

Absorbed Dose Determination in Small Fields of High Energy Photon Beams

Based on the German Standard DIN 6809-8

1. Introduction

This document constitutes an excerpt of procedures and data as published in the German standard DIN 6809-8. The aim is to determine absorbed dose to water in the center of small high-energy photon fields with dimensions of 4 cm x 4 cm or smaller.

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

2. General Instructions

2.1 Measuring phantom

This document assumes that all measurements are made in a water phantom.

2.2 Detector types

Dose measurements in a 4 cm x 4 cm field shall be made with a cylindrical vented ionization chamber that was calibrated in a ^{60}Co beam. Dose measurements at field sizes $s \leq 4 \text{ cm} \times 4 \text{ cm}$ shall be made with detectors featuring a high spatial resolution such as small-size ionization chambers, silicon diodes or diamond detectors. In this document such detectors are referred to as “small field detectors”.

2.3 Detector positioning

General rules

The dosimeter reading is obtained by positioning the detector’s effective point of measurement at the point of interest in the phantom.

The effective point of measurement may not coincide with the reference point of the detector. The reference point is defined by the manufacturer of the detector and serves for positioning the detector in the phantom. Usually, the reference point is a point on the central axis of a cylindrical detector with a stated distance from the detector tip. For solid state detectors such as silicon diodes or diamond detectors the manufacturer may select the effective point of measurement as the reference point.

For cylindrical ionization chambers the effective point of measurement is defined as a point shifted by $0.5r$ from the axis of the chamber towards the focus (r is the inner radius of the measuring chamber volume) [DIN 6800-2]. To measure dose at a focus distance of x cm, the axis of the cylindrical chamber must be positioned at a focus distance of $(x \text{ cm} + 0.5r)$, i. e. the chamber must be shifted away from the focus, i.e. downstream. The location of the effective point of measurement of solid state detectors can be taken from the data sheet of the detector.

The TRUFIX system

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



Figure 1: The TRUFIX detector positioning system.

2.4 Corrected reading M

In this document detector readings are designated as “corrected readings” M . For ionization chambers the reading of the dosimeter must be corrected for influence quantities as described in [DIN 6800-2]. The reader must compute the corrected reading M from the uncorrected reading M_{uncorr} and the reading without irradiation M_0 by

$$M = (M_{uncorr} - M_0) \cdot k_{TP} \cdot k_S \cdot k_{pol} \cdot k_h \quad (2-1)$$

The correction factors k_{TP} , k_S , k_{pol} and k_h correct for air density, incomplete charge collection, polarity effect and humidity, respectively. They are described in detail in [DIN 6800-2]. For solid state detectors some of the correction factors in equation (2-1) may not apply.

For absorbed dose determination in small fields, additional factors are to be applied to the corrected reading M as described in the following chapters.

3. Formalism for dose measurements in small fields

3.1 Overview

The determination of absorbed dose to water in small fields consists of three steps:

- (1) Measure the absorbed dose to water in a 4 cm x 4 cm field using a vented ionization chamber calibrated in a ^{60}Co beam. Make sure the ionization chamber is not too large for the field. See chapter 3.2.
- (2) Apply the same dose in the 4 cm x 4 cm field to a detector with high spatial resolution ("small field detector"), e.g. a silicon diode, diamond detector or PinPoint chamber, and calculate the cross-calibration factor for the small field detector by referring to the dose measured in (1). See chapter 3.3.
- (3) Use the small field detector for dose measurements in fields smaller than 4 cm x 4 cm, applying the correction factors described in chapter 3.4.

3.2 Step 1: Ionization chamber measurement at 4 cm x 4cm

The absorbed dose shall be measured in a water phantom at a depth of 10 cm with a source-to-surface distance of 100 cm. The field size is defined at the measuring depth. If a field size of 4 cm x 4 cm cannot be adjusted any field size between 3.5 cm x 3.5 cm and 5 cm x 5 cm is allowed. Dose homogeneity within 0.5 cm distance from the beam axis must be good enough to ensure that dose differences do not exceed $\pm 0.5\%$.

The absorbed dose to water D_W , measured with a vented cylindrical ionization chamber, is determined by the following equation:

$$D_W = k_r \cdot k_{Q,R} \cdot k_{NR,Q} \cdot k_V \cdot N_W \cdot M \quad (3-1)$$

where

D_W absorbed dose to water

$k_r = 1 + 0,03r$ (replacement correction factor, r is the inner radius of the measuring volume of the cylindrical chamber, given in cm)

$k_{Q,R}$ energy-dependant correction factor accounting for measuring in a high energy photon beam instead of a ^{60}Co beam. This factor can be taken from [DIN 6800-2] and is most accurate for the reference conditions described therein, especially for a field size of 10 cm x 10 cm. Note that this factor is denoted by k_Q in [DIN 6800-2].

$k_{NR,Q}$ correction factor accounting for the change of radiation quality when measuring in a 4 cm x 4 cm field instead of a 10 cm x 10 cm field

k_V correction factor accounting for the size of the ionization chamber, causing a volume effect in a 4 cm x 4 cm radiation field, see Table 1

N_W calibration factor for absorbed dose to water for ^{60}Co

M corrected reading of the dosimeter as described in chapter 2.4

PTW chamber type	k_V at 6 MV	k_V at 15 MV
PinPoint 31015 (0.03 cm ³)	1.000	1.001
Semiflex 31010 (0.125 cm ³)	1.001	1.002
Semiflex 31013 (0.3 cm ³)	1.004	1.008

Table 1: Correction factor k_V for ionization chamber measurements in a 4 cm x 4 cm field, for 6 MV and 15 MV. Data is taken from Table 3 and equation (C.11) in [DIN 6809-8].

In order to determine the correction factor $k_{Q,R}$ the radiation quality index Q must be known. Q can be obtained by depth dose measurements in a 10 cm x 10 cm field at depths of 10 cm and 20 cm according to the following equation [DIN 6800-2]:

$$Q = 1.2661 \cdot \frac{M(20)}{M(10)} - 0.0595 \quad (3-2)$$

where

Q radiation quality index
 $M(10), M(20)$ dose values at 10 cm and 20 cm depth, respectively. Source-to-surface distance 100 cm, field size at the phantom surface 10 cm x 10 cm.

If a field size of 10 cm x 10 cm cannot be adjusted for the determination of the quality index Q , the quality index is determined by [DIN 6809-8]:

$$Q = \frac{TPR_{20,10}(s) - b_1 - A_1 \left(1 - e^{-\frac{s}{t}}\right)}{b_2 + A_2 \left(1 - e^{-\frac{s}{t}}\right)} \quad (3-3)$$

where

$TPR_{20,10}$ Tissue phantom ratio $M(20)/M(10)$ at 100 cm source-to-detector distance
 s field dimension in one direction, in cm
 $t = 19.5$ cm
 $A_1 = 0.625$
 $A_2 = -0.679$
 $b_1 = -0.208$
 $b_2 = 1.213$

Equation (3-3) is valid for $0.62 < Q < 0.8$ and field dimensions $s \geq 0.4$ cm. For circular fields the field dimension s can be taken as $s = 0.9 \cdot d$, where d is the diameter of the circular field.

Hint: DIN 6800-2 offers an iteration process to increase the accuracy of equation (3-3). However, the increase of accuracy is smaller than the uncertainties of the parameters in equation (3-3). Therefore, an iteration process is not suggested in this document.

The correction factor $k_{Q,R}$ is taken from [DIN 6800-2]. Note that the notation in DIN 6800-2 is k_Q .

In a 4 cm x 4 cm field, the correction factor $k_{NR,Q}$ can be set to 1.000 for both beams with and without flattening filter.

3.3 Step 2: Cross-calibration of a “small field detector” in a 4 cm x 4 cm field

Detectors with high spatial resolution (“small field detectors”) are calibrated in a 4 cm x 4 cm field for which the dose has been determined with a calibrated ionization chamber as described in chapter 3.2. If M is the corrected reading of the small field detector (see chapter 2.4) and D_W the dose measured with the calibrated ionization chamber, the calibration factor for the small field detector N_{CC} is

$$N_{CC} = D_W / M \quad (3-4)$$

This calibration factor is valid for the radiation quality and the measuring depth used for the cross-calibration, and for a field size of 4 cm x 4 cm. Deviations from these calibration conditions are accounted for by applying correction factors to the reading as described in chapter 3.4.

Hint: If PinPoint chambers are used as small field detectors, and if a calibration factor at ^{60}Co as well as $k_{Q,R}$ factors are known, a cross calibration may not be necessary down to a field size of 1.5 cm x 1.5 cm.

3.4 Step 3: Measurements with “small field detectors” at field sizes $\leq 4 \text{ cm} \times 4 \text{ cm}$

The absorbed dose to water, measured with a detector of high spatial resolution (“small field detector”), is determined by

$$D_W = k_{NK} \cdot k_V \cdot N_{CC} \cdot M \quad (3-5)$$

where

- D_W absorbed dose to water
- k_{NK} correction factor accounting for variation of detector response when changing the field size from 4 cm x 4 cm to smaller fields, see Tables 2a and 2b
- k_V correction factor for the size of the small field detector, causing a volume effect in small fields, see Tables 3a and 3b
- N_{CC} calibration factor for the small field detector under cross-calibration conditions, see chapter 3.3
- M corrected reading of the dosimeter as described in chapter 2.4

Hint: Due to their size Semiflex chambers with a volume of 0.3 cm³ or 0.125 cm³ are not recommended for dosimetry at field sizes smaller than 4 cm x 4 cm.

PTW detector type	$s = 2.5 \text{ cm}$	$s = 4 \text{ cm}$	$s = 5 \text{ cm}$
Semiflex 31010 (0.125 cm ³)	1.007	1.000	1.007
PinPoint 31014 (0.015 cm ³)	1.006	1.000	1.007
PinPoint 3D 31016 (0.016 cm ³)	1.005	1.000	1.006
Dosimetry Diode P 60016	1.002	1.000	1.003
Dosimetry Diode 60017/60018 (PTW)	1.001	1.000	0.998
Dosimetry Diode 60017/60018 (MC)	1.006	1.000	1.003
Diamond Detector 60003	1.000	1.000	1.000
microDiamond 60019	1.000	1.000	1.000

Table 2a: Correction factor k_{NK} for measurements in the center of small fields at 10 cm depth. The field dimensions are designated by s , the radiation quality is 6 MV photons. Data is taken from Table E.1 in [DIN 6809-8]. All values are based on Monte Carlo simulations with the exception of the line labeled (PTW). The values for the diamond detectors are preliminary as no measurements or simulations have been published so far.

PTW detector type	$s = 2.5 \text{ cm}$	$s = 4 \text{ cm}$	$s = 5 \text{ cm}$
Semiflex 31010 (0.125 cm ³)	1.006	1.000	0.996
PinPoint 31014 (0.015 cm ³)	1.003	1.000	0.996
PinPoint 3D 31016 (0.016 cm ³)	1.003	1.000	0.995
Dosimetry Diode P 60016	1.002	1.000	0.991
Dosimetry Diode 60017/60018 (PTW)	1.000	1.000	0.997
Dosimetry Diode 60017/60018 (MC)	1.003	1.000	0.991
Diamond Detector 60003	1.000	1.000	1.000
microdiamond 60019	1.000	1.000	1.000

Table 2b: Correction factor k_{NK} for measurements in the center of small fields at 20 cm depth. The field dimensions are designated by s , the radiation quality is 6 MV photons. Data is taken from Table E.2 in [DIN 6809-8]. All values are based on Monte Carlo simulations with the exception of the lined labeled (PTW). The values for the diamond detectors are preliminary as no measurements or simulations have been published so far.

PTW detector type	$s = 1 \text{ cm}$	$s = 2 \text{ cm}$	$s = 3 \text{ cm}$	$s = 4 \text{ cm}$
Semiflex 31013 (0.3 cm ³)	1.570	1.067	1.012	1.004
PinPoint	1.076	1.007	1.001	1.000

Table 3a: Correction factor k_V for 6 MV photons as a function of field dimension s . Data is taken from Figure C.3 in [DIN 6809-8].

PTW detector type	$s = 1 \text{ cm}$	$s = 2 \text{ cm}$	$s = 3 \text{ cm}$	$s = 4 \text{ cm}$
Semiflex 31013 (0.3 cm ³)	1.543	1.091	1.023	1.008
PinPoint	1.075	1.009	1.002	1.001

Table 3b: Correction factor k_V for 15 MV photons as a function of field dimension s . Data is taken from Figure C.3 in [DIN 6809-8].

References

- [DIN 6800-2] DIN 6800-2, Deutsche Norm, Dosismessverfahren nach der Sondenmethode für Photonen- und Elektronenstrahlung, Teil 2: Dosimetrie hochenergetischer Photonen- und Elektronenstrahlung mit Ionisationskammern, März 2008
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