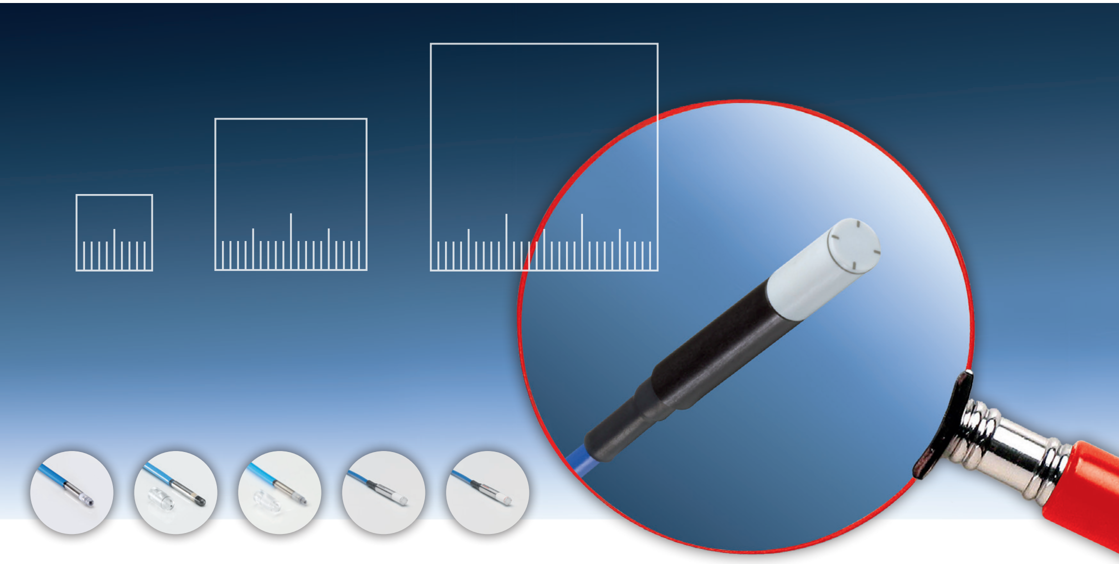
When small things matter.



# Small Field Dosimetry
## Application Guide

**Fully Revised Edition including Code of Practice TRS 483**

PTW THE DOSIMETRY COMPANY

**Contents**



# 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

Dose determination in small photon fields is an important and challenging task. Small photon fields are used in stereotactic radiosurgery as well as in IMRT and IMAT, where mini or micro MLCs create fields of 1 cm x 1 cm or smaller.

Classical dosimetry protocols such as IAEA 398, AAPM TG51, DIN 6800-2 describe procedures for reference dosimetry based on ionization chambers at field sizes of typically 10 cm x 10 cm. This brochure intends to give the reader an introduction into small field dosimetry. For deeper insights please refer to the scientific literature, [TRS483], [DIN6809-8], or the references given at the end of this document.

# 2 The Physics of Small Fields

## 2.1 Under which conditions can you consider a field as small?

- If one of the field dimensions is equal to or smaller than 4 cm [DIN6809-8].
- If the focus is partially hidden by the collimators.
- If lateral electron equilibrium is not given in the center of the field.

For more details, see chapter 6.

## 2.2 The dose volume effect

When the dose changes noticeably across the detector, the signal is subject to the volume effect. As a consequence of the volume effect, the dose in the field is *under*estimated and the width of the penumbra is *over*estimated.

In Figure 1 you can see a size comparison of some small field detectors against a 1 cm x 1 cm field.
From the figure it is apparent that a diode is probably small enough to characterize such a field but a Semiflex 0.125 $cm^3$ chamber is not.
In Figure 2 the effect of a too large detector is described in more detail, experimental results are shown in Figure 3.

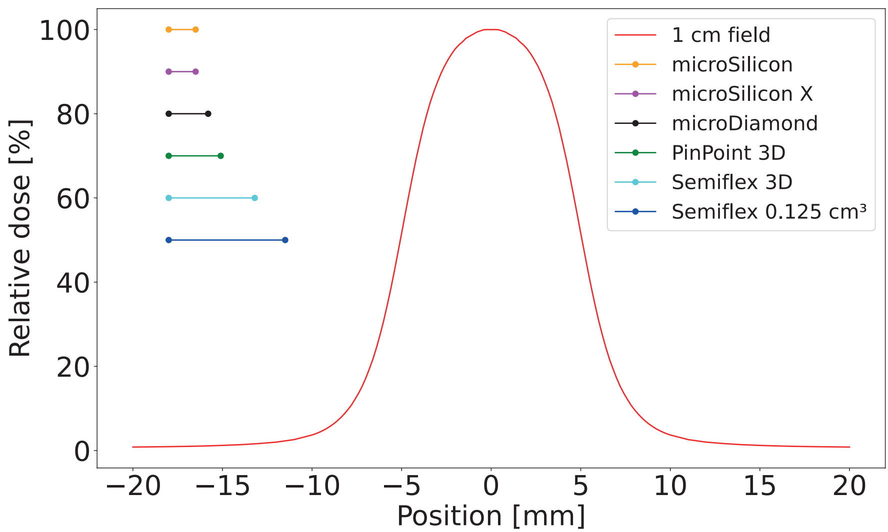
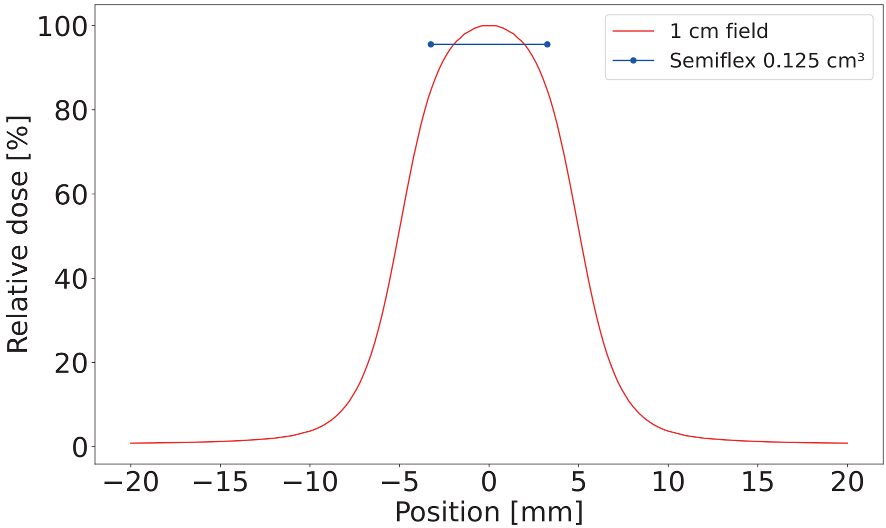


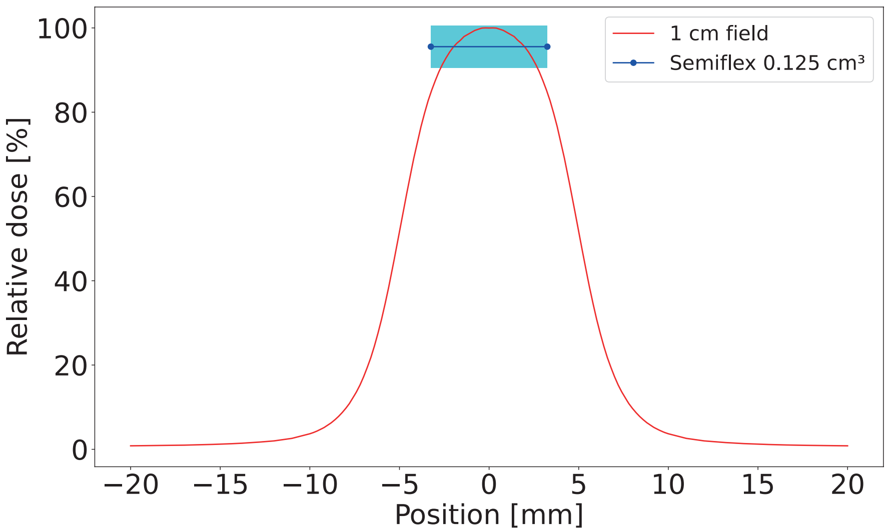

**Figure 1** Size comparison of a 1 cm x 1 cm small field profile with some small field detectors.

a



100
80
60
40
20
0
Relative dose [%]
−20
−15
−10
−5
0
5
10
15
20
Position [mm]
1 cm field
Semiflex 0.125 cm³


b



100
80
60
40
20
0
Relative dose [%]
−20
−15
−10
−5
0
5
10
15
20
Position [mm]
1 cm field
Semiflex 0.125 cm³

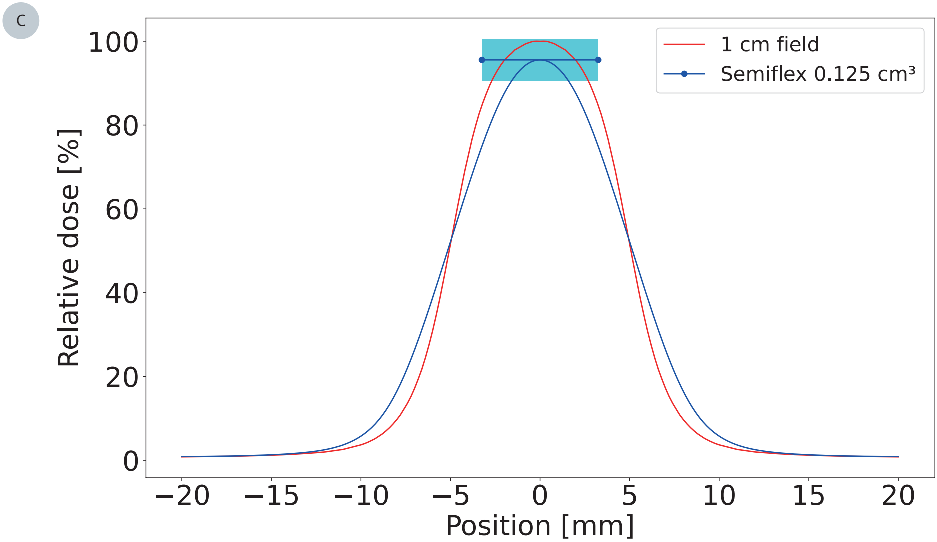



**Figure 2**

Viewgraph showing the origin of the volume effect.

In part a) you can see the size of a Semiflex 0.125 cm³ chamber against a 1 cm x 1 cm field profile. Clearly, the chamber seems to be too big to characterize that field.

In part b) you can see what that chamber will actually do: it will average the dose across its sensitive volume, depicted as a blue box. When you move the chamber through the field, it will always average across its volume at every measurement position.

The result is shown in part c). The blue curve shows the signal after averaging. The CAX[2] value of the dose is underestimated, and the penumbra is broadened.

Note, the volume averaging displayed in the plots is pure averaging. In a real measurement situation, the effect is increased because of the density perturbation effect.

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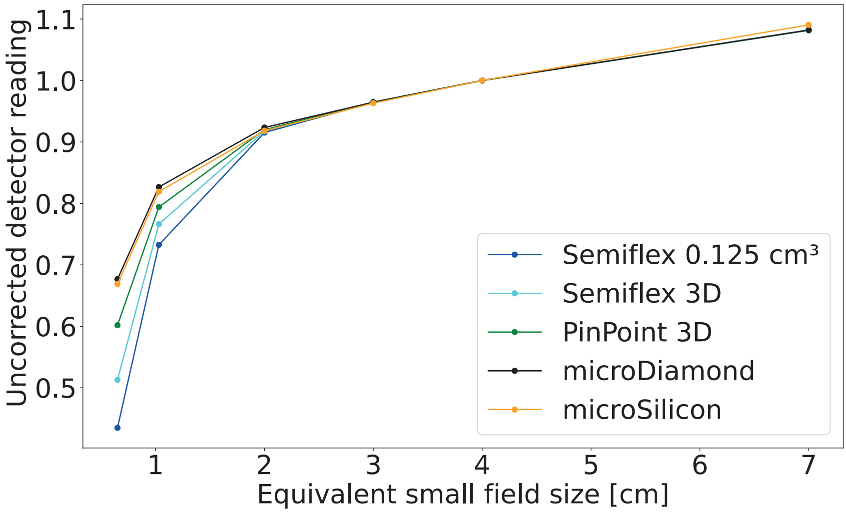
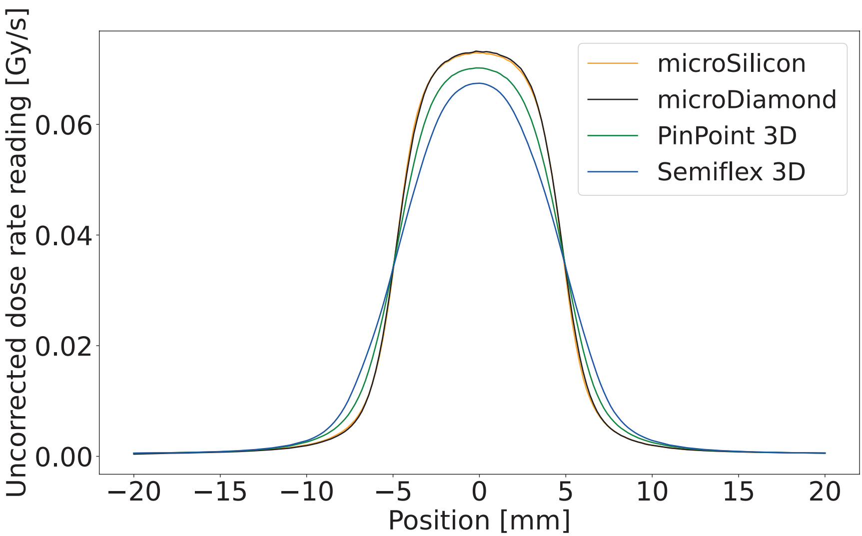
[2] CAX stands for central axis.

a



Uncorrected detector reading
1.1
1.0
0.9
0.8
0.7
0.6
0.5
1
2
3
4
5
6
7
Equivalent small field size [cm]
Semiflex 0.125 cm³
Semiflex 3D
PinPoint 3D
microDiamond
microSilicon


b



Uncorrected dose rate reading [Gy/s]
0.06
0.04
0.02
0.00
−20
−15
−10
−5
0
5
10
15
20
Position [mm]
microSilicon
microDiamond
PinPoint 3D
Semiflex 3D

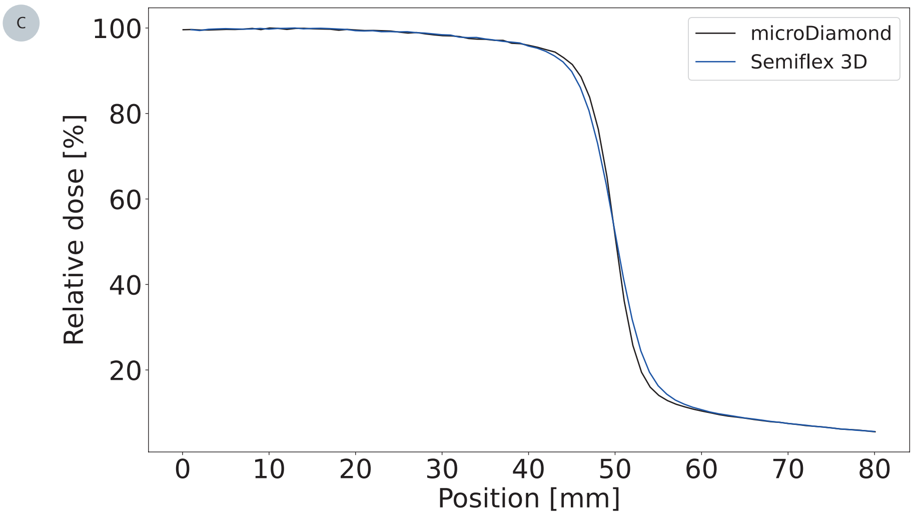



**Figure 3**

Experimental demonstration of the volume effect.

In part a) the uncorrected output factors[3] for small square fields are shown. For field sizes smaller than 2 cm x 2 cm, the reduction of the measured signal from the air-filled chambers is clearly visible.

Part b) shows profiles measured in a 1 cm x 1 cm field. All detectors have been cross-calibrated in a 4 cm x 4 cm field hence their signal can be displayed in "Gy". The uncorrected data clearly shows the reduced signal which is measured by air-filled chambers in such small fields.

In part c) the penumbra broadening of the Semiflex 3D chamber in a 10 cm x 10 cm field can be seen. Note that the field width (50 % isodose) is measured correctly. This is always the case when there is no volume effect in the field center.

[3] Synonyms for output factor: output ratio, relative dose factor and total scatter factor.

## Additional effects due to normalization

Usually, profiles are evaluated after performing a CAX normalization, i.e. all profiles are normalized such that their CAX-value corresponds to 100 %. For the example in Figure 3 b, this corresponds to multiplying the entire blue curve by 1.09. This includes the penumbra of the measurement and the out-of-field part. Hence if you combine the volume effect with a CAX normalization, the out-of-field dose and the penumbra dose will be slightly overestimated. This can be seen in Figure 4 where the data is taken from Figure 3 b) and normalized to the respective CAX values of the curves. The increase of the penumbra data leads to an increase of the apparent field width (i.e. the FWHM is broadened).

A similar effect can happen with percentage depth dose curves (PDDs) if there is a strong volume effect present. As the volume effect depends on field size and the field size depends on depth, the volume effect at the normalization point (at maximum dose) is different compared to positions deep in the water. A PDD subject to this effect will overestimate the dose deep in the water.

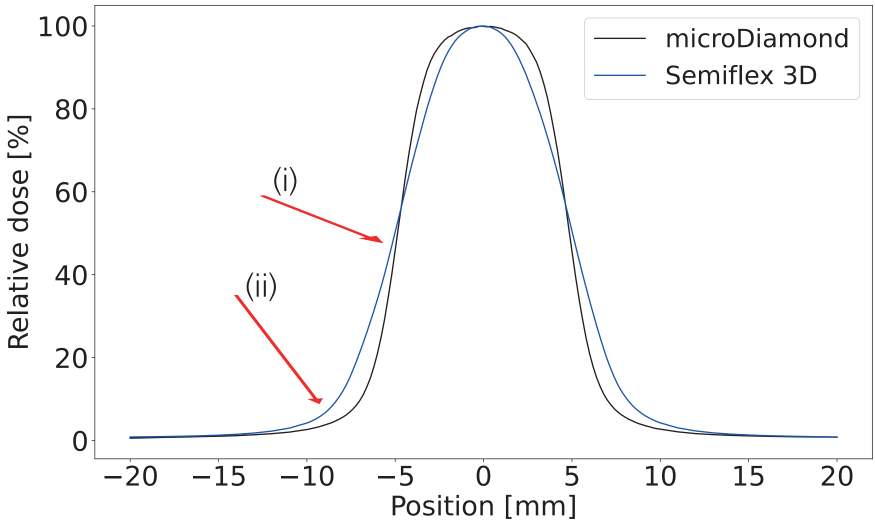



**Figure 4**
Profiles of a 6 MV 1 cm x 1 cm field measured with a microDiamond and a Semiflex 3D chamber after CAX normalization. The data is the same as in Figure 3 b). In addition to penumbra broadening two more effects are visible, indicated by arrows. (i) The FWHM of the Semiflex 3D measurement seems larger than that of the microDiamond. This is in contrast to the original measurement without CAX normalization shown in Figure 3 b). (ii) The dose in the out-of-field region is overestimated.

## 2.3 Low energy response

**Low energy scattered radiation is less important in small fields.**

In large fields there is a large dose contribution due to low-energy scattered radiation. In small fields, the dose contribution by this radiation is comparatively small. Consequently, the low-energy response (response to photons in the keV range) does not play a large role in small fields.

What about the out-of-field region? In the out-of-field region, the radiation consists only of scattered photons. For small fields this radiation contains a low-energy part but it is less important than for large fields.

Hence, for small fields:

- Shielding of silicon diodes is not necessary.
- In very small fields, shielding will lead to an overestimated dose due to the density perturbation effect.
- If silicon diode detectros are used, unshielded versions are recommended [TRS483].

## 2.4 Other effects in small fields

- The alignment of beam and detector is much more important compared to large field sizes.
- Often, an irradiation is composed of many small fields. To correctly add these up, the penumbras of the fields must be determined very accurately.
- For small fields the field size must not equal the set collimator value due to partial occlusion of the focus by the collimators and penumbra overlap.
- In field sizes below roughly 2 cm x 2 cm, lack of lateral electron equilibrium leads to the density perturbation effect, see e.g. [Fenwick2013]. We recommend to thoroughly study small field literature before working in such small fields.
- Some small field systems are flattening filter free linacs.

### Summary:

- If your detector is larger than roughly 1/4th of the lateral field dimension, you should expect a volume effect of several percent.
- keV scattered photon radiation is less important in small fields. Unshielded silicon diodes can be used.
- If the volume effect is present,
  - The dose in the field center will be underestimated;
  - The penumbra appears wider than it is.
- If you perform a CAX normalization in a small field in addition to the volume effect,
  - The field (50 % isodose) will appear wider than it is;
  - The dose in the out-of-field region will be overestimated;
  - The dose of PDDs at large depths can be overestimated.
- [TRS483] recommends to use more than one detector to perform a high quality characterization.
- For a thorough introduction see, e.g., [Wuerfel2013], [TRS483], [IPEM103]

# 3 Detector Types

The following section presents a quick introduction into the various types of single detectors used for dose measurements in a water phantom.

## 3.1 Medium-size vented ionization chambers

Gold standard for dose measurements are vented ionization chambers as specified in IEC 60731. The sensitive volume of such chambers is usually between 0.1 $cm^3$ and 1.0 $cm^3$. Their only disadvantage is the relatively large size.

When used in small fields, large detectors can be subject to the dose volume effect, see chapter 2.2.

## 3.2 Small-size vented ionization chambers

Small-size vented ion chambers (PinPoint chambers) have a sensitive volume in the order of 0.01 $cm^3$. They can typically be used for dose measurements in fields down to 2 cm x 2 cm. Care must be taken if PinPoint chambers are used in very large fields when stem and cable effects become important. Make sure that the chamber you use does not have a steel electrode.

## 3.3 Diamond detectors

Diamond detectors are solid state detectors combining small size and high response per volume. In addition, their response is almost independent upon energy, i.e. they are very much water equivalent. They also feature a very good directional response.

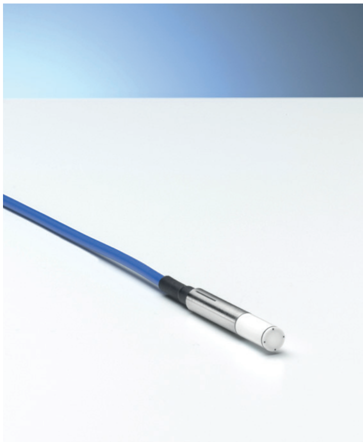
## 3.4 Silicon diodes

Silicon diode detectors feature the highest response per volume of all common detector types. Hence their sensitive volume is usually small enough to avoid dose volume effects down to very small fields. However, the density perturbation effect is still present.

The directional response of sillicon diodes is not ideal, as well as the response to low-energy scattered photons. To reduce the latter effect, diodes exist in a shielded design where the shield reduces the signal from these photons. In small fields the low-energy scatter contribution is low, hence diode shielding is not needed and unshielded diodes are recommended for small fields [IPEM103], [TRS483].

# 4 Detector Selection Guide

Which detector is best suited for my application?



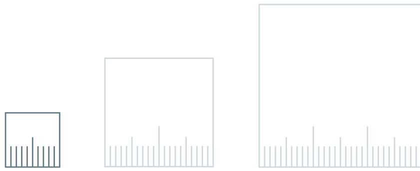
Detector Selection Tree

# Minimum field size required 1 cm x 1 cm

| | | | | |
|---|---|---|---|---|
| **MAXIMUM field size (cm) required:** | 10 x 10 | | 20 x 20 | |
| **Type of measurement:** | Absolute dose [1] & output factors | Profiles & PDDs | Absolute dose & output factors | Profiles & PDDs |
| **Suitable detectors:** | microSilicon<br>microSilicon X<br>microDiamond | microSilicon<br>microSilicon X<br>microDiamond | microSilicon X<br>microDiamond | microSilicon X<br>microDiamond |
| **Recommended detectors:** | microDiamond<br><br>microSilicon<br>  | microDiamond<br><br>microSilicon<br>  | microDiamond<br> | microDiamond<br> |

**Remarks**

[1] In small fields absolute dose measurement often requires cross-calibration, see chapter 7.



30 x 30

Absolute dose & output factors

microSilicon X
microDiamond

microDiamond for fields smaller than 20 cm x 20 cm

Semiflex 3D for larger fields

Profiles & PDDs

microSilicon X
microDiamond

microDiamond for fields smaller than 20 cm x 20 cm

Semiflex 3D for larger fields

40 x 40

Absolute dose & output factors

microSilicon X
microDiamond

microDiamond for fields smaller than 20 cm x 20 cm

Semiflex 3D for larger fields

Profiles & PDDs

microSilicon X
microDiamond

microDiamond for fields smaller than 20 cm x 20 cm

Semiflex 3D for larger fields

Both microDiamond and microSilicon X are well suited for the entire field size range from 1 cm x 1 cm up to 40 cm x 40 cm. But if you are aiming for utmost accuracy in large fields, a medium sized air-filled ionization chamber will be better than any solid state detector. In addition, measurements with an air-filled detector will be faster. If you can choose between microSilicon X and microDiamond, take the microDiamond.

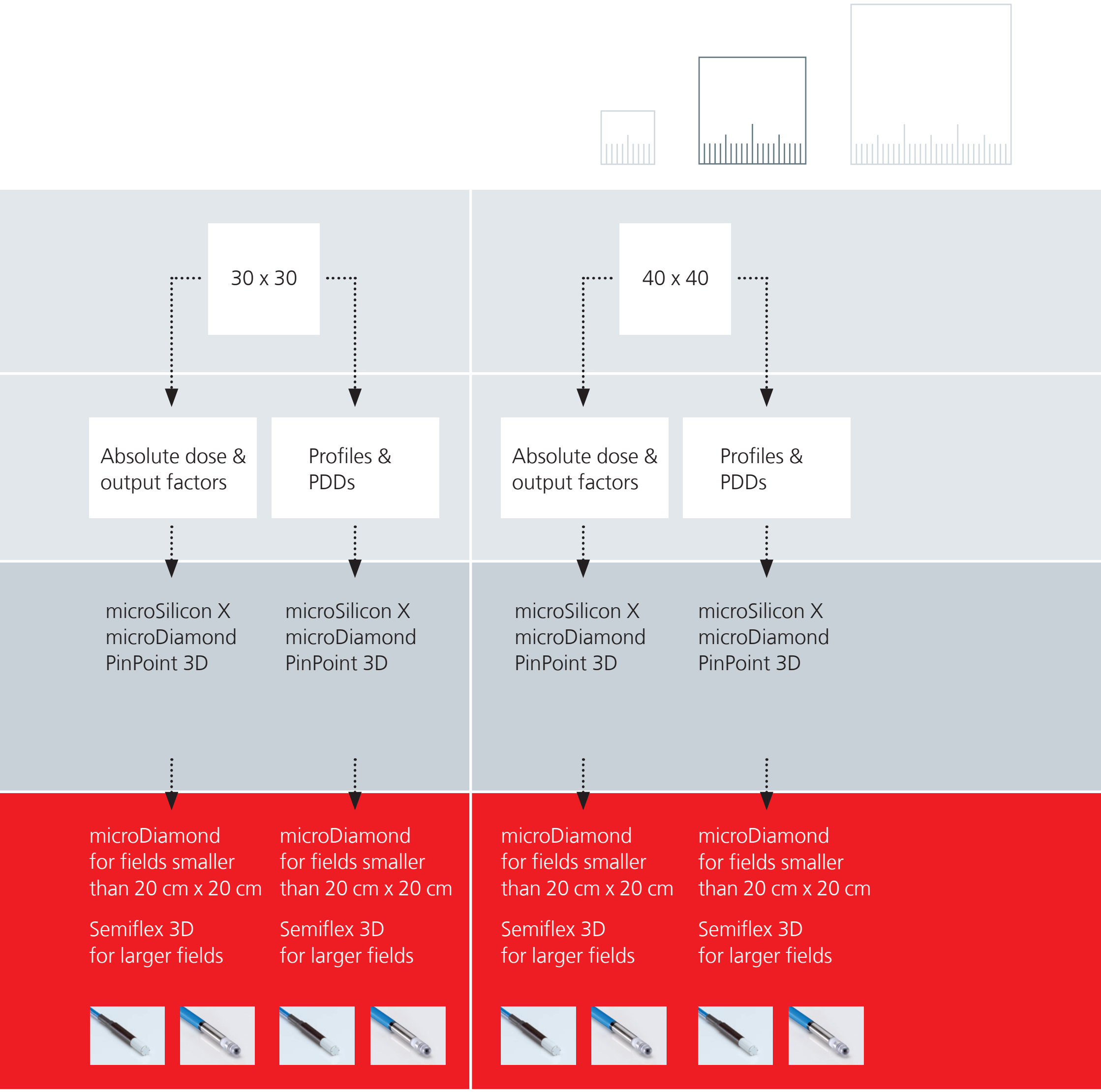
Detector Selection Tree

# Minimum field size required 2 cm x 2 cm

| | | | | |
|---|---|---|---|---|
| **MAXIMUM field size (cm) required:** | 10 x 10 | | 20 x 20 | |
| **Type of measurement:** | Absolute dose [1] & output factors | Profiles & PDDs | Absolute dose & output factors | Profiles & PDDs |
| **Suitable detectors:** | microSilicon<br>microSilicon X<br>microDiamond<br>PinPoint 3D | microSilicon<br>microSilicon X<br>microDiamond<br>PinPoint 3D | microSilicon X<br>microDiamond<br>PinPoint 3D | microSilicon X<br>microDiamond<br>PinPoint 3D |
| **Recommended detectors:** | PinPoint 3D  | microDiamond  | PinPoint 3D  | microDiamond  |

**Remarks**

[1] In small fields absolute dose measurement often requires cross-calibration, see chapter 7.




Both microDiamond and microSilicon X are well suited for the entire field size range from 1 cm x 1 cm up to 40 cm x 40 cm. But if you are aiming for utmost accuracy in large fields, a medium sized air-filled ionization chamber will be better than any solid state detector. In addition, measurements with an air-filled detector will be faster. If you can choose between microSilicon X and microDiamond, take the microDiamond.

Detector Selection Tree

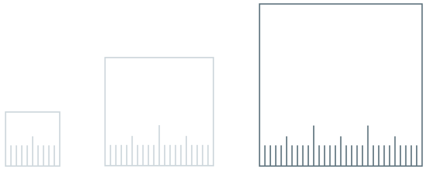
# **Minimum field size required 3 cm x 3 cm**

| | | | | |
|---|---|---|---|---|
| **MAXIMUM field size (cm) required:** | 10 x 10 | | 20 x 20 | |
| **Type of measurement:** | Absolute dose [1] & output factors | Profiles & PDDs | Absolute dose & output factors | Profiles & PDDs |
| **Suitable detectors:** | microSilicon<br>microSilicon X<br>microDiamond<br>PinPoint 3D<br>Semiflex 3D<br>Semiflex 0.125 | microSilicon<br>microSilicon X<br>microDiamond<br>PinPoint 3D | microSilicon X<br>microDiamond<br>PinPoint 3D<br>Semiflex 3D<br>Semiflex 0.125 | microSilicon X<br>microDiamond<br>PinPoint 3D |
| **Recommended detectors:** | Semiflex 3D  | microDiamond  | Semiflex 3D  | microDiamond  |

**Remarks**

The Semiflex 3D is best suited for absolute dose measurements as it does not need to be cross-calibrated.

[1] In small fields absolute dose measurement often requires cross-calibration, see chapter 7.



| 30 x 30 | | 40 x 40 | |
|---|---|---|---|
| Absolute dose & output factors | Profiles & PDDs | Absolute dose & output factors | Profiles & PDDs |
| microSilicon X<br>microDiamond<br>PinPoint 3D<br>Semiflex 3D<br>Semiflex 0.125 | microSilicon X<br>microDiamond<br>PinPoint 3D | microSilicon X<br>microDiamond<br>PinPoint 3D<br>Semiflex 3D<br>Semiflex 0.125 | microSilicon X<br>microDiamond<br>PinPoint 3D |
| Semiflex 3D | microDiamond for fields smaller than 20 cm x 20 cm<br>Semiflex 3D for fields larger than 20 cm x 20 cm | Semiflex 3D | microDiamond for fields smaller than 20 cm x 20 cm<br>Semiflex 3D for fields larger than 20 cm x 20 cm |

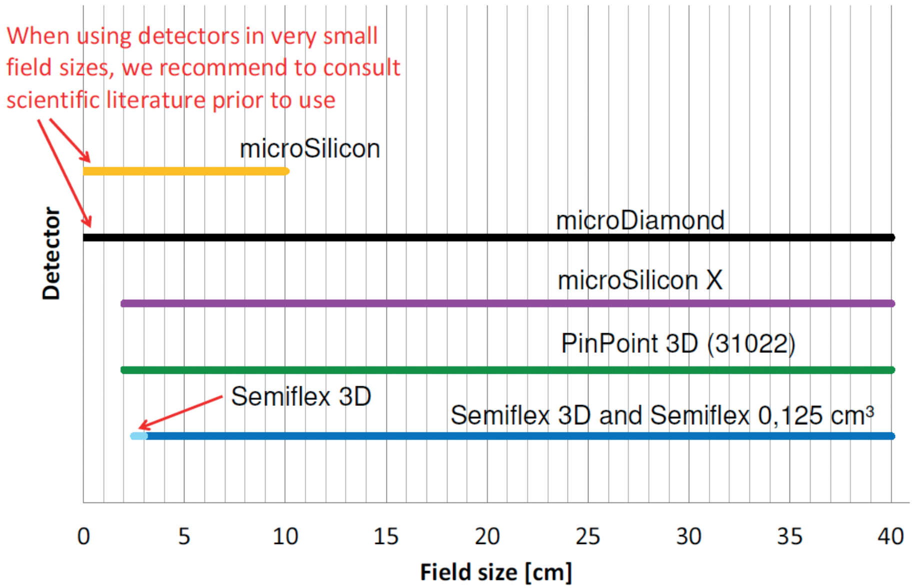





Though the PinPoint chambers, the microDiamond and the microSilicon X are well suited for measurements over the entire range from 3 cm x 3 cm to 30 cm x 30 cm, we recommend using a combination of two detectors for the most accurate profile and PDD measurements.

Both microDiamond and microSilicon X are well suited for the entire field size range from 1 cm x 1 cm up to 40 cm x 40 cm. But if you are aiming for utmost accuracy in large fields, a medium sized air-filled ionization chamber will be better than any solid state detector. In addition, measurements with an air-filled detector will be faster. If you can choose between microSilicon X and microDiamond, take the microDiamond. For accurate penumbra measurements in fields smaller or equal than 20 cm x 20 cm, a detector smaller than the Semiflex 0.125 should be used.

# **Overview:** Field Size Range




Field size range of PTW small field detectors. Data is taken from [DETECTORS] and valid for output factor measurements.

For more information on the selection of a detector, see also the PTW Detector Selector at ptwdosimetry.com.

# **Overview:** Smallest field size according to methology of TRS 483

| Detectors | Detector Type | Smallest allowed equivalent square small field size | Comment |
|---|---|---|---|
| Diode E | T60017 | 0.5 cm | [TRS483], unshielded silicon diode |
| Diode SRS | T60018 | 0.5 cm | [TRS483], unshielded silicon diode |
| microSilicon | T60023 | 0.4 cm | [Weber2020] and [Schoenfeld2019], unshielded silicon diode |
| Diode P | T60016 | 1.2 cm | [TRS483], shielded silicon diode |
| microSilicon X | T60022 | not enough data available | Shielded silicon diode |
| microDiamond | T60019 | 0.4 cm | [TRS483] |
| PinPoint 3D | T31016 | 1.0 cm | [TRS483] |
| PinPoint 3D | T31022 | 0.7 cm | [Looe2018], [Poppinga2018], [Casar2020] |
| PinPoint 0.015 $cm^3$ | T31014 | 1.2 cm | [TRS483] |
| PinPoint 0.015 $cm^3$ | T31023 | 1.0 cm | [Looe2018] and [Casar2020] |
| Semiflex 3D | T31021 | 1.2 cm | [Looe2018] and [Casar2020] |

Smallest allowed field size according to the methodology and detector orientation of [TRS483]. Values which are not included in [TRS483] have been added by PTW-Freiburg using the cited publications. In most cases, correction factors have to be applied when using detectors in very small fields. Note, in accordance with [TRS483] the smallest field size considered is 0.4 cm. Data is valid for classical linacs at 6 MV.

# **Overview:** Additional Selection Criteria

| Detectors | | Additional Selection Criteria | | | | | |
|---|---|---|---|---|---|---|---|
| | Penum-bra Accuracy | Out-Of-Field Dose Accuracy | Dose Stability | Dose Rate Independ-ence | Energy Response (MeV) | Energy Response (keV) | Fast Measure-ment[1] |
| microSilicon, unshielded | ++++ | ++ | +++ | ++++ | +++ | – | + |
| microSilicon X, shielded | +++ | +++ | +++ | ++++ | ++ | ++ | + |
| microDiamond Detector | ++++ | ++++ | ++++ | ++++ | ++++ | +++ | + |
| PinPoint Chamber 3D, 0.016 cm³ | ++ | ++++ | ++++ | ++++ [2] | ++++ [4] | +++ | +++ |
| Semiflex 3D Chamber, 0.07 cm³ | ++ | ++++ | ++++ | ++++ [2] | ++++ [4] | +++ | ++++ |
| Semiflex Chamber, 0.125 cm³ | + | ++++ | ++++ | ++++ [2] | ++++ [3] | ++++ | ++++ |

**++++ excellent   +++ very good   ++ good   + OK**

[1] see "Fast measurement" on next page
[2] can be corrected, see e.g. [DIN6800-2], [DETECTORS]
[3] can be corrected, $k_Q$ available in [DIN6800-2], [IAEA398] and [DETECTORS]
[4] can be corrected, $k_Q$ available in [DETECTORS] or from PTW technical support

# Why is it relevant?

## Penumbra accuracy

In IMRT and IMAT treatments, many small fields are superimposed to get the full dose. To make this work, the penumbra should be known to a high accuracy.

## Dose stability

When the dose stability is good, you seldom have to recalibrate your detector. This is useful if you use the detector for point dose plan verification. A bad dose stability requires more frequent recalibrations.

## Dose rate independence

A possible dose rate dependence of the detector will be part of the measurement uncertainty. The better the dose rate independence, the higher the accuracy of the measurement.

## Energy response (keV)

The keV energy response is important when the beam contains a lot of scattered radiation. This is the case for large fields (more than 10 cm x 10 cm), especially in the out-of-field region. In small fields (below 5 cm x 5 cm), the effect is not important within the field and of medium importance outside of the field.

## Energy response (MeV)

A good MeV energy response corresponds to a quality correction factor $k_Q$ close to 1 for all energies above $^{60}Co$. For air-filled ionization chambers, $k_Q$ is known, for other detectors this is not the case. Hence, the better the energy response, the smaller is the induced uncertainty. Note, the mean energy of a beam can slightly change over a beam cross section and with depth in the water.

## Out-of-field dose accuracy

In IMRT and IMAT treatments, many small fields are superimposed to get the full dose. The out-of-field dose can be several percent of the central dose and will add up to a background dose. In addition, it is a main contribution to the dose in the surrounding healthy tissue.

## Fast measurement

The figure of merit for fast scanning is the relative noise of the measurement which is defined by the absolute noise, i.e. the standard deviation of the signal, divided by the mean signal. The most important source of noise for photon dose measurements is quantum noise, i.e. the noise which is created because the photons of the radiation are quantized. Quantum noise is different from most other noise sources we are used to in everyday life and work. A very important property is that the amplitude of the relative noise mainly depends on the detector in use but not on the signal strength. As a rule of thumb, all ionization chambers, even the PinPoint chambers, have a lower noise compared to all solid state detectors. In other words, for fast scanning you will need an air-filled chamber while all solid state detectors are less fast. Scintillators are the slowest detectors.

# 5 Detector orientation for small field measurements

For PTW detectors, the orientation with respect to the beam is provided in the DETECTORS catalog and in the manuals of the respective detectors. The detectors have been validated in the orientations stated there. For a definition of the terminology see Figure 5.

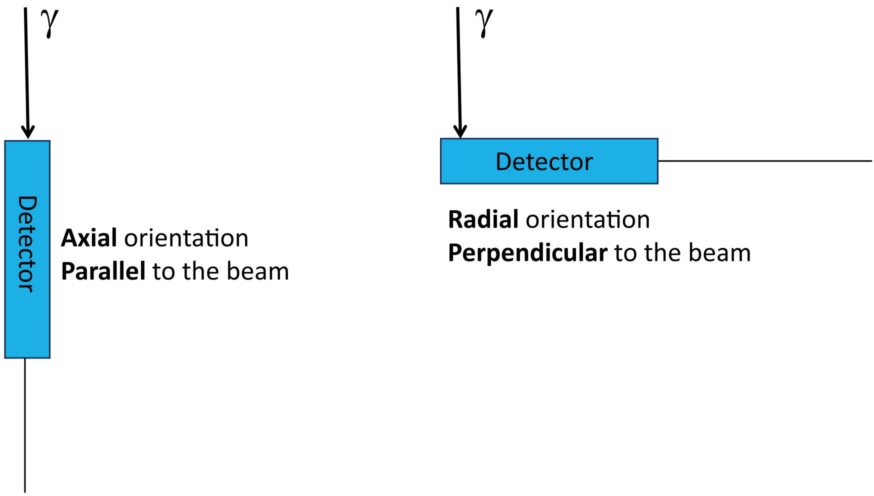



**Figure 5**
Definition of detector orientation. The terms ***axial*** and *radial* are used in the PTW documentation, *parallel* and *perpendicular* is used in [TRS483]. Both are defined with respect to the beam direction, designated with $\gamma$ here.
For relative dose measurements in a water phantom, i.e. output factor, PDD and profile measurements, we clearly recommend to use the detectors as specified. For reference dosimetry we recommend to use the orientation as defined in the standard you use, e.g. TRS 398, TG 51 or DIN 6800-2.

# 6 Code of Practice TRS 483

This chapter is an excerpt of TRS 483 and is based on [Palmans2018] and [TRS483].
Although the information in this chapter has been carefully assembled, PTW-Freiburg does not guarantee that this chapter is free of errors. PTW-Freiburg shall not accept any liability for the details provided being complete, correct and/or up-to-date.

## 6.1 Introduction to TRS 483

TRS 483 is a joint technical document of the IAEA and AAPM which treats the following topics:

- Some physics background on small field measurements
- Reference dosimetry of linacs which cannot provide a classical 10 x 10 cm² field
- Reference dosimetry of FFF linacs
- Methodology and correction factors for output factor measurements in small fields in water or plastic phantoms

All data included in TRS 483 is from 2015 or older.

In the following, we will provide a short code of practice of TRS 483 concerning the measurement of output factors in water. We will not cover other aspects of TRS 483. Although this chapter provides the reader with a concise overview of formulae and factors it shall not replace TRS 483 or other 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 dosimetric measurements. In some cases, where several options exist for a procedure, the option was chosen which we believe to be the most practical approach.

## 6.2 Typos in and clarifications of TRS 483

- T60019 microDiamond is still available.
- TM60003 DIAMOND is discontinued.
- T31018 microLion is **not** shielded.
- Exradin W1: small field output correction factors given in TRS 483 are only valid for orientation parallel to the beam.
- Exradin W1: cherenkov-calibration should be performed in same orientation as used in measurement.
- The x-axis of the figures in Appendix II is a logarithmic scale starting at 0.4 cm. The following positions of the axis are 0.8, 1.2, 1.6 and so on. For annotated axes of the same figures see [Palmans2018].

## 6.3 Preparation and background

### Detector reading M

The detector reading is assumed to be corrected for influence quantities as follows:

$$M = (M_{uncorr} - M_0) \cdot k_{elec} \cdot k_{TP} \cdot k_S \cdot k_{pol} \cdot k_h$$

Where

| | |
|---|---|
| $M_{uncorr}$ | Uncorrected reading |
| $M_0$ | Reading without radiation |

| | |
|---|---|
| $k_{elec}$ | When the ionization chamber and electrometer are calibrated separately, the calibration coefficient for the ionization chamber is given in units Gy/C or a multiple (e.g. mGy/nC or cGy/nC). The calibration factor $k_{elec}$ obtained for the electrometer converts the electrometer reading to charge and is expressed in units C/rdg. If the reading of the electrometer is in terms of charge, the electrometer calibration factor is dimensionless. If the ionization chamber and the electrometer are calibrated together, as one measurement assembly, no separate electrometer calibration factor has to be applied [TRS483]. Note from PTW: if you use PTW equipment, you can set $k_{elec}$ = 1. |
| $k_{TP}$ | Air density correction for water temperature and air pressure |
| $k_S$ | Recombination correction |
| $k_{pol}$ | Polarity correction |
| $k_h$ | No correction is necessary for relative humidity if the ionization chamber is used in a range of 20 % to 80 % relative humidity and has a calibration coefficient valid at a relative humidity of 50 % [TRS483] |

For more details on these correction factors, please refer to the code of practice for reference dosimetry which is in use in your country or the code of practice section in the PTW DETECTORS catalog.

## Definition of the output factor

The field output factor is defined as the ratio of absorbed dose to water in any non-reference field to that in a reference field at a given depth. For small field measurements this is, in general, not the ratio of detector readings but requires correction factors to convert the detector reading into a dose.
Note: synonyms for output factor are output ratio, relative dose factor and total scatter factor.

## It is wise to use more than one detector for small field measurements

TRS 483 recommends to use two or three detectors for the measurements in small fields. Together with the background knowledge on the physics of small fields and the detector properties, the results can be interpreted to judge the final result of the measurements.

## When using silicon diodes, prefer the non-shielded versions

Unshielded silicon diodes can be used for small field measurements. Shielded diodes are not recommended by [TRS483].
See FAQ section of this document for background information.

## When is a field small?

A very practical and easy-to-apply definition of a small field is given in the German small field protocol [DIN6809-8]: Any field where one of the field dimensions is equal to or smaller than 4 cm should be considered as a small field.
In most practical cases this definition will work.

A more rigorous, physics-based, and accurate definition is provided by [TRS483]: a field should be considered as small if any one of the following three conditions is met:

1. There is a loss of lateral charged particle equilibrium
2. There is partial occlusion of the primary photon source by the beam collimating devices
3. The size of the detector is similar to or larger than the dimensions of the field size in the plane of measurement

In practice, the first condition will in most cases define your small field.

To apply it, do the following:

- Draw a sketch of your detector in the field in the plane of measurement as shown in Figure 6. Draw this sketch to scale and use units of cm.
- Deduce the distance of the edge of the measurement volume of the detector to the field border in all directions.
- Take the minimum of this distance.
- If this distance is smaller than $r_{LCPE}$, you should consider the field as small

$r_{LCPE}$ is the lateral charged particle equilibrium range. It depends on the beam energy and is calculated in [cm] as:

$r_{LCPE} = 8.369 \cdot TPR_{20,10}(10) - 4.382$
or
$r_{LCPE} = 77.97 \cdot 10^{-3} \cdot \%dd(10,10)_x - 4.112$

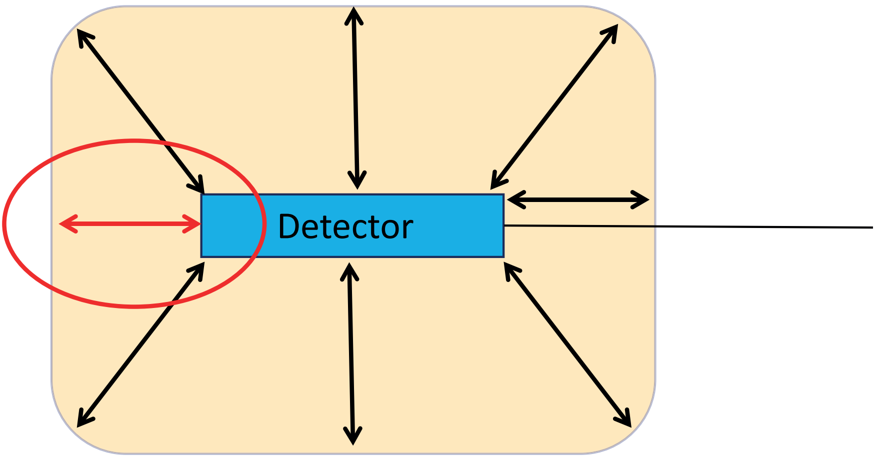



**Figure 6**
Small field condition according to the criterion of the range of laterally scattered secondary particles. The detector is placed in the center of the field and the distance from the edge of the detector to the edge of the field is measured on several positions. If the shortest of these distances – indicated by the red arrow and ellipse – is smaller than $r_{LCPE}$, the field should be considered as small.
Example: a Semiflex 3D (type 31021) is placed in a 4 x 4 cm² cross-calibration field in a 6 MV beam of $TPR_{20,10}$ = 0.669. This yields $r_{LCPE}$ = 1.22 cm. If you place the chamber in the field center, you will have a remaining distance between chamber boundary and field boundary of 2 cm minus half the chamber diameter, i.e. 2 cm – 0.24 cm = 1.76 cm. This is larger than $r_{LCPE}$, i.e. the chamber can still be used in that field size.

## Correction factors

When measuring small field output factors, you will in most cases have to apply small field output correction factors. Use only detectors where these correction factors are between 0.95 and 1.05 for the field sizes you wish to measure in. This defines the field size range of use of a small field detector. If more correction is needed, you should choose a different detector. For this reason, correction factors in TRS 483 and in this document are only provided for field sizes where the above condition applies. Note that small field output correction factors depend on the linac type[1] and on the beam quality. You should check for available correction factors before you start measuring. For some types of detectors the correction factor will also depend on the measurement depth, see FAQ section of this document for more information.

## Considering cross-calibration

The measurement of output factors is a relative measurement where dose values are referenced to a chosen reference field size. Hence, a real cross-calibration – which enables to get a reading in Gy or Gy/min – is in principle not necessary. Nevertheless, PTW – in line with the German small field code of practice [DIN6809-8] – recommends to perform a concrete cross-calibration anyway. The gain is confidence in your measurements and help for trouble shooting if any part of the data looks strange to you.

## Cross-calibration field size and MSR field size[2]

Before applying correction factors, you will have to decide about the cross-calibration field size of your measurement.

One option is to use the **MSR field size**. It is specified in [TRS483] as:

- Any linac that can provide a 10 cm x 10 cm field: 10 cm x 10 cm. This includes linacs with the possibility to add cones.
  Note, this type of linac will be called "classical linac" in this document
- CyberKnife: 6 cm diameter fixed collimator
- TomoTherapy: 5 cm × 10 cm field
- Gamma Knife: 1.6 cm or 1.8 cm diameter collimator helmet, all sources simultaneously out
- Add-on MLC: as close to 10 cm x 10 cm as possible

Another option is to use the **intermediate field method**, also called daisy chaining. Choose a field size where a small (but not very small) ionization chamber will still work. A good combination is for example a Semiflex 3D (type 31021) or Semiflex 0.125 cm³ (type 31010) in a 4 cm x 4 cm field. For these chambers, the correction factor in 4 cm x 4 cm is assumed to be 1.0 [DIN6809-8], i.e. no correction is required to get from the MSR field to the cross-calibration field. Cross-calibrate your small field detector against the ionization chamber in this intermediate field size and for smaller field sizes use your small field detector.

Both methods, i.e. using the MSR field or the intermediate field for cross-calibration, have advantages and disadvantages. The basic argument for the intermediate field method is that all unknown sources of error will be smaller, the closer you perform the cross-calibration to the end-use field size. Unknown sources of error can be, for example, dose rate dependence, energy dependence, or dependence of Cherenkov-correction on field size. If these or other properties of the detector are not

---

[1] TRS 483 discerns between the following linac types and energies: classical FFF or WFF linac at 6 MV, classical FFF or WFF linac at 10 MV, CyberKnife, TomoTherapy and GammaKnife

[2] The intermediate field method is described in [TRS483] but most of the reasoning whether and how to use it has been added by PTW-Freiburg

well known or depend on the measurement setup, you are on the safer side when cross-calibrating in the intermediate field instead of the MSR field. Note, that some influences, such as dose rate dependence or dependence of Cherenkov-correction, are not included in Monte Carlo simulations. Hence, they are not part of correction factors which result from Monte Carlo simulations.

The German small field protocol uses only the intermediate field method [DIN6809-9].
The main advantage of using the MSR field is simplicity and that you can measure the full range from 10 cm x 10 cm down to the small field with a single detector.
In case you work with the intermediate field method, it is important to re-normalize your correction factors to the intermediate field.

For example:

A detector has the following correction factors for an MSR field of 10 cm x 10 cm:

| Eq. sq. small-field size [cm] | 0.8 | 1 | 1.5 | 2 | 4 | 10 |
|---|---|---|---|---|---|---|
| Field output correction factor | 0.997 | 1.002 | 1.011 | 1.015 | 1.011 | 1.000 |

If this detector should be used for the intermediate field method in 4 cm x 4 cm, the factors have to be renormalized to 4 cm x 4 cm:

| Eq. sq. small-field size [cm] | 0.8 | 1 | 1.5 | 2 | 4 | 10 |
|---|---|---|---|---|---|---|
| Field output correction factor | 0.986 | 0.991 | 1.000 | 1.004 | 1.000 | 0.989 |

The actual procedure of performing the cross-calibration is described in chapter 6.4.

Note, for any detector where the correction between the MSR field and the intermediate field is 1.0, e.g. for the microDiamond detector, the intermediate field method is not needed.

## Equivalent square small field size

To describe the field size of small fields, TRS 483 uses the term "equivalent square small field size" $S_{clin}$ with the unit cm. It stands for an equivalent square field where the edge of the field is $S_{clin}$.
Field sizes are defined by the FWHM (Full Width Half Maximum) of their profile in the depth of measurement. In most cases the FWHM in X and Y directions will be different. In this case, the equivalent small field size is given by $S_{clin} = \sqrt{AB}$, when the FWHM field sizes are A and B respectively. For circular fields with radius r, the equivalent small field size is given by $S_{clin} = 1.77 * r$.
Note, these formulas are only valid for $S_{clin}$ smaller than or equal to 4 cm. If the aspect ratio of rectangular fields is outside of $0.7 < A/B < 1.4$, a higher uncertainty should be attributed to the small field correction factor.

Care needs to be taken to use a suitable detector for profile scanning in order to deduce the FWHM. TRS 483 recommends to use two different types of detectors, a low measurement speed (i.e. long integration times per data point) and a high resolution, typically 0.1 mm. In addition, PTW recommends to use only detectors whose small field output correction factor for the envisaged field size is less than 5 %. This ensures that the field shape is not distorted too much by uncorrected small field effects.

## Orientation of the detector

Definition of orientation: if the axis of rotation of the detector is parallel to the beam, this is called "parallel" or "axial" orientation. If the axis of rotation is perpendicular to the beam, this is called "perpendicular" or "radial" orientation.

For details and for a figure, see the chapter 5. "Parallel" and "perpendicular" are the terms used in [TRS483].

Orientation of detectors according to [TRS483]:

| | |
|---|---|
| All ionization chambers | Perpendicular (radial) |
| All PTW and IBA silicon diodes | Parallel (axial) |
| PTW microDiamond | Parallel (axial) |
| PTW microLion | Parallel (axial) |
| SNC EDGE silicon diode | Perpendicular (radial) |
| Exradin SI W1 | Parallel (axial)[3] |
| Radiochromic film | Surface perpenicular to beam |

Note: [TRS483] only describes the measurement of output factors. [TRS483] does not provide any recommendation on the orientation for profiles and PDDs.

## Polarity correction for ionization chambers in very small field sizes[4]

For field sizes roughly below 1 cm, the polarity effect of air-filled chambers should be checked and possibly corrected [Looe2018].
Note, correction factors provided in TRS 483 have not been corrected for polarity because this effect was not known at the time when TRS 483 was written.

PTW recommends to check the small field polarity effect by the following procedure:

- Measure at one polarity
- Change to opposite polarity
- Pre-irradiate until chamber is stable
- Measure for this polarity

[3] Rigorously speaking, the orientation of the W1 is not clearly stated in TRS 483. But from the correction factors provided in TRS 483 it follows that this orientation is meant. This has been confirmed by personal communiction with Hugo Palmans in 2018.

[4] Note, this subsection on the polarity effect has been added by PTW-Freiburg and is not contained in [TRS483].

To correct the polarity effect for a relative dose measurement, do the following: **measure the entire data set** at one polarity. Change polarity, perform pre-irradiation and measure the entire data set again. Take the average of both data sets. It is important to average data of the full data set and not only a part of it.
To deduce the possible measurement error of your data, compare the following two data sets:

- Data set 1: entire data (i.e. set of output factors) using data measured  at one polarity only
- Data set 2: entire data where both polarities were measured and the average of both data sets was taken

If you use small field output correction factors that have not been corrected for polarity, e.g. those of TRS 483, the full difference you observe in the above test should be considered as additional systematic error of your measurement.
You can only get rid of this error if you (i) use polarity corrected correction factor and (ii) perform a polarity corrected measurement.

The polarity effect in very small fields as described in [Looe2018] will be present for every ionization chamber independent of manufacturer or type of the chamber. The specific magnitude depends on the type of chamber and on its orientation in the beam. For radial (perpendicular) orientation, the effect is fairly weak for most (but not all) chamber models. The smaller the chamber, the stronger the polarity effect in [Looe2018]. In axial (parallel) orientation, the magnitude of the polarity effect is strongly increased and should always be evaluated.

As a rule of thumb: If you use the latest PTW chambers, such as the PinPoint 3D (type 31022) or Semiflex 3D (type 31021), and use them in radial (perpendicular) orientation, the polarity effect is negligible as long as you respect the TRS 483-type field size limits.

## 6.4 Application

### Depth positioning of detectors

For the measurement of output factors, TRS 483 recommends to position air-filled chambers on axis, i.e. not in the effective point of measurement (EPOM). All other detectors should be placed in their respective EPOM as specified by the manufacturer.

Comment from PTW on the depth positioning: to us it seems inconsistent to position some small field detectors in their EPOM and others not. We would find it more logic to position all small field detectors in their respective EPOM when measuring relative dosimetry data. The reason for this positioning is not known to us[5] but we assume that it is to make the cross-calibration procedure safer. When following TRS 398 [IAEA 398] or TG 51 [AAPM TG51], reference dosimetry is performed positioning the detector on axis. There is a risk of confusion when the first detector (to deduce absolute dose) is positioned on axis and the second detector (the one for small fields which is to be cross-calibrated) is positioned in its EPOM. Possibly this was the reason for the IAEA/AAPM recommendation in [TRS483].

Note, when measuring output factors, the difference of placing the chambers in their EPOM or on-axis will not be visible in the results within the uncertainty of measurement.

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[5] We tried to clarify this by personal communication with Saiful Huq and Jan Seuntjens at the ICMP/ALFIM 2019 but could not resolve the issue.

Note also: PTW TRUFIX will automatically position any detector in its respective EPOM regardless if it is an air-filled chamber or a solid state detector.

## Depth of measurement

The reference depth of the TRS 483 data for the measurement of output factors in water is 10 cm except for the CyberKnife where it is 1.5 cm and the GammaKnife where it is the center of the hemispere.

## SSD (Source Surface Distance)

For the measurement of small field output factors, the same SSD should be chosen as for reference dosimetry.

This is:

| | |
|---|---|
| Classical linacs | 100 cm |
| CyberKnife | 78.5 cm |
| TomoTherapy | 85 cm |
| Gamma Knife | 32 cm |

The depth of measurement where the small field output correction factors are valid is the same as the reference depth.

## Performing cross-calibration in the intermediate field size[6]

If you have decided to perform a real cross-calibration in the intermediate field size, this section describes the procedure how it's done. The cross-calibration should be performed in a water phantom and for each radiation quality you wish to apply. In case you have to work in solid state materials, please refer to TRS 483 directly.

The cross-calibration involves the following two steps:

1. Use a medium-size vented ionization chamber to determine the dose for the radiation quality and depth of interest under reference conditions except for the field size. Use $TPR_{20,10}$ or $\%dd(10)_x$ of the 10 cm x 10 cm field to deduce $k_Q$. Follow the code of practice valid in your country to do so or TRS 483 if your linac cannot provide a 10 cm x 10 cm field. Perform depth positioning as recommended in the code of practice you are using, e.g. on axis for TG 51 or TRS 398. Apply all the necessary correction factors.
   This is the dose of the intermediate field $D_{int}$. Make sure that the chamber is small enough and the field large enough, such that the field must not be considered as a small field (see section "When is a field small?" above). If you use a Semiflex 0.125 $cm^3$ or Semiflex 3D, this condition will hold for a field size of 4 cm x 4 cm or larger [DIN6809-8].
2. Replace the medium-size ionization chamber by the small field detector to be cross-calibrated. If you follow the TRS 483 recommendation, position an air-filled chamber on-axis in the depth of measurement and for other detectors put their respective EPOM in the depth of measurement. If you follow the more consistent depth-positioning approach as mentioned in chapter "Depth positioning of detectors", place the EPOM in the depth of measurement – independent of this detector being an air-filled chamber or another detector type.
   Apply the same number of monitor units as before and determine the reading $M_{small}$ of the small field detector. This reading should be in electrical units, i.e. in Coulomb.

[6] Note, this subsection has been written by PTW.

The cross-calibration factor for the small-size detector is the ratio $D_{ref} / M_{small}$.

Note, if you use this cross-calibration factor, the air-density correction ($k_{TP}$) of air-filled detectors is now referenced to the air pressure and water temperature at the time of cross-calibration. For longer measurement sessions, the water temperature can considerably change, and this should be taken into account.

Note, the cross-calibration factor depends on the detector orientation and on the beam quality.

## Actual measurement procedure of the field output factor

- Measure X and Y profiles to check if the CAX (central axis of the beam) is at the zero position of the water phantom.
- Measure X and Y profiles again to verify the new CAX position and to deduce FWHM field size in X and Y. Deduce equivalent small field size by applying the appropriate formula ($S_{clin} = \sqrt{AB}$ for square fields and $S_{clin} = 1.77*r$ for circular fields). Recommendation of PTW: use this FWHM information only if the detector was suited for the envisaged field size – see section "Preparation and background" for more information.
- Go to the CAX and measure the detector reading $M_{clin}$
- Look up the correction factor of your detector as function of equivalent square small field size. Use linear interpolation between field sizes or a suitable fitting function.
- Multiply the correction factor to the detector reading. This is the dose measurement in the clinical field size. In case you have performed a cross-calibration, this dose is given in Gy. If not, you should consider it as relative to the reference field dose.
- Divide this by the dose measurement obtained in the reference field size to get the field output factor.

Written as a formula, the field output factor $\Omega$ for the clinical field size $f_{clin}$ is given by:

$$\Omega_{clin} = \frac{M_{clin}}{M_{cross\text{-}cal}} \cdot k_{clin}$$

i.e. the ratio of detector readings $M_{clin}$ in the clinical small field and $M_{cross\text{-}cal}$ in the cross-calibration field, multiplied by the small field correction factor of the clinical field $k_{clin}$. The term "cross-cal" stands for the intermediate field size or the MSR field size depending on the method you use. Make sure that the correction factor $k_{clin}$ is consistently normalized to your cross-calibration field size. We have used reduced indices in our notation. For the full indices see [TRS483].

Note, except for the application of the correction factor, the above procedure is implemented in the PTW BEAMSCAN software version 4.4 or higher.

## 6.5 Correction factor tables

For detectors listed in TRS 483, the data presented in the following tables comes from:

- Classical linac 6 MV: Table 26
- Classical linac 10 MV: Table 27
- TomoTherapy: Table 24
- Gamma Knife: Table 25
- CyberKnife: Table 23

Note, TRS 483 data for air-filled ionization chambers is not corrected for the small field polarity effect.

For some recently developed PTW detectors correction factors are not included in [TRS483] because data was not yet available in 2015. This is the case for microSilicon (type 60023), microSilicon X (type 60022), PinPoint 3D (type 31022), PinPoint 0.015 cm³ (type 31023), and Semiflex 3D (type 31021). Where enough high-quality data was available – at least two publications are required – PTW has added data for these detectors. Details are given in the respective comments in the tables.

Where possible, data was fitted using the fitting formula No (62) from [TRS483]:

$$k_{\text{clin}} = \frac{1 + d \cdot e^{-\frac{10-a}{b}}}{1 + d \cdot e^{-\frac{S-a}{b}}} + c \cdot (S - 10) \quad \text{(Fit function 1)}$$

where $k_{\text{clin}}$ is the small field correction factor for the field size *S* and *a*, *b*, *c* and *d* are fitting parameters. For details see [TRS483].

In cases where the energy response of the detector could not be correctly displayed using [TRS483]-fitting formula, we have either set c=0 in the [TRS483] fitting formula or we have used:

$$k_{\text{clin}} = a \cdot S^b + 1 + c \cdot (S\text{-}10) \quad \text{(Fit function 2)}$$

where *a*, *b* and *c* are fitting parameters. This is the fitting formula of [Poppinga2018] with a linear term added.

The four data sets from [Casar2020] (Varian / Elekta and WFF / FFF ) have been grouped into one data set and fitted using the [TRS483] fitting formula. This one data set was then used in the evaluation of correction factors in comparison with other publications. Only “perpendicular” data from [Casar2020] was used.

## Correction factors classical linac, 6 MV

| Equivalent square field size [cm] | 10 | 8 | 6 | 4 | 3 | 2.5 | 2 | 1.5 | 1.2 | 1 | 0.8 | 0.6 | 0.5 | 0.4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| microDiamond, type 60019 [1] | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 0.999 | 0.997 | 0.993 | 0.989 | 0.984 | 0.977 | 0.968 | 0.962 | 0.955 |
| microSilicon, type 60023 [2] | 1.000 | 1.004 | 1.007 | 1.011 | 1.013 | 1.014 | 1.014 | 1.012 | 1.009 | 1.004 | 0.997 | 0.984 | 0.975 | 0.963 |
| Diode E, type 60017 [1] | 1.000 | 1.004 | 1.007 | 1.010 | 1.011 | 1.011 | 1.008 | 1.002 | 0.994 | 0.986 | 0.976 | 0.961 | 0.952 | -- |
| Diode SRS, type 60018 [1] | 1.000 | 1.004 | 1.007 | 1.010 | 1.011 | 1.009 | 1.006 | 0.998 | 0.990 | 0.983 | 0.973 | 0.960 | 0.952 | -- |
| Diode P, type 60016 [1] | 1.000 | 1.000 | 1.000 | 0.999 | 0.995 | 0.991 | 0.984 | 0.970 | 0.956 | -- | -- | -- | -- | -- |
| microLion, type 31018 [1] | 1.000 | 0.997 | 0.994 | 0.991 | 0.989 | 0.988 | 0.988 | 0.987 | 0.987 | 0.987 | 0.990 | 0.999 | 1.011 | 1.033 |
| PinPoint 3D, type 31022 [3] | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.001 | 1.002 | 1.005 | 1.010 | 1.018 | 1.033 | -- | -- | -- |
| PinPoint 3D, type 31016 [1] | 1.000 | 1.000 | 1.000 | 1.000 | 1.001 | 1.001 | 1.004 | 1.013 | 1.025 | 1.039 | -- | -- | -- | -- |
| PinPoint 0.015 $cm^3$, type 31023 [4] | 1.000 | 0.999 | 0.998 | 0.997 | 0.997 | 0.997 | 0.998 | 1.005 | 1.018 | 1.037 | -- | -- | -- | -- |
| PinPoint 0.015 $cm^3$, type 31014 [1] | 1.000 | 1.000 | 1.000 | 1.000 | 1.002 | 1.004 | 1.009 | 1.023 | 1.041 | -- | -- | -- | -- | -- |
| Semiflex 3D, type 31021 [5] | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.001 | 1.005 | 1.020 | 1.047 | -- | -- | -- | -- | -- |
| Semiflex 0.125 $cm^3$, type 31010 [1] | 1.000 | 1.000 | 1.000 | 1.000 | 1.001 | 1.002 | 1.008 | 1.025 | -- | -- | -- | -- | -- | -- |

For the detector orientation, see subchapter "Orientation of the detector" in chapter 6.3.

[1] [TRS483]

[2] Data is fit through the following three data sets: [Weber2020] experimetnal, [Weber2020] Monte Carlo and [Schoenfeld2019] experimental. For [Weber2020], we have used the experimental data from 4 cm x 4 cm to 10 cm x 10 cm also for the Monte Carlo data. For [Schoenfeld2019] we have used SIEMENS Artiste data to compare 4x4 $cm^2$ with 10x10 $cm^2$. Data for field sizes below 0.55 cm has been extrapolated using fit funcion 1.

[3] Data has been compiled from [Looe2018], [Poppinga2018] and [Casar2020]. Correction factor for 0.7 cm field size is 1.049

[4] Data has been compiled from [Looe2018] and [Casar2020]. Correction factor for 0.9 cm field size is 1.052

[5] Data has been compiled from [Looe2018] and [Casar2020]

## Correction factors classical linac, 10 MV

| Equivalent square field size [cm] | 10 | 8 | 6 | 4 | 3 | 2.5 | 2 | 1.5 | 1.2 | 1 | 0.8 | 0.6 | 0.5 | 0.4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| microDiamond, type 60019 [1] | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 0.999 | 0.997 | 0.993 | 0.989 | 0.984 | 0.977 | 0.968 | 0.962 | 0.955 |
| Diode E, type 60017 [1] | 1.000 | 1.002 | 1.004 | 1.006 | 1.006 | 1.005 | 1.003 | 0.996 | 0.988 | 0.980 | 0.969 | 0.954 | -- | -- |
| Diode SRS, type 60018 [1] | 1.000 | 1.002 | 1.004 | 1.006 | 1.006 | 1.004 | 1.000 | 0.992 | 0.984 | 0.976 | 0.966 | 0.953 | -- | -- |
| Diode P, type 60016 [1] | 1.000 | 1.000 | 1.000 | 0.999 | 0.995 | 0.991 | 0.984 | 0.970 | 0.956 | -- | -- | -- | -- | -- |
| microLion, type 31018 [1] | 1.000 | 0.998 | 0.996 | 0.994 | 0.994 | 0.993 | 0.993 | 0.992 | 0.992 | 0.993 | 0.995 | 1.005 | 1.017 | 1.039 |
| PinPoint 3D, type 31022 [2] | 1.000 | 0.999 | 0.999 | 0.998 | 0.998 | 0.998 | 0.999 | 1.003 | 1.013 | 1.028 | -- | -- | -- | -- |
| PinPoint 3D, type 31016 [1] | 1.000 | 1.000 | 1.000 | 1.000 | 1.001 | 1.001 | 1.004 | 1.013 | 1.025 | 1.039 | -- | -- | -- | -- |
| PinPoint 0.015 $cm^3$, type 31014 [1] | 1.000 | 1.000 | 1.000 | 1.000 | 1.002 | 1.004 | 1.009 | 1.023 | 1.041 | -- | -- | -- | -- | -- |
| Semiflex 0.125 $cm^3$, type 31010 [1] | 1.000 | 1.000 | 1.000 | 1.000 | 1.001 | 1.002 | 1.008 | 1.025 | -- | -- | -- | -- | -- | -- |

For the detector orientation, see subchapter "Orientation of the detector" in chapter 6.3.

[1] [TRS483]

[2] Data has been compiled from [Vieillevigne2018] (assuming the correction factor for 4 cm x 4 cm is 1.0) and [Casar2020].

## Correction factors TomoTherapy

| **Equivalent square field size [cm]** | **5** | **4** | **3.5** | **3** | **2.5** | **2** | **1.5** | **1.2** | **1** | **0.8** | **0.6** | **0.5** | **0.4** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| microDiamond, type 60019 [1] | 1.000 | 1.000 | 1.000 | 1.000 | 0.999 | 0.997 | 0.993 | 0.989 | 0.984 | 0.977 | 0.968 | 0.962 | 0.955 |
| Diode E, type 60017 [1] | 1.004 | 1.005 | 1.006 | 1.006 | 1.006 | 1.003 | 0.997 | 0.989 | 0.981 | 0.971 | 0.956 | -- | -- |
| Diode SRS, type 60018 [1] | 1.004 | 1.005 | 1.005 | 1.005 | 1.004 | 1.001 | 0.993 | 0.985 | 0.977 | 0.968 | 0.955 | -- | -- |
| Diode P, type 60016 [1] | 1.000 | 0.999 | 0.998 | 0.995 | 0.991 | 0.984 | 0.970 | 0.956 | -- | -- | -- | -- | -- |
| microLion, type 31018 [1] | 0.997 | 0.995 | 0.994 | 0.994 | 0.993 | 0.992 | 0.991 | 0.991 | 0.992 | 0.994 | 1.003 | 1.015 | 1.038 |
| PinPoint 3D, type 31016 [1] | 1.000 | 1.000 | 1.000 | 1.001 | 1.001 | 1.004 | 1.013 | 1.025 | 1.039 | -- | -- | -- | -- |
| PinPoint 0.015 $cm^3$, type 31014 [1] | 1.000 | 1.000 | 1.001 | 1.002 | 1.004 | 1.009 | 1.023 | 1.041 | -- | -- | -- | -- | -- |
| Semiflex 0.125 $cm^3$, type 31010 [1] | 1.000 | 1.000 | 1.000 | 1.001 | 1.002 | 1.008 | 1.025 | -- | -- | -- | -- | -- | -- |

For the detector orientation, see subchapter "Orientation of the detector" in chapter 6.3.

[1] [TRS483]

## Correction factors Gamma Knife

| **Circular collimator diameter [mm]** | **4** | **8** | **16** |
|---|---|---|---|
| microDiamond, type 60019 [1] | 0.993 | 1.005 | 1.000 |
| Diode E, type 60017 [1] | 0.961 | 0.997 | 1.000 |
| Diode P, type 60016 [1] | 0.958 | 0.981 | 1.000 |
| PinPoint 3D, type 31016 [1] | -- | 1.032 | 1.000 |
| PinPoint 0.015 $cm^3$, type 31014 [1] | -- | 1.030 | 1.000 |

For the detector orientation, see subchapter "Orientation of the detector" in chapter 6.3.

[1] [TRS483]

## Correction factors CyberKnife

| Circular field diameter [cm] | 5 | 4 | 3.5 | 3 | 2.5 | 2 | 1.5 | 1.2 | 1 | 0.8 | 0.6 | 0.5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| microDiamond, type 60019 [1] | 1.000 | 1.000 | 1.000 | 0.999 | 0.999 | 0.998 | 0.995 | 0.991 | 0.988 | 0.984 | 0.978 | 0.975 |
| Diode E, type 60017 [1] | 1.000 | 1.001 | 1.001 | 1.000 | 0.999 | 0.997 | 0.992 | 0.987 | 0.981 | 0.975 | 0.966 | 0.960 |
| Diode SRS, type 60018 [1] | 1.000 | 1.001 | 1.000 | 1.000 | 0.998 | 0.995 | 0.990 | 0.984 | 0.979 | 0.973 | 0.965 | 0.961 |
| Diode P, type 60016 [1] | 1.000 | 0.999 | 0.998 | 0.996 | 0.993 | 0.987 | 0.978 | 0.969 | 0.962 | 0.953 | -- | -- |
| microLion, type 31018 [1] | 1.000 | 0.999 | 0.999 | 0.999 | 0.998 | 0.998 | 0.998 | 0.998 | 0.999 | 1.002 | 1.010 | 1.019 |
| PinPoint 3D, type 31016 [1] | 1.000 | 1.000 | 1.000 | 1.001 | 1.002 | 1.004 | 1.011 | 1.021 | 1.031 | 1.046 | -- | -- |
| PinPoint 0.015 $cm^3$, type 31014 [1] | 1.000 | 1.000 | 1.001 | 1.002 | 1.004 | 1.008 | 1.019 | 1.032 | 1.044 | -- | -- | -- |
| Semiflex 0.125 $cm^3$, type 31010 [1] | 1.000 | 1.000 | 1.000 | 1.001 | 1.003 | 1.008 | 1.022 | 1.043 | -- | -- | -- | -- |

| Circular field diameter [cm] for microSilicon data | 6 | 2 | 1.5 | 1.25 | 1 | 0.75 | 0.5 |
|---|---|---|---|---|---|---|---|
| microSilicon, type 60023 [2] | 1.0000 | 1.0015 | 0.9960 | 0.9925 | 0.9855 | 0.9805 | 0.9740 |

For the detector orientation, see subchapter "Orientation of the detector" in chapter 6.3.

[1] [TRS483]

[2] The presented data is the average of the experimental data from [Weber2020] and the Monte Carlo data from [Francescon2020]. Both datasets have been evaluated for an M6 CyberKnife

# 7 Absolute Dose Measurements with PTW Small Field Detectors

The term „absolute dose measurement" is not uniquely defined in dosimetry. In most cases it is used for the following two different types of measurement:

- Reference dosimetry under reference conditions
- Point dose plan verification

In both cases the result of the measurement is an absolute dose value in Gy. Nevertheless, the procedure to get to this dose is quite different. Reference dose measurement requires to precisely follow the procedure described by a dosimetry standard such as TRS 398, TG 51 or DIN 6800-2 for classical linacs, or TRS 483 for small field linacs which cannot provide a 10 cm x 10 cm field.

Absolute dose measurement for point dose plan verification or other measurements, where a result in Gy is desired, require cross-calibration in a field where the absolute dose is known. In most cases this is either performed in reference conditions where the absolute dose was deduced using one of the standards as described above. In other cases the intermediate field method is used and cross-calibration performed in a field size which is between a small field and the reference field size. See chapter "Code of Practice TRS 483" for more details.

We recommend to perform cross-calibration before each measurement session to check for detector dose and temperature stability – this is especially important when using silicon diodes or scintillators – and to check for the reproducibility of the calibration procedure.

The procedure for cross-calibration is described in the chapter "Code of Practice TRS 483". Note, the cross-calibration depends on the radiation quality of the beam and also on the orientation of the detector. Note also that most detectors will require correction factors in small and very small fields for absolute dose measurement.

Note, this guide has a focus on water phantom measurements. Hence, we will not go deeper into the methods to perform point dose plan verification in small fields.

# 8 Frequently Asked Questions

### What if my detector is not (yet) listed in TRS 483?

You can use correction factors published in scientific literature if those have been determined following the methods of TRS 483. You might be required to renormalize the given correction factors to the cross-calibration field size which you use. If the data is for ionization chambers, keep an eye on the polarity effect and check if this was taken into account by the authors. If possible, we recommend to take more than one publication into consideration.
PTW scans current scientific literature for recently published correction factors and will make them available through PTW technical service or in this application guide.

### Why are non-shielded diodes preferable for small field measurements?

Shielded silicon diodes are generally not recommended for small field measurements, see e.g. [TRS483] or [IPEM103]. One reason is: if you don't need the shielding it is always better to work with a detector that has less perturbing material inside, i.e. one without shielding. To be more specific, the shielding is composed of high-Z and high-density material. This will lead to a density perturbation effect in addition to the already present density perturbation of the silicon itself. This has several consequences:

1. The over-estimation of dose in small and very small fields is increased. This can be seen when the small field output correction factors of the Diode P (type 60016, shielded) are compared with those of the Diode E (type 60017, unshielded). Hence, the range of use down to small fields is smaller for shielded silicon diodes compared to unshielded ones.

2. The over-sharpening of the penumbra which is already present for unshielded silicon diodes is further increased by the additional density perturbation.

3. In figure 4 of [Francescon2014], correction factors for PDD measurements are presented. This correction is no problem as long as it stays constant for the entire PDD. For the shielded diode evaluated in that work, the correction factor changes by 5 % within a single PDD.

### I have found correction factors for my detector but they are not in the measurement depth which I require. What can I do?

On pages 163 and 164, [TRS483] writes the following:
"All data were assumed to apply to a measurement depth of 10 cm in water. Values obtained at the depth of maximum dose were not considered. For detectors not showing a substantial field size dependence in square field sizes above 3 cm, published data obtained at 5 cm depth were assumed to be valid at 10 cm depth. For detectors exhibiting a substantial field size dependence for sizes above 3 cm, such as unshielded diodes, a linear field size dependent correction was applied based on data from publications where measurements at both depths were reported."
In other words: if your detector does not have a field size dependence, you can use the [TRS483] small field correction factors also in other depths. In case the detector does have a field size dependence, a correction is required. The latter will be the case (but is not limited to) for air-filled ionization chambers with steel electrode and for unshielded silicon diodes.

### How can I tell whether my detector is too big for my field size?

As a crude rule of thumb: if one dimension of your detector is more than 25 % of the field width, you might observe a volume effect of several %. To make sure, cross-calibrate a smaller detector against yours in a 4 cm x 4 cm or 5 cm x 5 cm field and compare their respective signals in the targeted small field. If the measured doses clearly deviate, you are probably experiencing a volume effect.

## Do I need special detectors to perform dosimetry in small fields?

Yes. In general, detectors are either well suited to perform highest accuracy measurements in small fields, such as very small air-filled chambers or solid state detectors, or they are well suited for highest accuracy measurements in large fields, such as the Semiflex type chambers or the Farmer chamber. The only exception is the microDiamond which will give results with high accuracy in small as well as large fields.

## Is film dosimetry the best solution for small fields?

No. The main advantage of film dosimetry is the very good spatial resolution. Unfortunately this is the only advantage. Silver films exhibit a very bad energy response in the keV-energy range and their quality depends a lot on the development process. [IPEM103] recommends not to use that type of film. Radiochromic films have a good energy dependence, but require a high dose for development, their result depends on handling, i.e. on staff, they darken by a few percent after exposure, their response can vary by several percent over the area of the film, and there are batch-to-batch variations [IPEM103].

## Is a scintillation detector the best solution for small fields?

Theoretically, a scintillator has a good water-equivalence because it can be built from plastic. In practice a dosemeter also needs good dosimetric properties. Scintillators can be subject to LET-, dose rate- and temperature dependence. Because of the low optical signal output, which even reduces with accumulated dose, scintillation detectors cannot be built as small as solid state detectors and they feature a very high quantum noise. The optical signal transfer (if performed in a PMMA light guide) leads to very strong stem- and cable-irradiation effects. If you correct for these effects using a two-color-channel method, this is very prone to handling-errors. All in all, using scintillation detectors is similar to using gafchromic film: if you want accurate results, you need to know very well what you are doing.

## My field is smaller than 1 cm x 1 cm. Which detector can I use?

If you need to measure smaller field sizes, we recommend to use non-shielded detectors with a small cross-section perpendicular to the beam. These are the microDiamond or the microSilicon. For any detector we recomend to look up correction factors for very small fields in scientific literature, [TRS483] or [DIN6809-8].

## My field is not square. Which detector is suitable?

There are formulas to calculate an equivalent square field size for non-square field shapes. The aim of these calculations is to predict the output factor of an irregular field. To estimate whether a detector will be prone to the volume effect, these formulas cannot be used. Instead, the smallest dimension of the field plays the central role. For **rectangular fields**, this is the small edge. For example, if your field size is 2 cm x 10 cm, take a detector that is suited for a 2 cm x 2 cm field.
For **circular small fields** use the formula $S_{clin} = 1.77 * r$ from [TRS483] to calculate the

equivalent square field size using the field radius r. Take $S_{clin}$ as field dimension to deduce weather your detector is suited to measure output factors in that field.

### What is the advantage of silicon diodes over air-filled ionization chambers?

Due to the higher density of atoms in silicon compared to air, a diode detector can be constructed very small and still have a good response. Hence in high-gradient regions, such as the penumbra, a diode detector will be more accurate. The microDiamond detector combines the advantages of silicon diodes and air-filled ionization chambers.

### What is the advantage of air-filled ionization chambers over silicon diodes?

In contrast to silicon diodes the response of air-filled ionization chambers to low-energy scattered radiation is excellent, except if they have a steel central electrode. For this reason, they are suited to accurately deduce the dose in large fields and in the out-of-field region. In addition, air-filled ionization chambers are perfectly suited to measure reference dose according to international dosimetry protocols. Air-filled ionization chambers do not suffer any response degradation due to irradiation.

### When do I use a shielded diode?

In shielded diodes, the over-response to keV-energy scattered radiation – which is mainly present in fields ≥ 10 cm x 10 cm – is compensated by a metal shield absorbing that type of radiation. Due to this combination, shielded diodes can be used in the entire field size range from 2 cm x 2 cm up to 40 cm x 40 cm. Nevertheless one must keep in mind that this large field size range does not come free of costs. Shielded diodes are a compromise. They can be used for small and large fields, but if you want to increase the accuracy, we recommend to use a microDiamond. For highest accuracy use a small field detector for small fields (e.g. an unshielded silicon diode or a microDiamond) and a large enough air-filled ionization chamber for large fields.

### How can I check if my detector is accurately positioned in the field?

For the BEAMSCAN software version 4.4 or higher, the output factor measurement module features a "search max" function. This will automatically position your detector on the CAX and in addition it will measure the equivalent square field size using the very same detector. Note, this equivalent square field size will only be correct if your detector is suited for the field size you are working in.
For older BEAMSCAN software versions you can use "Beam Center Adjustment" of the Auto Setup mode for detector centering. If you are working with Mephysto mcc, the "Center Check" module will do the job for you. In case you are using "Center Check" please make sure that you apply the PTW technical note D811.200.01 when working in small fields.
Note, all of these modules use the 50 % isodoses to define the field center.

### How can I tell the effective point of measurement and water equivalent window thickness of PTW solid state detectors?

Each PTW solid state detector has a colored ring which is situated at the water equivalent depth of the effective point of measurement of the detector. To find the "zero" water position, make the ring level with the water surface and define this as zero water level. The detector should be used in axial orientation for this procedure.
If you are using TRUFIX and the stop thimble

corresponding to your detector, the detector will directly be positioned in the correct depth. This, of course, requires that you first have correctly set the zero position with TRUFIX.

## Where do I place the reference detector in a small field?

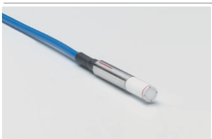
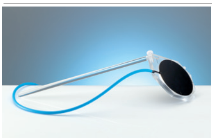
Placing a reference detector in a very small field without disturbing the main detector is not feasible. Simply placing the reference detector outside the field border is not a very good solution either, because the signal of the reference will then be very noisy and will lead to a noisy measurement (i.e. the curves will not be flat). There are several options what you could do:

- You can use the PTW T-REF chamber. This is a very thin transmission chamber providing a strong and very low noise reference signal
- If you are very sure that your linac is very stable, measure without reference
- You can increase your integration time. Four times longer integration time leads to half the noise
- You can measure the PDD, profile, etc. two times. If the curves coincide, the linac was stable. After this, you can take the average of the two curves which will reduce the noise of the measurement.
- You can measure step by step irradiating a fixed number of MUs for each data point

If you use a reference chamber outside of the beam, remember to pre-irradiate it if it has not been in the beam before. A more thorough description including measured data can be found in [Wuerfel2013].

# Notes

# 9 Detector Overview

| | | | **Dimensions, specs** | **Radiation Quality** |
|---|---|---|---|---|
|  | T31021 | 0.07 cm³<br>Semiflex 3D Chamber | radius of sensitive volume 2.4 mm, length 4.8 mm | $^{60}$Co … 50 MV photons<br>(9 … 45) MeV electrons |
|  | T31010 | 0.125 cm³<br>Semiflex Chamber | radius of sensitive volume 2.75 mm, length 6.5 mm | 140 kV … 50 MV photons<br>(10 … 45) MeV electrons<br>(50 … 270) MeV protons |
|  | T31022 | 0.016 cm³<br>PinPoint 3D Chamber | radius of sensitive volume 1.45 mm, length 2.9 mm | $^{60}$Co … 25 MV photons |
|  | T60019 | microDiamond | sensitive volume 0.004 mm³, radius of sensitive volume 1.1 mm, thickness 0.001 mm | 100 kV … 25 MV photons<br>(6 … 25) MeV electrons<br>(70 … 230) MeV protons<br>(115 … 380) MeV/u carbon ions |
|  | T60023 | microSilicon | sensitive volume 0.03 mm³, radius of sensitive volume 0.75 mm | $^{60}$Co … 25 MV photons<br>(6 ... 25) MeV electrons |
|  | T60022 | microSilicon X | sensitive volume 0.03 mm³, radius of sensitive volume 0.75 mm | $^{60}$Co … 25 MV photons |
|  | T34091 | T-REF Chamber | sensitive volume 10.5 cm³, radius of sensitive volume 40.8 mm | $^{60}$Co … 25 MV photons |

# 0.07 cm³ Semiflex 3D Chamber

## Type 31021

*Standard therapy chamber with excellent 3D characteristics for scanning systems and for reference dosimetry*

### Features

- Waterproof, semiflexible design for easy mounting in scanning water phantoms
- Excellent 3D characteristics
- Sensitive volume of 0.07 $cm^3$
- Reference class in accordance with IEC 60731 and AAPM TG-51 Addendum
- Designed for axial and radial irradiation

The 31021 Semiflex 3D chamber is ideal for dose measurements in small fields as encountered e.g. in IORT, IMRT and stereotactic beams as well as for dose measurements in standard fields up to 40 x 40 $cm^2$. Relative dose distribution 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 | reference dosimetry in radiotherapy beams |
| Measuring quantities | absorbed dose to water, air kerma, exposure |
| Reference radiation quality | $^{60}Co$ |
| Nominal sensitive volume | 0.07 $cm^3$ |
| Design | waterproof, vented, guarded |
| Reference point | on chamber axis, 3.45 mm from detector tip |
| Direction of incidence | axial, radial |
| Nominal response | 2 nC/Gy |
| Long-term stability | ≤ 0.3 % over 2 years |
| Chamber voltage | 400 V nominal<br>± 500 V maximal |
| Polarity effect at $^{60}Co$ | photons ≤ ± 0.8 %<br>electrons ≤ ± 1 % |
| Directional response in water | ≤ ± 0.5 % for rotation around the chamber axis<br>≤ ±1 % for tilting of the axis up to ± 70° |
| Leakage current | ≤ ± 4 fA |
| Cable leakage | ≤ 200 fC/(Gy·cm) |

### Materials and measures:

| | |
|---|---|
| Wall of sensitive volume | 0.57 mm PMMA, 1.19 g/$cm^3$<br>0.09 mm graphite, 1.85 g/$cm^3$ |
| Total wall area density | 84 mg/$cm^2$ |
| Dimension of sensitive volume | radius 2.4 mm<br>length 4.8 mm |
| Central electrode | Al 99.98, diameter 0.8 mm |
| Build-up cap | PMMA, thickness 3 mm |

### Ion collection efficiency at nominal voltage:

| | |
|---|---|
| Ion collection time | 118 µs |
| Max. dose rate for<br>≥ 99.5 % saturation<br>≥ 99.0 % saturation | <br>6.7 Gy/s<br>13.4 Gy/s |
| Max. dose per pulse for<br>≥ 99.5 % saturation<br>≥ 99.0 % saturation | <br>0.68 mGy<br>1.42 mGy |

### Useful ranges:

| | |
|---|---|
| Chamber voltage | ± (100 ... 400) V |
| Radiation quality | $^{60}Co$ ... 50 MV photons<br>(9 ... 45) MeV electrons |
| Field size | (2.5 x 2.5) $cm^2$ ... (40 x 40) $cm^2$<br>(3.0 x 3.0) $cm^2$ ... (40 x 40) $cm^2$<br>≥ 18 MV |
| Temperature | (10 ... 40) °C<br>(50 ... 104) °F |
| Humidity | (10 ... 80) %, max 20 g/$m^3$ |
| Air pressure | (700 ... 1060) hPa |

### Ordering Information

TN31021 Semiflex 3D chamber 0.07 $cm^3$, connecting system BNT

TW31021 Semiflex 3D chamber 0.07 $cm^3$, connecting system TNC

TM31021 Semiflex 3D chamber 0.07 $cm^3$, connecting system M

### Options

T48012 Radioactive check device $^{90}Sr$

T48002.1.004 Chamber holding device for check device

# 0.125 cm³ Semiflex Chamber

## Type 31010

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

## Features

- Waterproof, semiflexible design for easy mounting in scanning water phantoms
- Minimized directional response
- Sensitive volume of 0.125 cm³, vented
- 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 cm³ gives enough signal to use the chamber also for high precision reference 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 | reference dosimetry in radiotherapy beams |
| Measuring quantities | absorbed dose to water, air kerma, exposure |
| Reference radiation quality | $^{60}$Co |
| Nominal sensitive volume | 0.125 cm³ |
| Design | waterproof, vented, guarded |
| Reference point | on chamber axis, 4.5 mm from detector tip |
| Direction of incidence | radial |
| Nominal response | 3.3 nC/Gy |
| Long-term stability | ≤ 1 % per year |
| Chamber voltage | 400 V nominal<br>± 500 V maximal |
| Polarity effect at $^{60}$Co | < 2 % |
| Photon energy response | ≤ ± 2 % (140 kV ... 280 kV)<br>≤ ± 4 % (200 kV ... $^{60}$Co)<br>≤ ± 5 % (50 kV ... 150 kV) |
| 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,<br>1.19 g/cm³<br>0.15 mm graphite,<br>0.82 g/cm³ |
| Total wall area density | 78 mg/cm² |
| Dimension of sensitive volume | radius 2.75 mm<br>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 | 121 µs |
| Max. dose rate for<br>≥ 99.5 % saturation<br>≥ 99.0 % saturation | <br>6 Gy/s<br>12 Gy/s |
| Max. dose per pulse for<br>≥ 99.5 % saturation<br>≥ 99.0 % saturation | <br>0.5 mGy<br>1.0 mGy |

**Useful ranges:**

| | |
|---|---|
| Chamber voltage | ± (100 ... 400) V |
| Radiation quality | 140 kV ... 50 MV photons<br>(10 ... 45) MeV electrons<br>(50 ... 270) MeV protons |
| Field size | (3 x 3) cm² ... (40 x 40) cm² |
| Temperature | (10 ... 40) °C<br>(50 ... 104) °F |
| Humidity | (10 ... 80) %, max 20 g/m³ |
| Air pressure | (700 ... 1060) hPa |

## Ordering Information

TN31010 Semiflex chamber 0.125 cm³, connecting system BNT

TW31010 Semiflex chamber 0.125 cm³, connecting system TNC

TM31010 Semiflex chamber 0.125 cm³, connecting system M

## Options

T48012 Radioactive check device $^{90}$Sr

T48002.1.004 Chamber holding device for check device

# PinPoint 3D Chamber
## Type 31022

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

### Features
- Small polarity effect
- Minimal cable irradiation effect
- Short ion collection time
- Large field size range

The 31022 PinPoint 3D chamber is ideal for measurements in small fields but can also be used for measurements in large fields. Designed for radial beam orientation, the small-sized chamber shows excellent 3D characteristics. Relative dose distributions can be measured with high spatial resolution in any direction. It is waterproof and fully guarded, thus it can be used in air, solid state phantoms and in water.

### Specification

| | |
|---|---|
| Type of product | vented cylindrical ionization chamber |
| Application | dosimetry in photon beams |
| Measuring quantities | absorbed dose to water, air kerma, exposure |
| Reference radiation quality | $^{60}$Co |
| Nominal sensitive volume | 0.016 cm$^3$ |
| Design | waterproof, vented, guarded |
| Reference point | on chamber axis, 2.4 mm from chamber tip |
| Direction of incidence | radial, axial |
| Pre-irradiation dose | 1 Gy |
| Nominal response | 400 pC/Gy |
| Long-term stability | ≤ 0.5 % per year |
| Chamber voltage | 300 V nominal<br>± 500 V maximal |
| Polarity effect | ≤ ± 0.8 % |
| Directional response in water | ≤ ± 0.5 % for rotation around the chamber axis<br>≤ ±1 % for tilting of the axis up to ± 10° |
| Leakage current | ≤ ± 4 fA |
| Cable leakage | ≤ 100 fC/(Gy·cm) |

### Materials and measures:

| | |
|---|---|
| Wall of sensitive volume | 0.57 mm PMMA, 1.19 g/cm$^3$<br>0.09 mm graphite, 1.85 g/cm$^3$ |
| Total wall area density | 84 mg/cm$^2$ |
| Dimension of sensitive volume | radius 1.45 mm<br>length 2.9 mm |
| Central electrode | Al 99.98, diameter 0.6 mm |
| Build-up cap | PMMA, thickness 3 mm |

### Ion collection efficiency at nominal voltage:

| | |
|---|---|
| Ion collection time | 45 µs |
| Max. dose rate for<br>≥ 99.5 % saturation<br>≥ 99.0 % saturation | <br>46 Gy/s<br>91 Gy/s |
| Max. dose per pulse for<br>≥ 99.5 % saturation<br>≥ 99.0 % saturation | <br>0.8 mGy<br>2.2 mGy |

### Useful ranges:

| | |
|---|---|
| Chamber voltage | ± (100 ... 400) V |
| Radiation quality | $^{60}$Co ... 25 MV photons |
| Field size | (2 x 2) cm$^2$ ... (40 x 40) cm$^2$ |
| Small fields[1] | down to 0.8 cm |
| Temperature | (10 ... 40) °C<br>(50 ... 104) °F |
| Humidity | (10 ... 80) %, max 20 g/m$^3$ |
| Air pressure | (700 ... 1060) hPa |

### Ordering Information
TN31022 PinPoint 3D chamber 0.016 cm$^3$, connecting system BNT

TW31022 PinPoint 3D chamber 0.016 cm$^3$, connecting system TNC

TM31022 PinPoint 3D chamber 0.016 cm$^3$, connecting system M

### Options
T48012 Radioactive check device $^{90}$Sr

T48002.1.010 Chamber holding device for check device

[1] This detector is well suited for measurements in small and very small fields. Please note that for high accuracy measurements any detector may need correction factors in small fields. The small field size limit is provided as equivalent square field size following the methodology of IAEA TRS483:2017. In accordance with TRS483, the smallest field size considered is 0.4 cm.

# microDiamond

## Type 60019

*Diamond detector for dosimetry in high-energy photon, electron, proton and carbon ion beams, especially useful for small field dosimetry*

### Features

- Small sensitive volume of 0.004 $mm^3$
- Excellent radiation hardness and temperature independence
- Near tissue-equivalence
- Operates without high voltage
- All connecting systems available (BNT, TNC, M)

The microDiamond detector is a synthetic single crystal diamond detector (SCDD), based on a unique fabrication process [1, 2]. Significant advantages of the synthetic production are standardised assembly and consequently a high reproducibility of the dosimetric properties and good availability of the detector.

### Specification

| | |
|---|---|
| Type of product | synthetic single crystal diamond detector |
| Application | relative dosimetry in radiotherapy beams |
| Reference radiation quality | $^{60}Co$ |
| Nominal sensitive volume | 0.004 $mm^3$ |
| Design | waterproof, disk-shaped sensitive volume perpendicular to detector axis |
| Reference point | on detector axis, 1 mm from detector tip, marked by ring |
| Direction of incidence | axial |
| Pre-irradiation dose | 5 Gy |
| Nominal response | 1 nC/Gy |
| Long-term stability | ≤ 0.5 % per year |
| Dose stability | ≤ 0.25 %/kGy at 18 MV |
| Temperature response | ≤ 0.08 %/K |
| Energy response | at higher depths than $d_{max}$, the percentage depth dose curves match curves measured with ionization chambers within ± 0.5 % |
| Bias voltage | 0 V |
| Signal polarity | positive |
| Directional response in | ≤ ±1 % for tilting ≤ ± 40° |
| Leakage current[1] | ≤ ± 20 fA |
| Cable leakage | ≤ 200 fC/(Gy·cm) |

### Materials and measures:

| | |
|---|---|
| Entrance window | 0.3 mm RW3<br>0.6 mm Epoxy<br>0.01 mm Al 99.5 |
| Total window area density | 0.1 $g/cm^2$ |
| Water-equivalent window thickness | 1.0 mm |
| Sensitive volume | radius 1.1 mm, circular<br>thickness 1 µm |
| Outer dimensions | diameter 7 mm<br>length 45.5 mm |

### Useful ranges:

| | |
|---|---|
| Radiation quality | 100 keV ... 25 MV photons<br>(6 ... 25) MeV electrons<br>(70 ... 230) MeV protons[2]<br>(115 ... 380) MeV/u carbon ions[2] |
| Field size | (1 x 1) $cm^2$ ... (40 x 40) $cm^2$ |
| Small fields[3] | down to 0.4 cm |
| Temperature | (10 ... 35) °C<br>(50 ... 95) °F |
| Humidity range | (10 ... 80) %, max 20 $g/m^3$ |

### Ordering Information

TN60019 microDiamond, connecting system BNT

TW60019 microDiamond, connecting system TNC

TM60019 microDiamond, connecting system M

The microDiamond detector is realized in collaboration with Marco Marinelli and Gianluca Verona-Rinati and their team, Industrial Engineering Department of Rome Tor Vergata University, Italy.

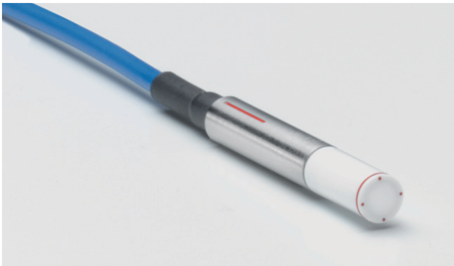
[1] I. Ciancaglioni, M. Marinelli, E. Milani, G. Prestopino, C. Verona, G. Verona-Rinati, R. Consorti, A. Petrucci and F. De Notaristefani, Dosimetric characterization of a synthetic single crystal diamond detector in clinical radiation therapy small photon beams, Med. Phys. **39** (2012), 4493

[2] C. Di Venanzio, M. Marinelli, E. Milani, G. Prestopino, C. Verona, G. Verona-Rinati, M. D. Falco, P. Bagalà, R. Santoni and M. Pimpinella, Characterization of a synthetic single crystal diamond Schottky diode for radiotherapy electron beam dosimetry, Med. Phys. **40** (2013), 021712

[1] At the high end of the temperature range, higher leakage currents may occur.

[2] In rare cases, an individual microDiamond can exhibit an LET dependence in proton or hadron radiation. If you suspect that this might be the case for your microDiamond, please contact PTW technical service.

[3] This detector is well suited for measurements in small and very small fields. Please note that for high accuracy measurements any detector may need correction factors in small fields. The small field size limit is provided as equivalent square field size following the methodology of IAEA TRS483:2017. In accordance with TRS483, the smallest field size considered is 0.4 cm.



# microSilicon
## Type 60023

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

### Features

- Useful for measurements in all electron fields and for photon fields ≤ (10 x 10) $cm^2$
- Excellent spatial resolution
- Thin entrance window for measurements in the vicinity of surfaces and interfaces
- Very small detector to detector variation
- Excellent dose stability

The microSilicon is ideal for dose measurements in electron and small photon fields. The excellent spatial resolution makes it possible to measure very precisely beam profiles even in the penumbra region of small fields. The microSilicon is recommended for dose measurements in all electron fields and for photon fields up to (10 x 10) $cm^2$. The waterproof detector can be used in air and in water.
The microSilicon shows a very small detector to detector variation which provides a sound basis for reliable small field correction factors.

### Specification

| | |
|---|---|
| Type of product | p-type silicon diode |
| Application | relative dosimetry in radiotherapy beams |
| Reference radiation quality | $^{60}Co$ |
| Nominal sensitive volume | 0.03 $mm^3$ |
| Design | waterproof, disk-shaped sensitive volume perpendicular to detector axis |
| Reference point[1] | on detector axis, 0.9 mm from detector tip |
| Direction of incidence | axial |
| Nominal response | 19 nC/Gy |
| Dose stability<br>Electrons<br><br>Photons | <br>≤ 0.5 %/kGy at 10 MeV<br>≤ 1 %/kGy at 21 MeV<br>≤ 0.1 %/kGy at 6 MV<br>≤ 0.5 %/kGy at 18 MV |
| Temperature response | ≤ 0.1 %/K typical |
| Bias voltage | 0 V |
| Signal polarity | negative |
| Directional response in water | ≤ ± 1 % for rotation around the detector axis<br>≤ ±1 % for tilting of the axis up to ± 20° |
| Leakage current | ≤ ± 100 fA |
| Cable leakage | ≤ 1 pC/(Gy·cm) |

### Materials and measures:

| | |
|---|---|
| Entrance window | 0.3 mm RW3<br>0.01 mm Al<br>0.48 mm epoxy |
| Total window area density | 92 mg/$cm^2$ |
| Water-equivalent window thickness | 0.9 mm |
| Sensitive volume | radius 0.75 mm<br>thickness 18 µm |
| Outer dimensions | diameter 7 mm<br>length 45.5 mm |

### Useful ranges:

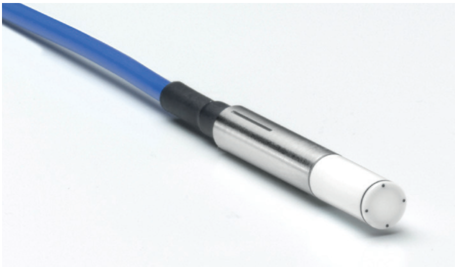
| | |
|---|---|
| Radiation quality | (6 ... 25) MeV electrons<br>$^{60}Co$ ... 25 MV photons |
| Field size | (1 x 1) $cm^2$ ... (40 x 40) $cm^2$ for electrons<br>(1 x 1) $cm^2$ ... (10 x 10) $cm^2$ for photons |
| Small fields[2] | down to 0.4 cm |
| Temperature | (10 ... 40) °C<br>(50 ... 104) °F |
| Humidity | (10 ... 80) %, max 20 g/$m^3$ |
| Air pressure | (700 ... 1060) hPa |

### Ordering Information

TN60023 microSilicon, connecting system BNT
TW60023 microSilicon, connecting system TNC
TM60023 microSilicon, connecting system M

[1]Photons: Reference point corresponds to the effective point of measurement.
Electrons: Effective point of measurement is 0.3 mm from tip.

[2]This detector is well suited for measurements in small and very small fields. Please note that for high accuracy measurements any detector may need correction factors in small fields. The small field size limit is provided as equivalent square field size following the methodology of IAEA TRS483:2017. In accordance with TRS483, the smallest field size considered is 0.4 cm.



# microSilicon X

## Type 60022

*Shielded silicon diode detector for all photon fields*

## Features

- Shielded diode detector for photon field sizes up to (40 x 40) cm$^2$
- The shielding reduces the low energy scattered radiation amount in the detector signal
- Ideal for percentage depth dose measurements, field size independent
- Excellent dose stability (≤ 0.1 %/kGy at 6 MV)
- Low dose per pulse dependence

Due to its newly developed shielding, the microSilicon X is perfectly suited for measurements in photon fields up to large field sizes. With its excellent spatial resolution, it is possible to measure very precisely beam profiles, even in the penumbra region.
The improved energy response enables the user to perform accurate, field size independent percentage depth dose measurements. In addition the new design results in a small water equivalent window thickness, which has positive effects on the measurements of output factors.

## Specification

| | |
|---|---|
| Type of product | shielded p-type silicon diode |
| Application | relative dosimetry in radiotherapy beams |
| Reference radiation quality | $^{60}$Co |
| Nominal sensitive volume | 0.03 mm$^3$ |
| Design | waterproof, disk-shaped sensitive volume perpendicular to detector axis |
| Reference point[1] | on detector axis, 0.9 mm from detector tip |
| Direction of incidence | axial |
| Nominal response | 19 nC/Gy |
| Dose stability | ≤ 0.1 %/kGy at 6 MeV<br>≤ 0.5 %/kGy at 18 MV |
| Temperature response | ≤ 0.1 %/K typical |
| Bias voltage | 0 V |
| Signal polarity | negative |
| Directional response in water | ≤ ± 1 % for rotation around the detector axis<br>≤ ±1 % for tilting of the axis up to ± 20° |
| Leakage current | ≤ ± 100 fA, typical |
| Cable leakage | ≤ 1 pC/(Gy·cm) |

**Materials and measures:**

| | |
|---|---|
| Entrance window | 0.3 mm RW3<br>0.01 mm Al<br>0.48 mm epoxy |
| Total window area density | 92 mg/cm$^2$ |
| Water-equivalent window thickness | 0.9 mm |
| Sensitive volume | radius 0.75 mm<br>thickness 18 µm |
| Outer dimensions | diameter 7 mm<br>length 45.5 mm |

**Useful ranges:**

| | |
|---|---|
| Radiation quality | $^{60}$Co ... 25 MV photons |
| Field size | (2 x 2) cm$^2$ ... (40 x 40) cm$^2$ |
| Temperature | (10 ... 40) °C<br>(50 ... 104) °F |
| Humidity | (10 ... 80) %, max 20 g/m$^3$ |
| Air pressure | (700 ... 1060) hPa |

## Ordering Information

TN60022 microSilicon X, connecting system BNT
TW60022 microSilicon X, connecting system TNC
TM60022 microSilicon X, connecting system M

[1]Reference point corresponds to the effective point of measurement.

# T-REF Chamber

## Type 34091

*Reference detector for small fields*

### Features

- Very low total area density of 72 mg/cm²
- No measurable perturbation of the beam
- High and very stable signal
- No contact to linac head
- Fast and easy to mount

The T-REF chamber 34091 provides a solution to the problem where to put a reference detector in small fields. The T-REF chamber is a large-area plane-parallel transmission reference chamber and proved to be easy to use. From the minimum distance to the water surface on, there are no measurable perturbations of the beam. The very good signal-to-noise-ratio makes it an excellent option for the use as a reference detector.

### Specification

| | |
|---|---|
| Type of product | vented plane-parallel ionization chamber |
| Application | relative dosimetry in high-energy photon beams |
| Nominal sensitive volume | 10.5 $cm^3$ |
| Design | waterproof, vented, guarded, perturbation-free |
| Reference point | inside of entrance window, center |
| Direction of incidence | perpendicular to the entrance window, see label "Focus" |
| Nominal response | 325 nC/Gy (at $^{60}$Co free in air) |
| Chamber voltage | 400 V nominal<br>± 500 V maximal |
| Polarity effect | ≤ ± 1 % |
| Leakage current | ≤ ± 100 fA |
| Cable leakage | ≤ 1 pC/(Gy·cm) |

**Materials and measures:**

| | |
|---|---|
| Total area density | 72 $mg/cm^2$ |
| Water-equivalent window thickness | 0.7 mm for photons |
| Dimension of sensitive volume | radius 40.8 mm<br>depth 2 mm |

**Ion collection efficiency at nominal voltage:**

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

**Useful ranges:**

| | |
|---|---|
| Chamber voltage | ± (300 ... 400) V |
| Radiation quality | $^{60}$Co ... 25 MV photons |
| Max. field size in 20 cm distance to water surface | (5 x 5) $cm^2$ |
| Temperature | (10 ... 40) °C<br>(50 ... 104) °F |
| Humidity | (10 ... 80) %, max 20 $g/m^3$ |
| Air pressure | (700 ... 1060) hPa |

### Ordering Information

TN34091 T-REF chamber, connecting system BNT including holder

TW34091 T-REF chamber, connecting system TNC including holder

TM34091 T-REF chamber, connecting system M including holder

# Notes

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# Notes


# Making Radiation Safer.

PTW is a global market leader for dosimetry and quality control solutions in radiation medicine, serving the needs of medical radiation experts in more than 160 countries worldwide. Starting with the famous Hammer dosemeter in 1922, the German manufacturer is the pioneer in medical radiation measurement, known for its unparalleled quality and precision. For PTW, making medical radiation safer is both a passion and lifetime commitment. The family-owned high-tech company operates the oldest and largest accredited calibration laboratory in the field of ionizing radiation and established THE DOSIMETRY SCHOOL to globally promote the exchange of knowledge in clinical dosimetry.

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