance in Medical Radiology

AAPM TG-24, Report #13

Physical aspects of quality assurance in radiation therapy

IEC 61223-2-6

Constancy tests  
X-ray equipment for computed tomography

## Secondary Standard Calibration

IPEM

Guidelines on dosimetry transfer instruments as a secondary standard dosimeter

EAL-R2

Report No. 2, Edition 1, April 1997  
Expression of the Uncertainty of Measurement in Calibration

ICRU Report 60

Fundamental Quantities and Units for Ionizing Radiation

## Abbreviations

AAPM

American Association of Physicists in Medicine

DIN

Deutsches Institut für Normung (German technical standards)

EAL

European Co-operation for Accreditation of Laboratories

IAEA

International Atomic Energy Agency

ICRU

International Commission on Radiation Units and Measurements

IEC

International Electrotechnical Commission

IPEM

Institute of Physics and Engineering in Medicine

ISO

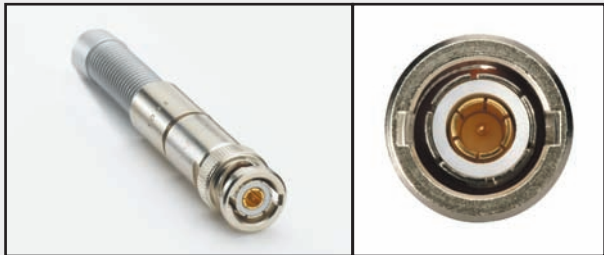
International Organization for Standardization



# Notes

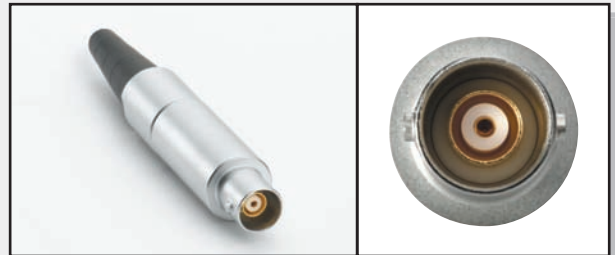
# The Connector Design

The following overview of connecting systems facilitates the identification of the adequate connector to fit your measuring system. Outer shape, colors and the size of the housing may vary, depending on the production year and the manufacturer. Some connectors may have protective covers which veil the real shape of the connector. All connectors are displayed without such protective covers. The images are not full-scale. See table on page 67 for approximate outer connector diameters. Supply of detectors with BNC connectors with banana pin, BNC biax connectors and DIAMENTOR F type connectors upon request.



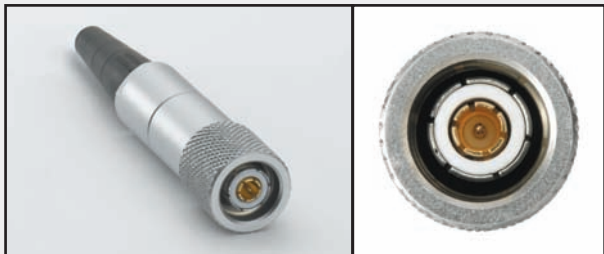
BNT Connector (N Type)

male



BNT Connector (n type)

female



TNC Connector (W type)

male



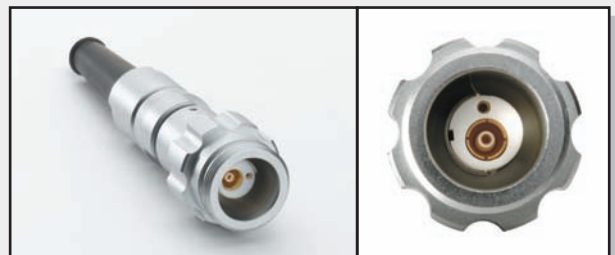
TNC Connector (w type)

female



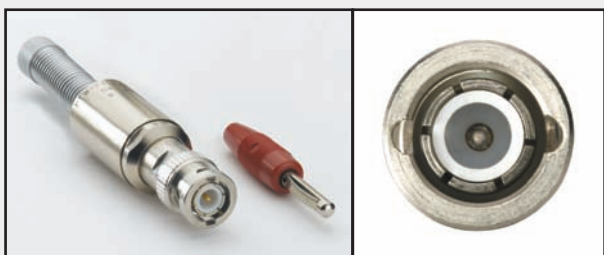
Triax PTW Connector (M type)

male



Triax PTW Connector (m type)

female



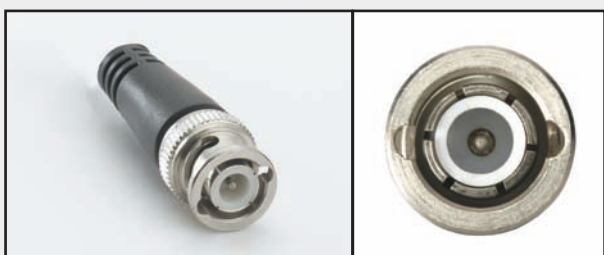
BNC Connector with Banana Pin (B type)

male



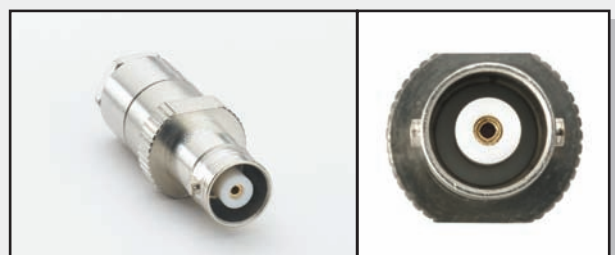
BNC Connector with Banana Pin (b type)

female



BNC Connector

male

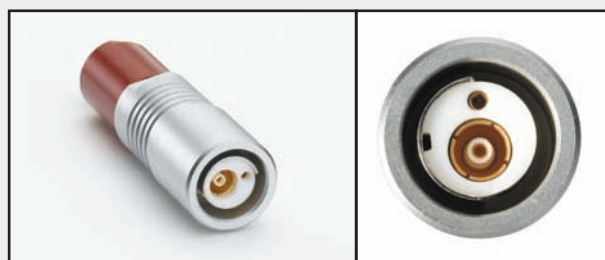


BNC Connector

female



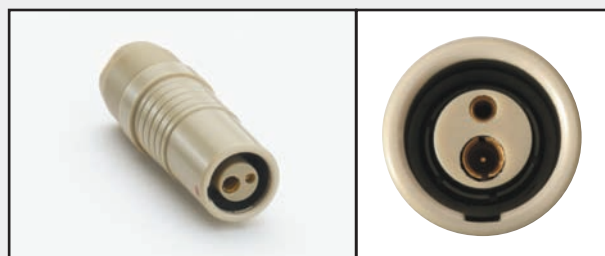
DIAMENTOR Connector (V type) male



DIAMENTOR Connector (v type) female



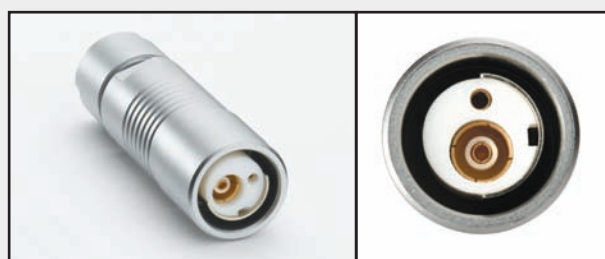
DIAMENTOR Connector (A type) male



DIAMENTOR Connector (a type) female



DIAMENTOR Connector (F type) male



DIAMENTOR Connector (f type) female

PTW can provide adaptation cables for all combinations of detectors shown above. In practice not all combinations make sense and are dangerous respectively. The reason for this is among other things, that the different connecting systems have diverse uses for the outer shielding of the cable. While some connecting systems use the cable's outer shielding for the high voltage supply of the ionization chamber, other systems use it for the grounding of the chamber and connect it to the chamber housing. Unsuitable adaptation cables may result in improper grounding of the chamber and in the worst case in the risk of an electric shock. Touchable parts of the chamber may conduct high voltage.

Adaptations between Triax PTW (M type) and BNC with Banana (B type) are problem-free. Likewise are adaptations between BNT (N type) and TNC (W type) systems in general unproblematic. The same applies to our different DIAMENTOR connecting systems. For all other combinations of connecting systems we strongly dissuade from using adaptation cables. Any use of such adaptation cables is definitely out of the intended use and left to the user's responsibility.

The following table shows the possible connector combinations used in radiation therapy.

	N, n	W, w	M, m	B, b
N, n	✓	✓	✗	✗
W, w	✓	✓	✗	✗
M, m	✗	✗	✓	✓
B, b	✗	✗	✓	✓

✓ Suitable adaptation cable

✗ Unsuitable adaptation cable














Approximate outer connector diameters:

Connector Type	Outer Diameter
N, n	15 mm, 14 mm
W, w	16 mm, 14 mm
M, m	25 mm, 24 mm
B, b	18 mm, 18 mm
V, v	15 mm, 16 mm
A, a	14 mm, 14 mm
F, f	18 mm, 19 mm

# Guide to PTW Detectors





This guide gives a review of the complete range of PTW radiation detectors arranged in the order of their scope. Some of the detectors are suitable for various applications. Especially the ion chambers designed for absolute dosimetry in radiotherapy can also be used for therapy beam analysis. All ionization chambers are supplied with vented sensitive volumes, open to the surrounding, except the sealed 0.1 cm<sup>3</sup> chamber models 23322 and 23323. The type numbers in brackets represent former chamber types with identical specification. Radiation detectors which are integrated components of radiation measuring systems such as LA48 Linear Array, DIAMENTOR or CURIEMENTOR, are not listed in this guide.

## Radiation Therapy

	30010 (30001)	0.6 cm <sup>3</sup> Farmer Chamber PMMA/Al	Thimble chamber with acrylic wall and Al electrode for measuring high-energy photon and electron radiation in air and phantom material. BNT, TNC or M connector	page 10
	30011 (30002)	0.6 cm <sup>3</sup> Farmer Chamber Graphite/Graphite	Thimble chamber with graphite wall and graphite electrode for measuring high-energy photon and electron radiation in air and phantom material. BNT or TNC connector	page 11
	30012 (30004)	0.6 cm <sup>3</sup> Farmer Chamber Graphite/Al	Thimble chamber with graphite wall and Al electrode for measuring high-energy photon and electron radiation in air and phantom material. BNT or TNC connector	page 12
	30013 (30006)	0.6 cm <sup>3</sup> Farmer Chamber Waterproof	Waterproof chamber with acrylic wall and Al electrode for measuring high-energy photon and electron radiation in air, water and phantom material. BNT, TNC or M connector	page 13
	31010 (31002)	0.125 cm <sup>3</sup> Semiflex Chamber	Waterproof thimble chamber for measuring high-energy photon and electron radiation in air, water and phantom material. BNT, TNC or M connector	page 14
	31013 (31003)	0.3 cm <sup>3</sup> Semiflex Chamber	Waterproof thimble chamber for measuring high-energy photon and electron radiation in air, water and phantom material. BNT, TNC or M connector	page 15
	30016 (23332)	0.3 cm <sup>3</sup> Rigid Stem Chamber	Thimble chamber with 25 cm rigid stem for measuring high-energy photon and electron radiation in air and phantom material. BNT, TNC or M connector	page 16
	30015 (23331)	1 cm <sup>3</sup> Rigid Stem Chamber	Thimble chamber with 25 cm rigid stem for measuring high-energy photon and electron radiation in air and phantom material. BNT, TNC or M connector	page 17
	34045	0.02 cm <sup>3</sup> Advanced Markus Electron Chamber	Improved plane parallel chamber with thin membrane for measuring high-energy electron radiation in water and phantom material. BNT, TNC or M connector	page 18
	23343	0.055 cm <sup>3</sup> Markus Electron Chamber	Classic plane parallel chamber with thin membrane for measuring high-energy electron radiation in water and phantom material. BNT, TNC or M connector	page 19
	34001	0.35 cm <sup>3</sup> Roos Electron Chamber	Precision plane parallel chamber for absolute dosimetry of high-energy electron radiation in water and phantom material. BNT, TNC or M connector	page 20
	34070	10.5 cm <sup>3</sup> Bragg Peak Chamber	Waterproof plane parallel chamber for measuring the exact location of the Bragg peak in proton beams. BNT, TNC or M connector	page 21
	34073	2.5 cm <sup>3</sup> Bragg Peak Chamber	Waterproof plane parallel chamber for measuring the exact location of the Bragg peak in horizontal proton beams. BNT, TNC or M connector	page 21

	31014	0.015 cm <sup>3</sup> PinPoint Chamber	Ultra small-sized waterproof therapy chamber for dosimetry in high-energy photon beams. BNT, TNC or M connector	page 22
	31015	0.03 cm <sup>3</sup> PinPoint Chamber	Small-sized waterproof therapy chamber for dosimetry in high-energy photon beams. BNT, TNC or M connector	page 22
	31016	0.016 cm <sup>3</sup> PinPoint 3D Chamber	Ultra small-sized waterproof therapy chamber with 3D characteristics for dosimetry in high-energy photon beams. BNT, TNC or M connector	page 23
	31018	microLion Chamber	Liquid filled ion chamber with very small sensitive volume for dose distribution measurements with high spatial resolution. BNT, TNC or M connector	page 24
	60003	Diamond Detector	Waterproof small volume diamond detector for dose distribution measurements in high-energy photon and electron beams. M connector	page 25
	60016	Dosimetry Diode for Photons	Waterproof p-type Si diode detector for dose distribution measurements in high-energy photon beams. BNT, TNC or M connector	page 26
	60017	Dosimetry Diode for Electrons and Photons	Waterproof p-type Si diode detector for dose distribution measurements in high-energy electron and photon beams. BNT, TNC or M connector	page 27
	23342	0.02 cm <sup>3</sup> Soft X-ray Chamber	Plane parallel chamber with thin membrane for measuring therapeutic X-ray beams between 10 and 100 kV in air and phantom material. BNT, TNC or M connector	page 28
	23344	0.2 cm <sup>3</sup> Soft X-ray Chamber	Plane parallel chamber with thin membrane for measuring therapeutic X-ray beams between 10 and 100 kV in air and phantom material. BNT, TNC or M connector	page 29
	34013	0.005 cm <sup>3</sup> Soft X-ray Chamber	Plane parallel chamber with thin membrane for measuring small size therapeutic X-ray beams between 15 and 50 kV in air and phantom material. BNT, TNC or M connector	page 30
	34051	SourceCheck Source Strength Test Chamber	Flat chamber for source strength measurement of radioactive interstitial therapy seeds and intravascular brachytherapy sources. BNT, TNC or M connector	page 31
	33004	Well-type HDR Chamber	Well-type chamber for source strength measurement of after-loading sources. BNT, TNC or M connector	page 32

## Diagnostic Radiology

	34060	75 cm <sup>3</sup> SFD Diagnostic Chamber	Shadow-free plane parallel chamber for absolute dosimetry in diagnostic radiology. BNT, TNC or M connector	page 36
	34069	6 cm <sup>3</sup> SFD Mammo Chamber	Shadow-free plane parallel chamber for absolute dosimetry in diagnostic radiology and mammography. BNT, TNC or M connector	page 37
	30009 30017	CT Chambers	Vented cylindrical chambers for dose length product measurements in computed tomography. BNT, TNC or M connector	page 38
	233612	30 cm <sup>3</sup> Flat Chamber	Flat circular transmission chamber for dose measurements of diagnostic X-rays in the energy range above 35 keV. BNT, TNC or M connector	page 39

## Health Physics

	T32001	100 cm <sup>3</sup> Cylindrical Chamber	Cylindrical aluminum chamber for stationary high level gamma radiation measurement above 80 keV. Special connectors for signal and HV	page 42
	T34031 T32004	3 Liter Cylindrical Chamber	Cylindrical poly ethylene chamber for stationary low level gamma radiation measurement above 80 keV. Special connectors for signal and HV	page 43
	T7262	50 Liter Cylindrical Chamber	Cylindrical pressurized steel chamber for stationary lowest level gamma radiation measurement above 80 keV. Special connectors for signal and HV	page 44
	32002	1 Liter Spherical Chamber	Spherical chamber, 140 mm diameter, for low level gamma radiation protection measurements in the energy range of 45 keV to 50 MeV. BNT, TNC or M connector	page 45
	32003	10 Liter Spherical Chamber	Spherical chamber, 270 mm diameter, for lowest level gamma radiation protection measurements in the energy range of 45 keV to 50 MeV. BNT, TNC or M connector	page 45
	32007S	50 cm <sup>3</sup> Spherical Chamber PS-50	Spherical chamber, 53 mm diameter, for primary standard radiation protection measurements in <sup>60</sup> Co and <sup>137</sup> Cs beams. BNT connector	page 46
	32008S	10 cm <sup>3</sup> Spherical Chamber PS-10	Spherical chamber, 34 mm diameter, for primary standard radiation protection measurements in <sup>60</sup> Co and <sup>137</sup> Cs beams. BNT connector	page 46
	32005	30 cm <sup>3</sup> Spherical Chamber	Spherical chamber, 22 mm diameter, for gamma radiation protection measurements in the energy range of 25 keV to 1.3 MeV. BNT, TNC or M connector	page 47
	23361	30 cm <sup>3</sup> Cylindrical Chamber	Cylindrical reference chamber, 31 mm diameter, for gamma radiation protection measurements in the energy range of 30 keV to 50 MeV. BNT, TNC or M connector	page 48
	34035 L981937 L981938	H <sub>p</sub> (10) Secondary Standard Chamber	Plane parallel reference chamber embedded in an acrylic slab phantom for direct measurement of Personal Dose Equivalent H <sub>p</sub> (10). M or BNC/banana connector	page 49
	34047	100 cm <sup>3</sup> Reference Soft X-ray Chamber	Circular plane parallel reference chamber for radiation protection measurements of 5 keV to 20 keV low energy X-rays. BNT, TNC or M connector	page 50
	TN34014 TW34014 TM786	Transmission Monitor Chambers for Calibration Benches	Circular transmission chambers of 155 mm resp. 148 mm sensitive diameter for radiation monitoring of calibration benches. BNT, TNC, M or BNC/banana connector	page 51
	TM7862	Transmission Monitor Chamber for X-ray Therapy Units	Circular transmission chamber of 96.5 mm sensitive diameter for radiation monitoring of X-ray therapy units. M or BNC/banana connector	page 52
	T23392	Böhm Extrapolation Chamber	Precision extrapolation chamber with adjustable depth of the sensitive volume between 0.5 mm and 10.5 mm for dose measurements of Beta and soft X-rays. BNC sockets	page 53

# Codes of Practice

## Absorbed Dose Determination in Photon and High Energy Electron Beams

Based on Standards of  
Absorbed Dose to Water

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### Disclaimer

*Although the information in this document has been carefully assembled, PTW-Freiburg does not guarantee that this document is free of errors.*

*PTW-Freiburg shall not be liable in any way for any consequence of using this document.*

# 1 Introduction

This document constitutes an excerpt of procedures and data from various dosimetry protocols for the determination of absorbed dose to water using ionization chambers. As most modern dosimetry protocols (e.g. IAEA, AAPM, DIN) refer to ionization chambers calibrated in absorbed dose to water, this document does not describe dose determination with ionization chambers having other calibration factors.<sup>1</sup>

The chapters referring to high energy radiation describe the formalisms outlined in IAEA TRS 398, AAPM TG-51 and DIN 6800-2 as these dosimetry protocols are widely used, see references [IAEA 398], [AAPM 51] and [DIN 6800-2]. The chapter referring to kilovoltage X-ray beams describes only the formalism outlined in the DIN standards as IAEA TRS 398 differs only slightly from DIN, and AAPM TG-51 does not address this energy range.

Although this document provides the reader with a concise overview of formulae and factors it shall not replace pertinent protocols and publications, nor is it intended to give all of the details that are important for accurate dosimetry. Also, the procedures outlined in this document are not the only ones described in the referenced literature, they constitute only one of several possibilities for absorbed dose determination.

The present document is limited to

- the use of open (vented) ionization chambers
- the use of plane-parallel chambers in case of low energy X-ray beams
- the use of cylindrical chambers in case of medium energy X-ray beams
- PTW chambers if factors are given that depend on the design of the ionization chamber.

## NOTE

*The terms 'Markus Chamber', 'Advanced Markus Chamber' and 'Roos Chamber' are the propriety of PTW-Freiburg. The published data specific to these chambers are not valid for chambers manufactured by other companies, even if they are sold as 'Markus' or 'Roos' type chambers.*

A summary of PTW chamber data is given in Appendix A.

<sup>1</sup> Document D560.210.0 refers to chambers calibrated in Air Kerma, Absorbed Dose to Air, and Exposure.



## 2 General Instructions

### 2.1 Corrected reading $M$

All formulae in this document used for the determination of absorbed dose to water  $D_w$  refer to a dosimeter reading  $M$  which is corrected for the influence quantities given in chapters 2.4 - 2.7. The reader must compute the corrected reading  $M$  from the uncorrected reading  $M_{\text{uncorr}}$  and the reading without irradiation  $M_0$  by

$$M = (M_{\text{uncorr}} - M_0) \cdot k_{\text{elec}} \cdot k_{\text{TP}} \cdot k_{\text{S}} \cdot k_{\text{pol}} \cdot k_{\text{h}} \quad (2-1)$$

The correction factor  $k_{\text{elec}}$  corresponds to the calibration factor of the electrometer if the electrometer readout is in terms of charge or current [IAEA 398, AAPM 51]. If the electrometer and the ionization chamber are calibrated together and the readout is in terms of Gy or Gy/s, a value of unity is to be used for  $k_{\text{elec}}$ .

The correction factors  $k_{\text{TP}}$ ,  $k_{\text{S}}$ ,  $k_{\text{pol}}$  and  $k_{\text{h}}$  are described in chapters 2.4 - 2.7. For absorbed dose determination, additional factors are to be applied to the corrected reading  $M$  as described in chapters 3 - 6.

### 2.2 Measuring phantoms

This document assumes that all measurements are made in a water phantom, except for chapter 3.1 where the measurements are made at the surface of an acrylic (PMMA) phantom. If measurements are nevertheless made in other than water phantoms, the measures described in chapter 6 are to be taken. It should be noted, however, that most dosimetry protocols prescribe measurements in water only.

### 2.3 Chamber positioning

#### 2.3.1 General rules

The dosimeter reading is obtained by positioning the ionization chamber at the point of interest in the phantom. Depending on the dosimetry protocol and radiation quality, either the effective point of measurement or the reference point of the ionization chamber is positioned at the point of interest. This document states the correct positioning method in each of the related chapters.

The effective point of measurement is defined as

- a point on the axis of a cylindrical chamber in case of photon beams with energy < 1.33 MeV
- a point shifted by  $0.5 r$  from the axis of a cylindrical chamber towards the focus<sup>2</sup> in case of high energy photon and electron beams ( $r$  is the inner radius of the measuring chamber volume) [IAEA 398, DIN 6800-2]
- a point at the center of the inner side of the entrance window of a plane-parallel chamber, independent of radiation quality. Care must be taken to scale the thickness of the entrance window to water-equivalent thickness.

The reference point is defined as

- a point on the central axis of a cylindrical chamber as stated by the manufacturer
- a point at the center of the inner side of the entrance window of a plane-parallel chamber.

<sup>2</sup> To measure dose at a focus distance of  $x$  cm, the axis of the cylindrical chamber must be positioned at a focus distance of  $x$  cm +  $0.5 r$ , i. e. the chamber must be shifted away from the focus, i.e. downstream.

### 2.3.2 Plane-parallel chambers

Plane-parallel chambers usually have entrance windows which are not exactly water-equivalent. For the correct positioning of a plane-parallel chamber in water, the geometrical thickness  $d_p$  of the entrance window must be scaled to equivalent water thickness  $d_w$ . The effective point of measurement is then located behind the water-equivalent thickness  $d_w$  of the entrance window.

The scaling of the geometrical thickness (e.g. plastic thickness)  $d_p$  to water equivalent thickness  $d_w$  is done by [IAEA 398]

$$d_w = d_p \cdot \frac{\rho_p}{\rho_w} \quad (2-1)$$

where  $\rho_p$  and  $\rho_w$  are the densities of the entrance window and water, respectively<sup>3</sup>. Using the area density  $\sigma_p$  and  $\rho_w = 1 \text{ g/cm}^3$ , equation (2-1) can be written as

$$d_w = \frac{\sigma_p}{\rho_w} = \frac{\sigma_p}{1 \text{ g/cm}^3} \quad (2-2)$$

The area density  $\sigma_p$  of PTW plane-parallel chambers is given in Appendix A. For instance, the water-equivalent thickness of the entrance window of a Roos chamber type 34001 ( $\sigma_p = 132 \text{ mg/cm}^2$ ) is  $d_w = 1.32 \text{ mm}$ . The entrance window of the Advanced Markus chamber (including protection cap, ( $\sigma_p = 106 \text{ mg/cm}^2$ )) has a water-equivalent thickness of  $d_w = 1.06 \text{ mm}$ .

#### Example

How to position the effective point of measurement of an Advanced Markus chamber with protection cap at a measuring depth of  $z = 10 \text{ mm}$  in water:

- according to Appendix A, the area density of the entrance window, including the protection cap and air gap, is  $\sigma_p = 106 \text{ mg/cm}^2$

- according to (2-2) the water-equivalent thickness of the entrance window is  $d_w = 1.06 \text{ mm}$ , i.e. the effective point of measurement is located behind a 'water layer' of 1.06 mm from the chamber surface
- the measuring depth in water shall be  $z = 10 \text{ mm}$ . As the entrance window contributes 1.06 mm, the chamber surface has to be positioned at a water depth of  $10 \text{ mm} - 1.06 \text{ mm} = 8.94 \text{ mm}$ .

### 2.3.3 The TRUFIX system

The task of positioning various types of ionization chambers precisely in their effective point of measurement can be quite challenging. The patented TRUFIX system (see Figure 1) facilitates this task considerably. TRUFIX can be used on automated PTW water phantoms (MP2, MP3 etc.) in connection with most PTW therapy detectors. A plastic tip lets you easily locate the water surface where the coordinate system is set to (0,0,0). Then the plastic tip is replaced by a holding device specific to each detector type, and the effective point of measurement is automatically placed at the tip's earlier position. The radius of cylindrical chambers, the water-equivalent window thickness of plane-parallel chamber windows and the chamber centers are automatically accounted for.



Figure 1: The TRUFIX chamber positioning system.

<sup>3</sup> DIN 6800-2 suggests to use the electron volume densities of the materials rather than the physical densities. The difference is neglected in this document.

## 2.4 Air density

### 2.4.1 The T&P method

Open (vented) ionization chambers must be corrected for air density according to [IAEA 398]

$$k_{TP} = \frac{P_0 \cdot (273.2 + T)}{P \cdot (273.2 + T_0)} \quad (2-3)$$

$T$  and  $P$  are the temperature and pressure in the measuring environment, the reference values are  $P_0 = 101.3 \text{ kPa}$  and  $T_0 = 20^\circ\text{C}$ . Note that in some countries the reference temperature given in the calibration certificate is  $22^\circ\text{C}$  instead of  $20^\circ\text{C}$ . AAPM TG-51 uses a value of  $22^\circ\text{C}$  as reference and a value of  $P_0 = 101.33 \text{ kPa}$  for the reference pressure.

Care must be taken to ensure the use of correct values for the barometric pressure  $P$  existing in the measuring environment. Details can be found in the literature [Christ 2004].

### 2.4.2 The check source method

Instead of using (2-3) measurements in a radioactive check source can be made. The temperature of the check source and the ionization chamber must be the same as the temperature of the phantom in which the dose measurements are performed. The reference value  $k_{\text{protocol}}$  of the check source reading is given in the calibration certificate for a given date and for reference conditions (e.g.  $101.3 \text{ kPa}$ ,  $20^\circ\text{C}$ ). The reader must correct the reference value  $k_{\text{protocol}}$  for the decay of the radioactive material. Then an actual check source reading  $k_{\text{measured}}$  is taken and the correction factor for air density is determined from

$$k_{TP} = \frac{k_{\text{protocol}}}{k_{\text{measured}}} \quad (2-4)$$

#### NOTE

*The results of (2-3) and (2-4) normally coincide better than 0.5 %. If not, the reason must be found.*

#### NOTE

*In the calibration certificates of PTW-Freiburg the reference reading  $k_{\text{protocol}}$  is described as  $k_p$ , the check reading  $k_{\text{measured}}$  is described as  $k_m$ .*

$k_p$  and  $k_m$  must not be mixed up with correction factors described in other chapters of this document.

## 2.5 Ion recombination

### 2.5.1 The two-voltage method

Correction factors for insufficient charge collection in the measuring volume of the ionization chamber can be measured using the two-voltage method [IAEA 398, AAPM 51]. They depend on the geometry of the ionization chamber and on the dose rate or dose per pulse, respectively.

For pulsed or pulsed-scanned radiation the correction factor  $k_S$  can be determined from [IAEA 398]

$$k_S = \frac{M_1/M_2 - 1}{V_1/V_2 - 1} + 1 \quad (2-5)$$

where  $M_1$  and  $M_2$  are the readings at two voltages  $V_1$  and  $V_2$ .  $V_1$  is the normally used voltage, and  $V_2$  is a voltage reduced by a factor of at least 3. Formula (2-5) is valid for  $k_S < 1.03$ . If  $k_S \geq 1.03$  refer to chapter 2.5.2.

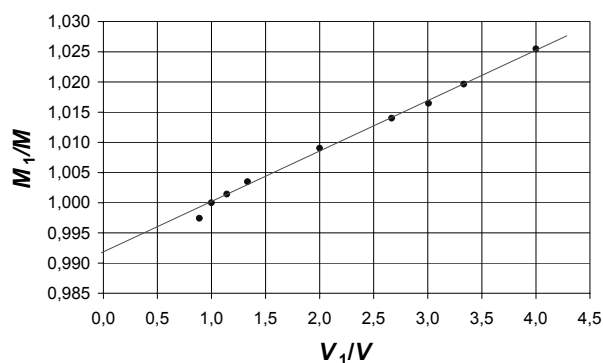
For continuous radiation  $k_S$  is taken from [IAEA 398]

$$k_S = \frac{(V_1/V_2)^2 - 1}{(V_1/V_2)^2 - (M_1/M_2)} \quad (2-6)$$

Formula (2-5) assumes a linear relationship between  $1/M$  and  $1/V$ , formula (2-6) a linear relationship between  $1/M$  and  $1/V^2$ . New chambers should be tested in accordance with the following chapter.

### 2.5.2 Jaffé diagrams

A Jaffé diagram represents the inverse reading  $1/M$  of an ionization chamber as a function of the inverse voltage  $1/V$  ( $1/V^2$  in case of continuous radiation). The reading  $M$  is corrected for polarity effect, i.e.  $M$  is the mean value of  $M_+$  and  $M_-$ , see chapter 2.6. Figure 2 shows a Jaffé diagram for pulsed radiation with the axes normalized to the usual voltage  $V_1$  and the corresponding reading  $M_1$ .



**Figure 2:** Jaffé diagram of a typical Farmer chamber usually operated at  $V_1 = 400\text{ V}$ . The regression line to the linear part intersects the  $M_1/M$  axis at 0.992 resulting in a correction factor  $k_S = 1/0.992 = 1.008$ . The dose per pulse was 0.974 mGy.

The useful range for the chamber voltage should be limited to the linear part of the Jaffé diagram. This document suggests to measure Jaffé diagrams at the lowest and at the highest dose per pulse or dose rate for each radiation quality, and to determine the linear range for the used ionization chamber from these diagrams.

The two-voltage method (see chapter 2.5.1) can be applied only if both voltages  $V_1$  and  $V_2$  are within the linear range of the Jaffé diagram. If this is not the case, the ionization chamber should be operated at the highest voltage of the linear range of the Jaffé diagram, and the correction factor  $k_S$  should be determined by extrapolating the linear part of the Jaffé diagram to an infinite voltage ( $1/V = 0$ ). It should be noted that operating an ionization chamber at a voltage other than stated in the calibration certificate may cause an error as the calibration factor sometimes depends on the applied voltage.

### 2.5.3 The DPP method

If the dose per pulse (DPP) of the accelerator at the point of measurement is known, the correction factor can be calculated by [DIN 6800-2]

$$k_S = 1 + \frac{\gamma}{U} + \frac{\delta}{U} \cdot D_P \quad (2-7)$$

$D_P$  is the absorbed dose to water per accelerator pulse, expressed in mGy,  $U$  is the chamber voltage in V, and the coefficients  $\gamma$  and  $\delta$  are listed in Table 1 [Bruggmoser 2007]. Formula (2-7) is only valid if the frequency of the accelerator pulses is smaller than the reciprocal of the ion collection time.

Chamber type	$\gamma$ V	$\delta$ V / mGy	Dose per pulse mGy	Chamber voltage V
PTW 30006/30013 Farmer	0.01	3.44	0.15 – 0.35 > 0.35 – 42	100 – 300 300 – 400
PTW 23332/30016 0.3 cm <sup>3</sup> Rigid	0.13	1.05	0.15 – 0.5 > 0.5 – 5.5	100 – 250 250 – 400
PTW 31002/31010 0.125 cm <sup>3</sup> Flexible	0.38	2.40	0.15 – 0.6 > 0.6 – 5.5	100 – 300 300 – 400
PTW 23331/30015 1 cm <sup>3</sup> Rigid	0.00	5.68	0.25 – 1.5	100 – 400
PTW 34001 Roos	0.06	1.69	0.15 – 0.5 > 0.5 – 42	50 – 200 200 – 300
PTW 34045 Advanced Markus	0.43	0.49	0.25 – 1.0 > 1.0 – 5.5	50 – 200 200 – 300
PTW 23343 Markus	0.32	1.99	0.15 – 0.55 > 0.55 – 3.0	100 – 250 250 – 300

**Table 1:** Coefficients  $\gamma$  and  $\delta$  for formula (2-7), applicable within the stated dose per pulse and voltage ranges, according to [Bruggmoser 2007, Bruggmoser 2008].

## 2.6 Polarity effect

The polarity effect depends on the radiation beam quality  $Q$ . The correction factor can be determined by [IAEA 398, DIN 6800-2]

$$k_{\text{pol}} = \frac{[(M_+ + M_-)/M_+]_Q}{[(M_+ + M_-)/M_+]_{\text{Co}}} \quad (2-8)$$

$M_+$  = positive reading obtained with the usual polarity

$M_-$  = positive reading obtained with the opposite polarity

The index Co refers to the readings obtained in a  $^{60}\text{Co}$  beam during calibration. This value is normally not given in the calibration certificate. If  $^{60}\text{Co}$  is available the user should measure this value, if not, this value should be requested from the calibration laboratory [IAEA 398, AAPM 51] or should be measured with the lowest available photon energy [DIN 6800-2]. If the effect of this value is smaller than 0.3 % for 6 MV photon beams (or lower energy), the denominator in formula 2-8 can be set to 1, otherwise it must be taken into account [AAPM 51].

## 2.7 Humidity

A correction factor for humidity has to be applied only if the  $^{60}\text{Co}$  calibration factor refers to dry air [IAEA 398]:

$$k_h = 0.997 \quad (2-9)$$

Usually the  $^{60}\text{Co}$  calibration factor refers to a relative humidity of 50 %; in this case  $k_h$  is taken as 1.000.

### 3 Kilovoltage X-Ray Beams

#### 3.1 10 kV to 100 kV

$$D_w = k_Q \cdot N_w \cdot M \quad (3-1)$$

- $D_w$  = absorbed dose to water [DIN 6809-4]  
 $k_Q$  = energy dependent correction factor, given in the calibration certificate for several radiation qualities. PTW offers calibrations at 15, 30, 50, and 70 kV  
 $N_w$  = calibration factor for absorbed dose to water for the reference radiation quality stated in the calibration certificate  
 $M$  = corrected reading of the dosimeter, see chapter 2.1. Measurements are to be made at the surface of an acrylic (PMMA) phantom. For measurements at other depths, water-equivalent material is to be added

Influence Quantity	Reference Condition
Phantom material	PMMA
Chamber	plane-parallel, Type PTW 23342, 23344, or 34013
Depth	phantom surface
Chamber positioning	outer surface of entrance window
SSD	as stated in calibration certificate
Field size	as stated in calibration certificate, or 3 cm x 3 cm at the measuring plane

#### NOTE

*DIN 6809-4 suggests the use of a 0.1 mm water-equivalent plastic foil in front of the ionization chamber when measuring above 50 kV. This foil should provide adequate build-up and eliminate low energy electrons scattered upstream. IAEA TRS 398 suggests total material thicknesses (build-up foils plus entrance window) depending upon radiation quality (IAEA Table 24. Foil thicknesses should read  $\mu\text{m}$ ). Ideally, the chamber and the build-up foils should be calibrated together, but this calibration is not available from PTW. If the user decides*

*to use build-up foils, he should determine a correction factor for each beam geometry and radiation quality used.*

#### 3.2 100 kV to 300 kV

$$D_w = k_F \cdot k_Q \cdot N_w \cdot M \quad (3-2)$$

- $D_w$  = absorbed dose to water [DIN 6809-5]  
 $k_F$  = correction factor for field sizes other than 10 cm x 10 cm (or circular fields of 10 cm in diameter), see Table 3  
 $k_Q$  = energy dependent correction factor, given in the calibration certificate for several radiation qualities. PTW offers calibrations at 100, 140, 200, 280 kV, and  $^{60}\text{Co}$ . If no calibration data specific to the chamber is available, use the values given in Table 2. This will increase the uncertainty of the measured value  
 $N_w$  = calibration factor for absorbed dose to water for  $^{60}\text{Co}$   
 $M$  = corrected reading of the dosimeter, see chapter 2.1

Influence Quantity	Reference Condition
Phantom material	water
Chamber	cylindrical
Depth	5 cm
Chamber positioning	chamber axis
SSD	100 cm
Field size	as stated in calibration certificate, or 10 cm x 10 cm at the phantom surface

Radiation Quality (Gen. Voltage, HVL)	PTW 23331, 30015 1.0 cm <sup>3</sup> Rigid	PTW 23332, 30016 0.3 cm <sup>3</sup> Rigid	PTW 31013, 31003 0.3 cm <sup>3</sup> Flexible	PTW 31010, 31002 0.125 cm <sup>3</sup> Flexible
T100 (0.17 mm Cu)	1.025	-	-	-
T120 (0.28 mm Cu)	1.017	-	-	-
T140 (0.50 mm Cu)	1.008	1.045	1.025	1.025
T150 (0.85 mm Cu)	1.000	-	-	-
T200 (1.65 mm Cu)	0.998	1.002	0.999	0.999
T250 (2.5 mm Cu)	0.998	-	-	-
T280 (3.4 mm Cu)	0.996	0.996	0.994	0.994
<sup>60</sup> Co	1.000	1.000	1.000	1.000

**Table 2:**  $k_Q$  for the reference depth of 5 cm and the reference field size of 10 cm x 10 cm [DIN 6809-5]. The values for PTW 31002/31010 have been added by PTW-Freiburg. The values for the new chamber types PTW 30015 and PTW 30016 should be similar to those given in the DIN table for PTW 23331 and PTW 23332, respectively.

Radiation Quality	PTW 23331, 30015 1.0 cm <sup>3</sup> Rigid		PTW 23332, 30016 0.3 cm <sup>3</sup> Rigid	
	5 cm x 5 cm	15 cm x 15 cm	5 cm x 5 cm	15 cm x 15 cm
T100	1.02	1.00	1.00	1.00
T140	1.03	1.00	1.02	1.00
T200	1.04	0.99	1.03	1.00
T280	1.03	0.99	1.02	0.99

**Table 3:** Field size dependent correction factor  $k_F$  at the reference depth of 5 cm [DIN 6809-5]. The values for the new chamber types PTW 30015 and PTW 30016 should be similar to those given in the DIN table for PTW 23331 and PTW 23332, respectively.

## 4 High Energy Photon Beams

### 4.1 IAEA TRS 398

$$D_w = k_Q \cdot N_w \cdot M \quad (4-1)$$

- $D_w$  = absorbed dose to water  
 $k_Q$  = energy dependent correction factor, see Table 4  
 $N_w$  = calibration factor for absorbed dose to water for  $^{60}\text{Co}$   
 $M$  = corrected reading of the dosimeter, see chapter 2.1

Influence Quantity	Reference Condition
Phantom material	water
Chamber	cylindrical
Depth	10 cm (or 5 cm) for $TPR_{20,10} < 0.7$ 10 cm for $TPR_{20,10} \geq 0.7$
Chamber positioning	chamber axis
SSD / SDD	100 cm
Field size	10 cm x 10 cm SSD setup: field size defined at surface SDD setup: field size defined in detector plane

The tissue phantom ratio  $TPR_{20,10}$  is measured for each nominal accelerating voltage.  $TPR_{20,10}$  is defined as the ratio  $M_{20} / M_{10}$  of two ionization readings of a dosimeter at different depths.  $M_{20}$  is obtained at 20 cm depth of water,  $M_{10}$  at 10 cm depth of water at a fixed source-detector-distance  $SDD = 100$  cm and a field size of 10 cm x 10 cm at the depth of measurement.

#### NOTE

In case  $TPR_{20,10}$  values are not available, they can be determined from [IAEA 398]

$$TPR_{20,10} = 1.2661 \cdot PDD_{20,10} - 0.0595$$

where  $PDD_{20,10}$  is the ratio of the percent depth doses at 20 cm and 10 cm depth, respectively. The  $PDD$  values must be measured at  $SSD = 100$  cm with a field size of 10 cm x 10 cm at the phantom surface.

For beam quality specification measurements with a cylindrical chamber, the chamber axis should be positioned at the measuring depth. It is allowed to use a plane-parallel chamber to determine beam quality.



Photon Beam Quality  $TPR_{20,10}$	PTW 23331  1.0 cm <sup>3</sup> Rigid	PTW 23332  0.3 cm <sup>3</sup> Rigid	PTW 23333/ 30001/ 30010 Farmer	PTW 30002/ 30011 Farmer	PTW 30004/ 30012 Farmer	PTW 30006/ 30013 Farmer	PTW 31002/ 31010 0.125 cm <sup>3</sup> Flexible	PTW 31003/ 31013 0.3 cm <sup>3</sup> Flexible
0.50	1.004	1.004	1.004	1.006	1.006	1.002	1.003	1.003
0.53	1.003	1.003	1.003	1.004	1.005	1.002	1.002	1.002
0.56	1.000	1.001	1.001	1.001	1.002	1.000	1.000	1.000
0.59	0.999	0.999	0.999	0.999	1.000	0.999	0.999	0.999
0.62	0.997	0.997	0.997	0.997	0.999	0.997	0.997	0.997
0.65	0.993	0.994	0.994	0.994	0.996	0.994	0.994	0.994
0.68	0.990	0.990	0.990	0.992	0.994	0.990	0.990	0.990
0.70	0.988	0.988	0.988	0.990	0.992	0.988	0.988	0.988
0.72	0.985	0.984	0.985	0.987	0.989	0.984	0.984	0.984
0.74	0.982	0.980	0.981	0.984	0.986	0.980	0.980	0.980
0.76	0.978	0.976	0.976	0.980	0.982	0.975	0.975	0.975
0.78	0.971	0.968	0.969	0.973	0.976	0.968	0.968	0.968
0.80	0.964	0.961	0.962	0.967	0.969	0.960	0.960	0.960
0.82	0.956	0.954	0.955	0.959	0.962	0.952	0.952	0.952
0.84	0.945	0.943	0.943	0.948	0.950	0.940	0.940	0.940

**Table 4:** Typical  $k_Q$  values for PTW cylindrical chambers [IAEA 398]. For <sup>60</sup>Co beams  $k_Q$  is 1.000. The new chamber types 31010 and 31013 have been added by PTW-Freiburg.

## 4.2 AAPM TG-51

$$D_w = k_Q \cdot N_w \cdot M \quad (4-2)$$

- $D_w$  = absorbed dose to water
- $k_Q$  = energy dependent correction factor, see Table 5
- $N_w$  = calibration factor for absorbed dose to water for  $^{60}\text{Co}$
- $M$  = corrected reading of the dosimeter, see chapter 2.1

Influence Quantity	Reference Condition
Phantom material	water
Chamber	cylindrical, no nylon-wall chambers
Depth	10 cm
Chamber positioning	chamber axis
SSD/SDD	100 cm
Field size	10 cm x 10 cm
	SSD setup: field size defined at surface
	SDD setup: field size defined in detector plane

The beam quality specifier  $\%dd(10)_x$  is the percentage depth dose at 10 cm depth in a water phantom due to photons only.  $\%dd(10)_x$  is defined at  $SSD = 100$  cm for a field size of 10 cm x 10 cm at the phantom surface.

At energies about 10 MV and above, a 1 mm lead foil (thickness  $\pm 20\%$ ) should be used when measuring the depth dose curve for the determination of  $\%dd(10)_x$ . The lead foil should be placed ( $50 \pm 5$ ) cm or if this is impossible, ( $30 \pm 1$ ) cm above the phantom surface.

The beam quality specifier is obtained from the corresponding value  $\%dd(10)_{Pb}$  by one of the following formulae

lead foil at ( $50 \pm 5$ ) cm and  $\%dd(10)_{Pb} \geq 73\%$

$$\%dd(10)_x = (0.8905 + 0.0015 \cdot \%dd(10)_{Pb}) \cdot \%dd(10)_{Pb} \quad (4-3)$$

lead foil at ( $30 \pm 1$ ) cm and  $\%dd(10)_{Pb} \geq 71\%$

$$\%dd(10)_x = (0.8116 + 0.00264 \cdot \%dd(10)_{Pb}) \cdot \%dd(10)_{Pb} \quad (4-4)$$

If  $\%dd(10)_{Pb}$  is below the above thresholds,  $\%dd(10)_x$  equals  $\%dd(10)_{Pb}$ .

**NOTE**

*The lead foil is used for beam quality specification only. Remove lead foil for dose measurements.*

For beam quality specification measurements with a cylindrical chamber, the chamber axis must be shifted downstream by  $0.6r$ , where  $r$  is the inner radius of the measuring volume. It is allowed to use a plane-parallel chamber to determine beam quality.

Photon Beam Quality $\%dd(10)_x$	PTW 23333/30001/30010 Farmer	PTW 30002/30011 Farmer	PTW 30004/30012 Farmer	PTW 30006/30013 Farmer	PTW 31002/31010 Flexible 0.125 cm <sup>3</sup>	PTW 31003/31013 Flexible 0.3 cm <sup>3</sup>
58.0	1.000	1.000	1.000	1.000	1.000	1.000
63.0	0.996	0.997	0.998	0.996	0.996	0.996
66.0	0.992	0.994	0.995	0.992	0.992	0.992
71.0	0.984	0.987	0.988	0.984	0.984	0.984
81.0	0.967	0.970	0.973	0.967	0.967	0.967
93.0	0.945	0.948	0.952	0.945	0.946	0.946

**Table 5:** Typical  $k_Q$  values for PTW cylindrical chambers [AAPM 51]. For  $^{60}\text{Co}$  beams  $k_Q$  is 1.000. The chamber types which are not listed in the TG-51 table have been added by PTW-Freiburg after investigating the differences between the corresponding  $k_Q$  values in IAEA TRS 398. The values for Farmer chambers PTW 30006/30013 where taken from type 30001. They should not deviate by more than 0.3 % (compare [IAEA 398]).

### 4.3 DIN 6800-2

$$D_w = k_r \cdot k_Q \cdot N_w \cdot M \quad (4-5)$$

- $D_w$  = absorbed dose to water  
 $k_r$  =  $1 + 0.03 r$  replacement correction factor ( $r$  is the inner radius of the measuring volume of a cylindrical chamber, given in cm).  $k_r$  is not applicable for plane-parallel chambers). See Table 7  
 $k_Q$  = energy dependent correction factor, see Table 6  
 $N_w$  = calibration factor for absorbed dose to water for  $^{60}\text{Co}$   
 $M$  = corrected reading of the dosimeter, see chapter 2.1

Influence Quantity	Reference Condition
Phantom material	water
Chamber	cylindrical
Depth	5 cm for $^{60}\text{Co}$ 10 cm for photons
Chamber positioning	effective point of measurement, see chapter 2.3
SSD	95 cm for $^{60}\text{Co}$ 100 cm for photons
Field size	10 cm x 10 cm at 5 cm depth for $^{60}\text{Co}$ 10 cm x 10 cm at phantom surface for photons

The beam quality index  $Q$  is to be measured for each nominal accelerating voltage.  $Q$  is defined as the ratio  $M_{20}/M_{10}$  of two ionization readings of a dosimeter at different depths.  $M_{20}$  is obtained at 20 cm depth of water,  $M_{10}$  at 10 cm depth of water at a fixed source-detector-distance  $SDD = 100$  cm and a field size of 10 cm x 10 cm at the depth of measurement.

#### NOTE

In case  $M_{10}$  and  $M_{20}$  values are not available,  $Q$  can be determined from [DIN 6800-2]

$$Q = 1.2661 \cdot m - 0.0595$$

where  $m$  is the ratio of the percent depth doses at 20 cm and 10 cm depth, respectively. The percent depth doses must be measured at  $SSD = 100$  cm with a field size of 10 cm x 10 cm at the phantom surface.

For beam quality specification measurements with a cylindrical chamber, the chamber axis must be shifted downstream by  $0.5 r$ , where  $r$  is the inner radius of the measuring volume. It is allowed to use a plane-parallel chamber to determine beam quality.

Chamber Type	Beam Quality Index $Q$														
	0.50	0.53	0.56	0.59	0.62	0.65	0.68	0.70	0.72	0.74	0.76	0.78	0.80	0.82	0.84
PTW 23331 Rigid	1.0090	1.0053	1.0008	0.9987	0.9957	0.9907	0.9867	0.9841	0.9806	0.9771	0.9727	0.9652	0.9576	0.9487	0.9363
PTW 23332 Rigid	1.0071	1.0044	1.0015	0.9988	0.9962	0.9926	0.9880	0.9856	0.9812	0.9770	0.9727	0.9644	0.9570	0.9495	0.9376
PTW 23333	1.0078	1.0048	1.0016	0.9988	0.9960	0.9922	0.9875	0.9850	0.9816	0.9772	0.9719	0.9645	0.9581	0.9494	0.9363
PTW 30001/30010	1.0078	1.0048	1.0016	0.9988	0.9960	0.9922	0.9875	0.9850	0.9816	0.9772	0.9719	0.9645	0.9571	0.9494	0.9363
PTW 30002/30011	1.0099	1.0058	1.0016	0.9988	0.9960	0.9922	0.9895	0.9870	0.9836	0.9802	0.9759	0.9685	0.9620	0.9533	0.9412
PTW 30004/30012	1.0099	1.0068	1.0026	0.9998	0.9980	0.9942	0.9915	0.9890	0.9856	0.9822	0.9779	0.9715	0.9640	0.9563	0.9432
PTW 30006/30013	1.0058	1.0038	1.0006	0.9988	0.9960	0.9922	0.9875	0.9850	0.9806	0.9762	0.9709	0.9635	0.9551	0.9464	0.9333
PTW 31002/31010 Flex	1.0065	1.0036	1.0006	0.9988	0.9961	0.9924	0.9877	0.9853	0.9809	0.9766	0.9713	0.9640	0.9556	0.9469	0.9339
PTW 31003/31013 Flex	1.0065	1.0036	1.0006	0.9988	0.9961	0.9924	0.9877	0.9853	0.9809	0.9766	0.9713	0.9640	0.9556	0.9469	0.9339
PTW 31014 PinPoint	1.0052	1.0036	1.0012	0.9989	0.9977	0.9944	0.9912	0.9880	0.9839	0.9788	0.9737	0.9656	0.9574	0.9502	0.9388
PTW 31016 PinPoint 3D	1.0052	1.0036	1.0012	0.9989	0.9977	0.9944	0.9912	0.9880	0.9839	0.9788	0.9737	0.9656	0.9574	0.9502	0.9388

**Table 6:**  $k_Q$  values for PTW cylindrical chambers [DIN 6800-2]. For  $^{60}\text{Co}$  beams  $k_Q$  equals 1.000. The data for the 31016 PinPoint 3D have been added by PTW-Freiburg.

Chamber Type	Radius $r$ [cm]	Correction Factor $k_r$
PTW 0.6 cm <sup>3</sup> Farmer	0.305	1.009
PTW 0.125 cm <sup>3</sup> Flexible	0.275	1.008
PTW 0.3 cm <sup>3</sup> Flexible	0.275	1.008
PTW 23331 1.0 cm <sup>3</sup> Rigid	0.395	1.012
PTW 23333 1.0 cm <sup>3</sup> Rigid	0.250	1.008
PTW 31014 0.015 cm <sup>3</sup> PinPoint	0.100	1.003
PTW 31016 0.016 cm <sup>3</sup> PinPoint 3D	0.145	1.004

**Table 7:** Radius of the measuring volume of PTW cylindrical chambers and values for the correction factor  $k_r$ . For details see Appendix A.

## 5 High Energy Electron Beams

### 5.1 IAEA TRS 398

#### 5.1.1 Chambers calibrated at $^{60}\text{Co}$

$$D_w = k_Q \cdot N_w \cdot M \quad (5-1)$$

- $D_w$  = absorbed dose to water  
 $k_Q$  = energy dependent correction factor, see Table 8  
 $N_w$  = calibration factor for absorbed dose to water for  $^{60}\text{Co}$   
 $M$  = corrected reading of the dosimeter, see chapter 2.1

Influence Quantity	Reference Condition
Phantom material	water (for beams with $R_{50} < 4 \text{ g/cm}^2$ (approx. $E_0 \geq 10 \text{ MeV}$ ) a plastic phantom may be used)
Chamber	plane-parallel (for beams with $R_{50} \geq 4 \text{ g/cm}^2$ (approx. $E_0 \geq 10 \text{ MeV}$ ) a cylindrical chamber may be used)
Depth	$z_{\text{ref}} = 0.6 \cdot R_{50} - 0.1 \text{ g/cm}^2$ ( $z_{\text{ref}}$ and $R_{50}$ in $\text{g/cm}^2$ )
Chamber positioning	effective point of measurement, see chapter 2.3
SSD	100 cm
Field size	10 cm x 10 cm at phantom surface, or that used for normalization of output factors, whichever is larger

The beam quality is specified by  $R_{50}$ , the depth in water at which the absorbed dose is 50 % of its value at the absorbed dose maximum<sup>4</sup>.  $R_{50}$  is to be measured under the above reference conditions, but at field sizes of at least

<sup>4</sup> The mean energy  $E_0$  can be estimated by

$$E_0 = 2.33 \cdot R_{50} \quad (R_{50} \text{ in } \text{g/cm}^2 \text{ and } E_0 \text{ in MeV}).$$

10 cm x 10 cm for  $R_{50} \leq 7 \text{ g/cm}^2$

20 cm x 20 cm for  $R_{50} > 7 \text{ g/cm}^2$

From the depth ionization distribution measured with an air-filled ionization chamber, the quantity  $R_{50,\text{ion}}$  is obtained. This quantity can be converted to  $R_{50}$  by

$$R_{50} = 1.029 \cdot R_{50,\text{ion}} - 0.06 \text{ g/cm}^2 \quad (5-2)$$

( $R_{50,\text{ion}} \leq 10 \text{ g/cm}^2$ )

$$R_{50} = 1.059 \cdot R_{50,\text{ion}} - 0.37 \text{ g/cm}^2 \quad (5-3)$$

( $R_{50,\text{ion}} > 10 \text{ g/cm}^2$ )

For beam quality specification measurements with a cylindrical chamber, the chamber axis must be shifted downstream by  $0.5 r$ , where  $r$  is the inner radius of the measuring volume. For  $R_{50} < 4 \text{ g/cm}^2$  a plane-parallel chamber must be used.

#### 5.1.2 Cross-calibration

IAEA TRS 398 recommends the cross-calibration of plane-parallel chambers against a cylindrical chamber which is calibrated at  $^{60}\text{Co}$ . Dose measurements are performed under reference conditions (see chapter 5.1.1) using the highest available electron energy  $Q_{\text{cross}}$ .

**Step 1:** measure a reference dose  $D_{w,Q_{\text{cross}}}$  with a cylindrical chamber which was calibrated at  $^{60}\text{Co}$ , following the procedure described in chapter 5.1.1.

**Step 2:** irradiate the plane-parallel chamber with the same dose. Take the plane-parallel chamber's corrected reading  $M$  and determine its calibration factor for the energy used for cross-calibration

$$N_{w,Q_{\text{cross}}} = \frac{D_{w,Q_{\text{cross}}}}{M} \quad (5-4)$$

**Step 3:** use the cross-calibrated plane-parallel chamber to measure dose at any electron energy  $Q$  other than  $Q_{\text{cross}}$

$$D_w = \frac{k_Q}{k_{Q_{\text{cross}}}} \cdot N_{w,Q_{\text{cross}}} \cdot M \quad (5-5)$$

$k_{Q_{\text{cross}}}$  is the plane-parallel chamber's  $k_Q$  value for the cross-calibration energy  $Q_{\text{cross}}$ . Values for  $k_Q$  are obtained from Table 8.

Electron Beam Quality $R_{50}$ [g/cm <sup>2</sup> ]	PTW 23343 Markus	PTW 34045 Advanced Markus	PTW 34001 Roos	PTW 30001/ 30010 Farmer	PTW 30002/ 30011 Farmer	PTW 30004/ 30012 Farmer	PTW 30006/ 30013 Farmer	PTW 31002/ 31010 0.125 cm <sup>3</sup> Flexible	PTW 31003/ 31013 0.3 cm <sup>3</sup> Flexible
1.0	—	0.966	0.965	—	—	—	—	—	—
1.4	—	0.956	0.955	—	—	—	—	—	—
2.0	0.925	0.945	0.944	—	—	—	—	—	—
2.5	0.920	0.938	0.937	—	—	—	—	—	—
3.0	0.916	0.932	0.931	—	—	—	—	—	—
3.5	0.913	0.926	0.925	—	—	—	—	—	—
4.0	0.910	0.921	0.920	0.911	0.916	0.920	0.911	0.912	0.912
4.5	0.907	0.917	0.916	0.909	0.914	0.918	0.909	0.910	0.910
5.0	0.904	0.912	0.912	0.907	0.912	0.916	0.907	0.908	0.908
5.5	0.901	0.909	0.908	0.905	0.910	0.915	0.905	0.906	0.906
6.0	0.899	0.905	0.904	0.904	0.909	0.913	0.904	0.905	0.905
7.0	0.894	0.899	0.898	0.901	0.906	0.910	0.901	0.901	0.901
8.0	0.889	0.893	0.892	0.898	0.903	0.907	0.898	0.898	0.898
10.0	0.881	0.883	0.882	0.893	0.897	0.902	0.893	0.893	0.893
13.0	0.870	0.871	0.870	0.885	0.890	0.894	0.885	0.885	0.885
16.0	0.860	0.861	0.860	0.877	0.882	0.887	0.877	0.877	0.877
20.0	0.849	0.849	0.848	0.868	0.873	0.877	0.868	0.867	0.867

**Table 8:** Typical  $k_Q$  values for PTW plane-parallel and cylindrical chambers [IAEA 398]<sup>5</sup>. The values for the Advanced Markus chamber and the Farmer chambers type 30006/30013 have been added by PTW-Freiburg. They were calculated according to IAEA TRS 398<sup>6</sup>.

<sup>5</sup> With corrigendum STI/DOC/010/398.

<sup>6</sup> For details refer to PTW's Technical Note D661.200.0.

## 5.2 AAPM TG-51

### 5.2.1 Chambers calibrated at $^{60}\text{Co}$

$$D_w = P_{gr}^Q \cdot k'_{R_{50}} \cdot k_{ecal} \cdot N_w \cdot M \quad (5-6)$$

$D_w$  = absorbed dose to water

$P_{gr}^Q$  = correction for gradient effects, not needed for plane-parallel chambers. For cylindrical chambers with a cavity radius  $r$  the correction factor at the reference depth  $d_{ref}$  is obtained from

$$P_{gr}^Q = M(d_{ref} + 0.5 \cdot r) / M(d_{ref})$$

$k'_{R_{50}}$  = electron quality conversion factor, see formulae (5-9) and (5-10)

$k_{ecal}$  = photon-electron conversion factor, see Table 9

$N_w$  = calibration factor for absorbed dose to water for  $^{60}\text{Co}$

$M$  = corrected reading of the dosimeter, see chapter 2.1

Influence Quantity	Reference Condition
Phantom material	water
Chamber	plane-parallel preferred for $R_{50} \leq 4.3$ cm (10 MeV) plane-parallel mandatory for $R_{50} \leq 2.6$ cm (6 MeV)
Depth	$d_{ref} = 0.6 \cdot R_{50} - 0.1$ cm
Chamber positioning	chamber axis for cylindrical chambers, effective point of measurement for plane-parallel chambers, see chapter 2.3
SSD	90 - 110 cm
Field size	$\geq 10$ cm x 10 cm at phantom surface for $R_{50} \leq 8.5$ cm (20 MeV), $\geq 20$ cm x 20 cm at phantom surface for $R_{50} > 8.5$ cm

The beam quality is specified by  $R_{50}$ , the depth in water at which the absorbed dose is 50 % of its value at the absorbed dose maximum.  $R_{50}$  is to be measured under the above reference conditions, but at  $SSD = 100$  cm and at field sizes at the phantom surface of at least

10 cm x 10 cm for  $R_{50} \leq 8.5$  cm

20 cm x 20 cm for  $R_{50} > 8.5$  cm

From the depth ionization distribution measured with an air-filled ionization chamber, the quantity  $I_{50}$  is obtained. This quantity can be converted to  $R_{50}$  by

$$R_{50} = 1.029 \cdot I_{50} - 0.06 \text{ cm} \quad (2 \leq I_{50} \leq 10 \text{ cm}) \quad (5-7)$$

$$R_{50} = 1.059 \cdot I_{50} - 0.37 \text{ cm} \quad (I_{50} > 10 \text{ cm}) \quad (5-8)$$

Chamber Type	$k_{ecal}$
PTW 34001 Roos	0.901
PTW 34045 Advanced Markus	0.905
PTW 23343 Markus	0.905
PTW 30001/30010 Farmer	0.897
PTW 30002/30011 Farmer	0.900
PTW 30004/30012 Farmer	0.905
PTW 30006/30013 Farmer	0.896
PTW 31003/31013 0.3 cm <sup>3</sup> Flexible	0.898
PTW 31002/31010 0.125 cm <sup>3</sup> Flexible	0.898
PTW 23331 1.0 cm <sup>3</sup> Rigid	0.896
PTW 23332/30016 0.3 cm <sup>3</sup> Rigid	0.898

**Table 9:** Values of the photon-electron conversion factor  $k_{ecal}$ . The values not listed in [AAPM 51] have been added by PTW-Freiburg; they were calculated according to [Rogers 1998].

For beam quality specification measurements with a cylindrical chamber, the chamber axis must be shifted downstream by  $0.5 r$ , where  $r$  is the inner radius of the measuring volume. Cylindrical chambers should be used only for  $R_{50} > 4.3$  cm.

The electron quality conversion factor is obtained from the following formulae with  $R_{50}$  expressed in cm.

For cylindrical chambers and  $2 \leq R_{50} \leq 9$  cm

$$k'_{R_{50}} = 0.9905 + 0.071 \cdot e^{-\frac{R_{50}}{3.67}} \quad (5-9)$$

and

for well-guarded plane-parallel chambers and  
 $2 \leq R_{50} \leq 20$  cm

$$k'_{R_{50}} = 1.2239 - 0.145 \cdot (R_{50})^{0.214} \quad (5-10)$$

### 5.2.2 Cross-calibration

AAPM TG-51 recommends the cross-calibration of plane-parallel chambers against a cylindrical chamber which is calibrated at  $^{60}\text{Co}$ . Dose measurements are performed under reference conditions (see chapter 5.2.1) using the highest available electron energy  $Q_{\text{cross}}$ .

**Step 1:** measure a reference dose  $D_{w,Q_{\text{cross}}}$  with a cylindrical chamber which was calibrated at  $^{60}\text{Co}$ , following the procedure described in chapter 5.2.1.

**Step 2:** irradiate the plane-parallel chamber with the same dose. Take the plane-parallel chamber's corrected reading  $M$  and determine its calibration factor for the energy used for cross-calibration

$$N_{w,Q_{\text{cross}}} = \frac{D_{w,Q_{\text{cross}}}}{M} \quad (5-11)$$

**Step 3:** use the cross-calibrated plane-parallel chamber to measure dose at any electron energy  $Q$  other than  $Q_{\text{cross}}$

$$D_w = \frac{k'_{R_{50}}}{k'_{R_{50},Q_{\text{cross}}}} \cdot N_{w,Q_{\text{cross}}} \cdot M \quad (5-12)$$

$k'_{R_{50},Q_{\text{cross}}}$  is the plane-parallel chamber's  $k'_{R_{50}}$  value for the cross-calibration energy  $Q_{\text{cross}}$ .

$k'_{R_{50}}$  values are obtained from formula (5-10).

## 5.3 DIN 6800-2

### 5.3.1 Chambers calibrated at $^{60}\text{Co}$

$$D_w = k_r \cdot k_E \cdot N_w \cdot M \quad (5-13)$$

$D_w$  = absorbed dose to water at  $z_{\text{ref}}$

$k_r$  =  $1 + 0.03r$  replacement correction factor ( $r$  is the inner radius of the measuring volume of a cylindrical chamber, given in cm).  $k_r$  is not applicable for plane-parallel chambers)

$k_E$  =  $k'_E \cdot k''_E$  energy dependent correction factor, see chapter 5.3.3

$N_w$  = calibration factor for absorbed dose to water for  $^{60}\text{Co}$

$M$  = corrected reading of the dosimeter at  $z_{\text{ref}}$ , see chapter 2.1

Influence Quantity	Reference Condition
Phantom material	water
Chamber	plane-parallel for $R_{50} \geq 4$ cm a cylindrical chamber can be used
Depth	$z_{\text{ref}}$ (see chapter 5.3.2)
Chamber positioning	effective point of measurement, see chapter 2.3
SSD	100 cm
Field size	20 cm x 20 cm at phantom surface

### 5.3.2 Determination of $R_{50}$ and $z_{\text{ref}}$

$R_{50}$  is defined as the depth at which the absorbed dose has dropped to 50 % of the maximum value.

$R_{50}$  is determined from the corresponding value  $R_{50,\text{ion}}$  of a depth ionization curve, measured at  $\text{SSD} = 100$  cm with a field size of 20 cm x 20 cm (optionally 10 cm x 10 cm for  $R_{50} \leq 7$  cm)

$$R_{50} = 1.029 \cdot R_{50,\text{ion}} - 0.06 \text{ cm} (R_{50,\text{ion}} \leq 10 \text{ cm}) \quad (5-14)$$

$$R_{50} = 1.059 \cdot R_{50,\text{ion}} - 0.37 \text{ cm} (R_{50,\text{ion}} > 10 \text{ cm}) \quad (5-15)$$

The reference depth for dose measurements is defined as ( $z_{\text{ref}}$  and  $R_{50}$  in cm)

$$z_{\text{ref}} = 0.6 \cdot R_{50} - 0.1 \quad (5-16)$$



### 5.3.3 Determination of $k_E = k_E' \cdot k_E''$

$k_E'$  is independent of the chamber type ( $R_{50}$  in cm)

$$k_E' = 1.106 - 0.1312 \cdot (R_{50})^{0.214} \quad (5-17)$$

a)  $k_E''$  for **plane-parallel chambers** is determined from

$$k_E'' = \frac{(\rho_{\text{wall}} \cdot \rho_{\text{cav}})_{R_{50}}}{(\rho_{\text{wall}} \cdot \rho_{\text{cav}})_{\text{Co}}} \quad (5-18)$$

The relevant factors are listed in Table 10.

Chamber type	$(\rho_{\text{cav}})_{R_{50}}$	$\frac{(\rho_{\text{wall}})_{R_{50}}}{(\rho_{\text{wall}} \cdot \rho_{\text{cav}})_{\text{Co}}}$
PTW 34001 Roos	1.000	0.981
PTW 34045 Adv. Markus	1.000	0.985
PTW 23343 Markus	$1 - 0.037 \cdot e^{-0.27 \cdot R_{50}}$	0.982

**Table 10:** Perturbation correction factors for plane-parallel chambers at the reference depth  $z_{\text{ref}}$  [Christ 2002, Kapsch 2007, DIN 6800-2].

b)  $k_E''$  for **cylindrical chambers** at the reference depth  $z_{\text{ref}}$  is calculated from

$$k_E'' = \frac{(\rho_{\text{cav}} \cdot \rho_{\text{cel}})_{R_{50}}}{(\rho_{\text{wall}} \cdot \rho_{\text{cel}})_{\text{Co}}} \quad (5-19)$$

and

$$(\rho_{\text{cav}})_{R_{50}} = 1 - 0.217 \cdot r \cdot e^{-0.153 \cdot R_{50}} \quad (5-20)$$

where  $r$  and  $R_{50}$  are given in cm.  $r$  can be taken from Table 7,  $(\rho_{\text{wall}})_{\text{Co}}$  and  $(\rho_{\text{cel}})_{R_{50}} / (\rho_{\text{cel}})_{\text{Co}}$  are listed in Table 11.

### 5.3.4 Dose measurements at depths other than $z_{\text{ref}}$

The dose at depth  $z$  is determined by

$$D_w(z) = k_r \cdot k_E \cdot k_{\text{NR}} \cdot N_w \cdot M(z) \quad (5-21)$$

$k_E$  is the correction factor at  $z_{\text{ref}}$  as described in chapter 5.3.3,  $k_{\text{NR}}$  is given by

$$k_{\text{NR}} = \frac{S_{w,a}^{\Delta}(z) \cdot \rho_{\text{cav}}(z)}{S_{w,a}^{\Delta}(z_{\text{ref}}) \cdot \rho_{\text{cav}}(z_{\text{ref}})} \quad (5-22)$$

and

$$S_{w,a}^{\Delta}(z) = \frac{a + bx + cx^2 + dy}{1 + ex + fx^2 + gx^3 + hy} \quad (5-23)$$

where  $x = \ln(R_{50})$  and  $y = z/R_{50}$  ( $z$  and  $R_{50}$  in cm) and

$$a = 1.0752 \quad b = -0.50867 \quad c = 0.08867$$

$$d = -0.08402 \quad e = -0.42806 \quad f = 0.06463$$

$$g = 0.003085 \quad h = -0.1246$$

The cavity perturbation factor depends on the chamber type

a) **Roos and Advanced Markus chambers**

$$\rho_{\text{cav}}(z) = \rho_{\text{cav}}(z_{\text{ref}}) = 1.000$$

b) **Markus chambers**

$$\rho_{\text{cav}}(z) = \frac{1}{1 + e^{a \cdot \left( \frac{z}{R_{50}} + b + c \cdot R_{50} + d \cdot z \right)}} \quad (5-24)$$

with  $z$  and  $R_{50}$  in cm and with

$$a = 0.1498 \quad b = -21.7336 \quad c = -4.3379$$

$$d = 4.0487$$

c) **Cylindrical chambers**

$$\rho_{\text{cav}}(z) = 1 - 0.2155 \cdot r \cdot e^{-0.2852 \cdot R_{50}} \cdot \left[ 1 - \frac{z}{1.271 \cdot R_{50} - 0.23} \right] \quad (5-25)$$

with  $r$ ,  $z$  and  $R_{50}$  in cm.

Chamber type	$(p_{\text{wall}})_{\text{Co}}$	$\frac{(p_{\text{cel}})_{R_{50}}}{(p_{\text{cel}})_{\text{Co}}}$
PTW 23331 1 cm <sup>3</sup> Rigid	1.001	1.005
PTW 30015 1 cm <sup>3</sup> Rigid	1.000	1.005
PTW 23332 0.3 cm <sup>3</sup> Rigid	1.001	1.005
PTW 30016 0.3 cm <sup>3</sup> Rigid	0.999	1.005
PTW 23333 Farmer (3 mm build-up cap)	1.001	1.005
PTW 23333 Farmer (4.6 mm build-up cap)	1.001	1.005
PTW 30001/30010 Farmer	1.001	1.005
PTW 30002/30011 Farmer	0.991	1.000
PTW 30004/30012 Farmer	0.991	1.005
PTW 30006/30013 Farmer	1.001	1.005
PTW 31002/31010 0.125 cm <sup>3</sup> Flexible	1.001	1.005
PTW 31003/31013 0.3 cm <sup>3</sup> Flexible	1.001	1.005
PTW 31014/31015 PinPoint	0.998	1.005
PTW 31016 PinPoint 3D	0.998	1.005

**Table 11:** Perturbation and central electrode correction factors for cylindrical chambers [DIN 6800-2]. Chambers not listed in DIN 6800-2 have been added by PTW-Freiburg.

## 6 Measurements in Acrylic Phantoms

### 6.1 General

For dosimetry in high energy photon or electron beams all dosimetry protocols described in this document (IAEA TRS 398, AAPM TG-51, DIN 6800-2) require absorbed dose measurements in real water. Solid state phantoms may only be used for routine QA measurements, and a transfer factor has to be established [AAPM 51]. The phantom should extend at least 5 cm beyond all sides of the field and at least 5 cm beyond the maximum depth of measurement [IAEA 398].

This chapter helps to establish transfer factors and 'equivalent' measuring depths for measurements in acrylic (PMMA, Perspex, C<sub>5</sub>H<sub>8</sub>C<sub>2</sub>) phantoms.

### 6.2 High energy photons

#### 6.2.1 Conversion of measuring depth

Photon beams are attenuated and scattered differently in water and solid phantoms. To take these differences into account, correction procedures have to be carried out.

Differences in photon beam attenuation are determined by the ratio of the mean linear attenuation coefficients of water and PMMA. The measuring depth in water  $z_w$  can be determined from the measuring depth in PMMA  $z_p$  assuming the same

source-detector-distance [AAPM 21]

$$z_w = 1.136 \cdot z_p \quad \text{for } ^{60}\text{Co} - 35 \text{ MV} \quad (6-1)$$

#### 6.2.2 Excess scatter correction

In PMMA phantoms the fraction of scattered photons is increased compared with water phantoms. To convert measuring values from PMMA to water, the measuring value has to be multiplied by a correction factor  $k_{\text{ESC}}$  (Excess Scatter Correction). Table 12 shows  $k_{\text{ESC}}$  values as a function of accelerator voltage and field size [AAPM 21].

### 6.3 High energy electrons

Solid phantoms may be used below 10 MeV to determine absorbed dose at  $z_{\text{ref}}$  [IAEA 398]. The measuring depth in water  $z_w$  can be determined from the measuring depth in PMMA  $z_p$  assuming the same source-detector distance

$$z_w = \rho \cdot c_{\text{pl}} \cdot z_p = 1.120 \cdot z_p \quad (6-2)$$

$c_{\text{pl}}$  is the depth scaling factor and  $\rho$  the nominal density of PMMA [IAEA 398]. The reading in the PMMA phantom  $M_p$  must be corrected by the fluence scaling factor  $h_{\text{pl}}$  to obtain the equivalent reading in water  $M$

$$M = h_{\text{pl}} \cdot M_p = 1.009 \cdot M_p \quad (6-3)$$

Energy (MV)	Depth (cm)	Field size at depth (cm <sup>2</sup> )			
		5x5	10x10	20x20	30x30
<sup>60</sup> Co	0.5	0.997	0.996	0.995	0.996
	5.0	0.986	0.987	0.989	0.991
2	0.4	0.998	0.994	0.997	
	5.0	0.984	0.982	0.989	
4	1.0	0.998	0.997	0.998	
	5.0	0.994	0.993	0.993	
6	1.5	0.999	0.998	0.998	
	5.0	0.994	0.994	0.996	

**Table 12:**  $k_{\text{ESC}}$  as a function of energy and field size.

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## Appendix A: Summary of PTW Chamber Data

### PTW Cylindrical Chambers

Type No.	Chamber Name	Measuring Volume [cm <sup>3</sup> ]	Wall	Electrode	Wall Area Density [mg/cm <sup>2</sup> ]	Radius of Measuring Volume [mm]	Ion Collection Time at nominal HV
30001	Farmer	0.6	0.275 mm PMMA + 0.15 mm C	Al Ø1 mm	45 (1)	3.05	0.14 ms (400 V)
30010	Farmer	0.6	0.335 mm PMMA + 0.09 mm C	Al Ø1.1 mm	57 (2)	3.05	0.13 ms (400 V)
30011 30002	Farmer, all graphite	0.6	0.425 mm C	C Ø1 mm	79 (2)	3.05	0.14 ms (400 V)
30012 30004	Farmer	0.6	0.425 mm C	Al Ø1 mm	79 (2)	3.05	0.14 ms (400 V)
30013 30006	Farmer, waterproof	0.6	0.335 mm PMMA + 0.09 mm C	Al Ø1.1 mm	57 (2)	3.05	0.13 ms (400 V)
31002	Flexible	0.125	0.55 mm PMMA + 0.15 mm C	Al Ø1 mm Graphite coated	78 (1)	2.75	0.10 ms (400 V)
31010	Flexible	0.125	0.55 mm PMMA + 0.15 mm C	Al Ø1.1 mm	78 (1)	2.75	0.10 ms (400 V)
31003	Flexible	0.3	0.55 mm PMMA + 0.15 mm C	Al Ø1.5 mm Graphite coated	78 (1)	2.75	0.08 ms (400 V)
31013	Flexible	0.3	0.55 mm PMMA + 0.15 mm C	Al Ø0.9 mm	78 (1)	2.75	0.08 ms (400 V)
23331	Rigid	1.0	0.40 mm PMMA + 0.15 mm C	Al Ø1.5 mm Graphite coated	60 (1)	3.95	0.21 ms (400 V)
30015	Rigid	1.0	0.4 mm PMMA + 0.135 mm C	Al Ø1.1 mm	73 (2)	3.95	0.23 ms (400 V)
23332	Rigid	0.3	0.35 mm PMMA + 0.15 mm C	Al Ø2 mm Graphite coated	54 (1)	2.5	0.04 ms (400 V)
30016	Rigid	0.3	0.35 mm PMMA + 0.135 mm C	Al Ø0.85 mm	67 (2)	2.5	0.08 ms (400 V)
31014	PinPoint	0.015	0.57 mm PMMA + 0.09 mm C	Al Ø0.3 mm	85 (2)	1.0	0.02 ms (400 V)
31015	PinPoint	0.03	0.57 mm PMMA + 0.09 mm C	Al Ø0.3 mm	85 (2)	1.45	0.04 ms (400 V)
31016	PinPoint	0.016	0.57 mm PMMA + 0.09 mm C	Al Ø0.3 mm	85 (2)	1.45	0.06 ms (400 V)

(1) Graphite density 0.82 g/cm<sup>3</sup>

(2) Graphite density 1.85 g/cm<sup>3</sup>

**PTW Plane Parallel Chambers**

Type No.	Chamber Name	Measuring Volume [cm <sup>3</sup> ]	Entrance Window	Electrode Diameter [mm]	Window Area Density [mg/cm <sup>2</sup> ]	Electrode Distance [mm]	Ion Collection Time at nominal HV
34001	Roos	0.39	1 mm PMMA + 0.02 mm C + 0.1 mm Varnish	15.6	132	2	0.13 ms (200 V)
34045	Advanced Markus	0.02	0.87 mm PMMA + 0.4 mm Air + 0.03 mm CH <sub>2</sub> (Polyethylene) (3)	5	106	1	0.02 ms (300 V)
23343	Markus	0.057	0.87 mm PMMA + 0.4 mm Air + 0.03 mm CH <sub>2</sub> (Polyethylene) (3)	5.3	106	2	0.09 ms (300 V)
23342	Soft X-Ray	0.02	0.03 mm CH <sub>2</sub> (Polyethylene)	3	2.8	1	0.02 ms (300 V)
23344	Soft X-Ray	0.2	0.03 mm CH <sub>2</sub> (Polyethylene)	13	2.8	1.5	0.04 ms (400 V)
34013	Soft X-Ray	0.0053	0.03 mm CH <sub>2</sub> (Polyethylene)	1.7	2.8	0.75	0.01 ms (400 V)

(3) with protection cap in place

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