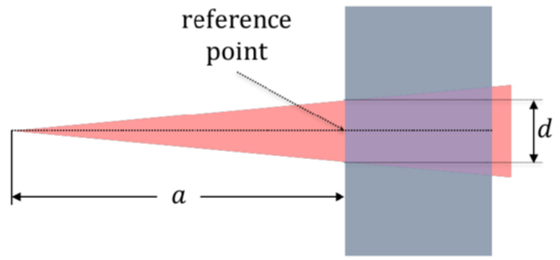
Determination of chamber geometry correction factors for phantom-based absorbed dose determination in external therapeutic low-energy kV x-ray beams

L. BÜERMANN and S. KETELHUT, Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany

JULY 12–16 2020 VIRTUAL
JOINT AAPM | COMP MEETING
EASTERN TIME [GMT-4]

INTRODUCTION

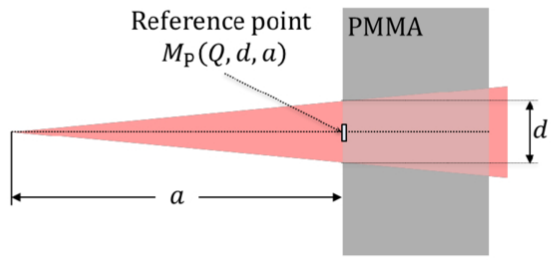
The absorbed dose to water, D_w, at the surface of a water phantom is the reference dose quantity needed in therapeutic low-energy kV-x-ray beams (10 kV – 100 kV). D_w depends on the radiation quality Q, source to surface distance a, and field size d.



There is no direct primary standard for D_w in this energy range. Therefore, D_w is obtained from an air kerma measurement free-in-air:

$$D_\mathrm{w}(Q,d,a) = K_\mathrm{air}(Q,d,a)\ (\mu_\mathrm{en}/\rho)_\mathrm{w,air}(Q,d,a)\ B_\mathrm{w}(Q,d,a) \qquad (1)$$

The air kerma K_air is measured with a free air chamber, mean values of the water to air ratio of the mass-energy absorption coefficients $(\mu_\mathrm{en}/\rho)_\mathrm{w,air}$ and water backscatter factors B_w are calculated.



Plane parallel ionization chambers mounted on the surface of a PMMA phantom, are calibrated in terms of D_w. Dividing both sides of equation (1) by the chamber reading $M_\mathrm{P}(Q,d,a)$ yields:

$$N^\mathrm{P}_{D,\mathrm{w}}(Q,d,a) = N^\mathrm{P}_K(Q,d,a)\ (\mu_\mathrm{en}/\rho)_\mathrm{w,air}(Q,d,a)\ B_\mathrm{w}(Q,d,a) \qquad (2)$$

N^P_K is the air kerma calibration factor of the chamber and PMMA phantom assembly.

Calibrations are performed at reference conditions a_0 = 30 cm and beam size d_0 = 3 cm. However, the user needs the calibration factor for clinical beam conditions *(a,d)* which is obtained by the chamber type specific geometry correction factor:

$$k^\mathrm{P}_\mathrm{g,type}(Q,d,a) = \frac{N^\mathrm{P}_{D,\mathrm{w}}(Q,d,a)}{N^\mathrm{P}_{D,\mathrm{w}}(Q,d_0,a_0)} = \frac{N^\mathrm{P}_K(Q,d,a)*(\mu_\mathrm{en}/\rho)_\mathrm{w,air}(Q,d,a)*B_\mathrm{w}(Q,d,a)}{N^\mathrm{P}_K(Q,d_0,a_0)*(\mu_\mathrm{en}/\rho)_\mathrm{w,air}(Q,d_0,a_0)*B_\mathrm{w}(Q,d_0,a_0)} \qquad (3)$$

AIM

To determine values of k_g for the chamber types PTW 23342 and PTW 23344 and provide them for the updated IAEA TRS 398 [1] international code of practice.

METHODS AND MATERIALS

$(\mu_\mathrm{en}/\rho)_\mathrm{w,air}$ is nearly independent of *a* and *d* and cancels in eq. (3). Therefore, the geometry correction factor is obtained from the remaining two ratios in eq. (3):

$\frac{B_\mathrm{w}(Q,d,a)}{B_\mathrm{w}(Q,d_0,a_0)}$ Data obatined from Andreo 2019 [2])

$\frac{N^\mathrm{P}_K(Q,d,a)}{N^\mathrm{P}_K(Q,d_0,a_0)}$ Data obtained from measurements at a_0 = 30 cm and d = 3, 5 and 10 cm. Comprehensive data set obtained from Monte Carlo simulations using EGSnrc [2] for *a* = 20, 30 and 50 cm, and *d* = 2, 3, 5, 8, 10, 15 and 20 cm.

Physical interpretation of k_g: If the chamber reading when mounted on the PMMA phantom would exactly be proportional to the variation of the backscatter factor of water then the geometry factor would be equal to 1.

Measurements: Ionization chambers: PTW M23342 (SN 592,2565,2878) and PTW M23344 (SN 1058, 1059) X-ray facility: Comet MXR160/0.4-3.0, W-anode angle 20°, 1 mm Be inherent filtration. Radiation qualities: PTB TW-series 10 kV – 100 kV, HVL range 0.03 – 4.41 mm Al. Photon fluence spectra measured with a high-purity Germanium detector.

PTW 23342 plane parallel ionization chamber mounted at the centre of a PMMA phantom. The entrance window of the chamber is flush with the phantom surface. The phantom dimensions are 13 x 13 x 8 cm³.

PTW 23342:
Nominal volume 0.02 cm³
Entrance window: 0.03 PE
Housing:
PMMA box, 61 x 22 x 14.4 mm³

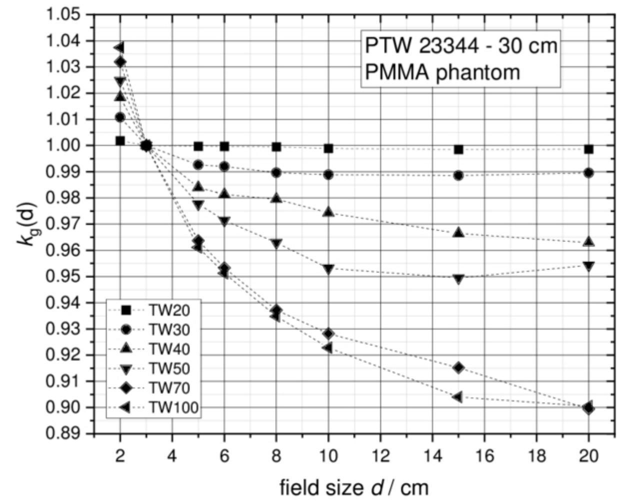
PTW 23344:
Nominal volume 0.2 cm³
Entrance window: 0.03 PE
Housing:
PMMA box, 61 x 30 x 14.4 mm³

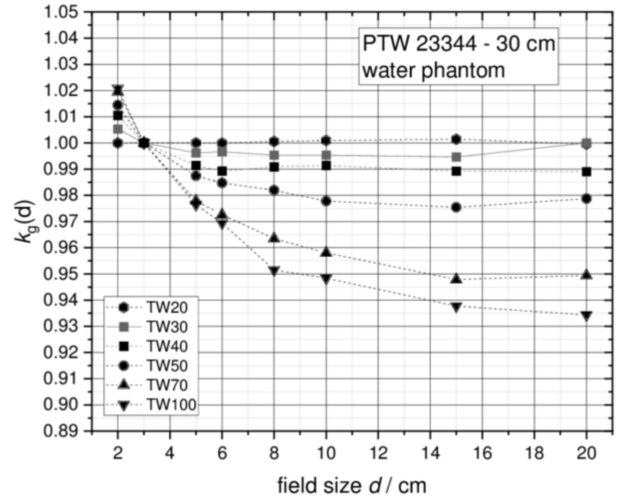
Monte Carlo simulations: The egs_chamber code of the EGSnrc code system [3] was used to calculate the deposited energy in the sensitive air cavity of the chamber. The geometry of the chambers were taken from technical drawings in the PTW catalogue. Essentially, the simulation geometry is simply an air cavity in a PMMA box as shown in the above figures. Simulations were done with the chambers mounted in a PMMA or water phantom of dimensions 20 x 20 x 10 cm³. Transport parameters: ECUT= 0.512, PCUT= 0.001, all relevant transport options were set to "on". The source was simulated as a point source with source surface distances of 20 cm, 30 cm and 50 cm.

CONTACT INFORMATION

ludwig.bueermann@ptb.de

RESULTS





Geometry correction factors calculated for the plane parallel chamber PTW M23344 as a function of the beam diameter d ranging from 2 cm to 20 cm. The left and right diagrams refer to the chamber mounted on a PMMA and water phantom, respectively. The correction factors for the chamber when used on a water phantom are significantly closer but not equal to 1.The latter result is expected for an air cavity in a water phantom. However, the relatively large chamber housing consists of PMMA and contributes significantly to the scattering of photons into the sensitive volume (air cavity) which causes the geometry correction factor to deviate from 1.

The relative standard uncertainty of the calculated backscatter ratios was estimated at about 1 %. The measured ratios of calibrations coefficients at different field sizes have a relative uncertainty of less than 0.5 %. Thus, the measured values of the geometry correction factor was estimated at 1.1 %. The relative statistical uncertainty of the Monte Carlo calculated chamber cavity dose was always less than 0.5 %. Thus, the uncertainty of the calculated geometry correction factor is 1.2 %. Measured and calculated geometry correction factors deviated by no more than 1%. It is concluded that the more comprehensive calculated data set can be recommended for use in the updated international dosimetry protocoll IAEA TRS398.

CONCLUSIONS

A comprehensive set of validated geometry correction factors for the chamber types PTW 23342 and 23344 is provided for the updated IAEA TRS 398 code of practice for low energy kilovoltage x-ray beams.

REFERENCES

[1] International Atomic Energy Agency 2001 Absorbed dose determination in external beam radiotherapy: an international code of practice for dosimetry based on standards of absorbed dose to water Techincal Report Series 398 (Vienna: IAEA)
[2] Pedro Andreo 2019: Data for the dosimetry of low- and medium-energy kV x rays, Phys. Med. Biol. 64 205019[3]
[3] Kawrakow I, Mainegra-Hing E, Rogers D W O, Tessier F and Walters B R B 2017 The EGSnrc code system: Monte Carlo simulation of electron and photon transport Technical Report PIRS-701 (Ottawa: National Research Council Canada) (http://nrc-cnrc.github.io/EGSnrc/doc/pirs701-egsnrc.pdf)