Monte Carlo and water calorimetric determination of ionization chamber correction factors for medium energy x-ray beams

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INTRODUCTION

The clinical reference dosimetry of medium energy radiotherapy x-ray beams is based on the measurement of the absorbed dose to water at a depth of 2 cm in a water phantom, $D_{w,z=2cm}$ (IAEA; 2001, Ma et al.; 2001).

An overall ionization chamber correction factor, $P_{Q,cham}$, is required which accounts for changes in the chamber response due to:

1. the displacement of water by the chamber cavity and wall.
2. the presence of the stem.
3. the change in incident photon energy and angular distribution in the phantom to that in air.

AIM

The main aim of this work is to determine new kilovoltage beam chamber correction factors through Monte Carlo simulations and water calorimetry measurements. A planned update to the IAEA TRS-398 protocol will aim to include these new factors

This work is driven by the need to update previously published data sets for overall chamber correction factors.

1. The MC codes used in these studies (EGS4) are now out of date in comparison to modern MC codes such as EGSnrc.
2. The publication of the ICRU Report 90 (Seltzer et. al.; 2016) which provides updated electron and photon interaction data.
3. Recent developments in kilovoltage beam absorbed dose to water primary standards. Of note is the PTB water calorimetry-based absorbed dose to water primary standard.

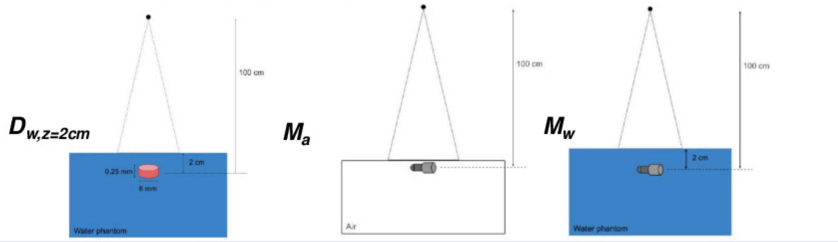
METHOD

The product of the overall chamber correction factor, $P_{Q,cham}$, and the waterproof sheath correction factor (if the chamber requires one), P_{sheath}, is extracted through the following:

$$P_{Q,\mathrm{cham}}P_{\mathrm{sheath}} = \frac{\left(\frac{D_{w,z=2\mathrm{cm}}}{K_a}\right)\left(\frac{M_a}{M_w}\right)}{\left[\left(\frac{\mu_{en}}{\rho}\right)_{w,a}\right]_{w,Q,z=2\mathrm{cm}}} \quad (1)$$

where M_w and M_a are the corrected ionization chamber readings at a depth 2 cm in the phantom and free in air, respectively. The air kerma is denoted as K_a.

Each component in (1) was calculated with the EGSnrc radiation transport toolkit. Measured beam spectra, supplied by PTB were used in the simulations.



RESULTS

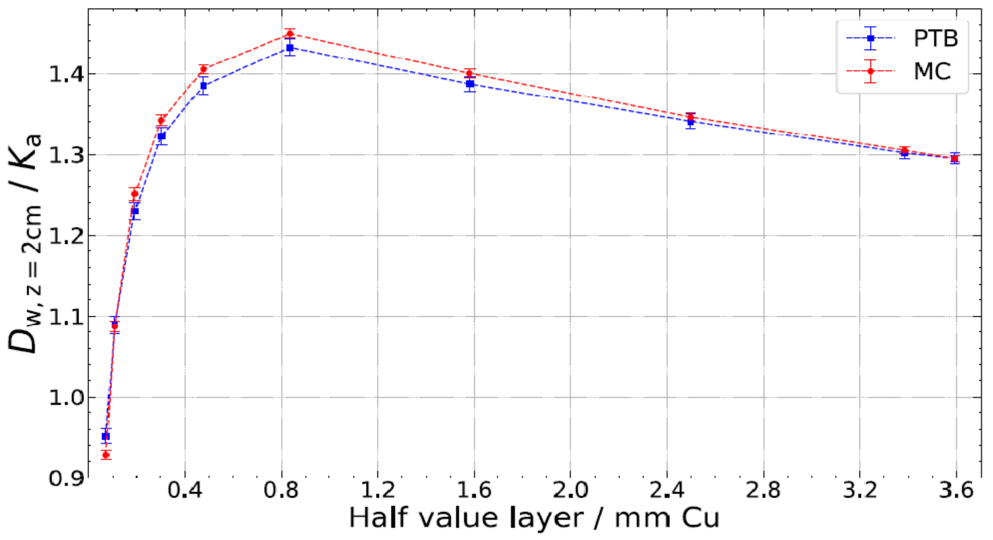
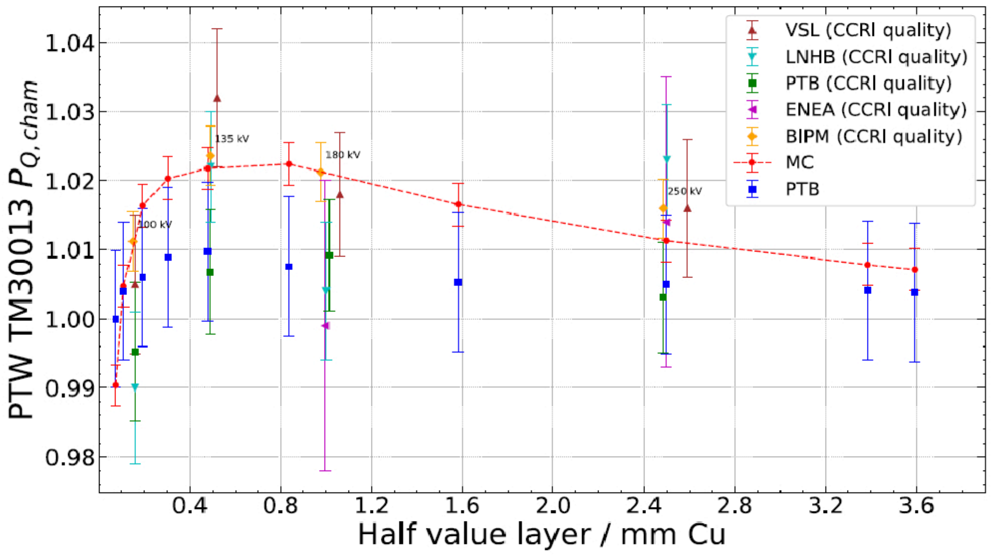
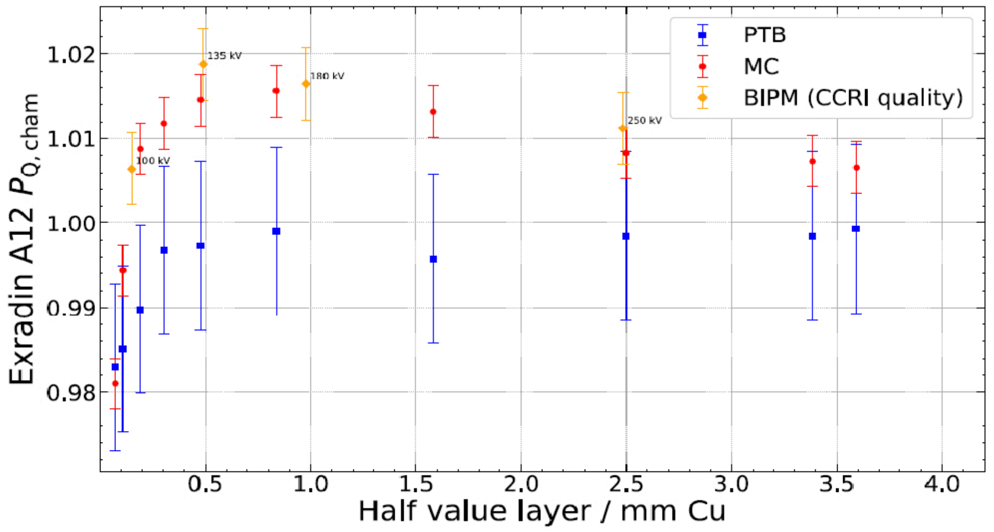


FIGURE 1

Monte Carlo (MC) simulations results for $D_{w,z=2cm}/K_a$, the ratio of the absorbed dose to water at a depth of 2 cm and air kerma. These values are compared to experimental values obtained at PTB with their water calorimetry-based absorbed dose to water primary standard and free air chamber-based air kerma primary standard.

The standard uncertainty on the simulated values varies from 0.6% to 0.3%. This uncertainty takes into account field size, beam spectrum and photon cross sections. The standard uncertainty on the experimental values varies from 1% to 0.5%.





FIGURES 2 & 3

The overall chamber correction factor, $P_{Q,cham}$, for the PTW TM30013 and Exradin A12 chamber. The overall chamber correction factors determined by several national metrological institutes (NMIs) are included (Büermann; 2016, Burns; 2018). It should be noted that some NMIs used the CCRI beam qualities which are different to those used in the MC simulations (PTB TH series).

PTB, VSL and LNE-LNHB used water calorimetry-based absorbed dose to water primary standards while the ENEA-INMRI used a graphite calorimetry-based primary standard. The BIPM standard is based on a pre-existing air kerma standard and MC calculations.

The standard uncertainty on the MC calculated factors is 0.3%. The standard uncertainties on the NMI values are on the order of 1%, except for the ENEA-INMRI and BIPM where the standard uncertainty is 2.1% and 0.42%, respectively.

The uncertainty on the simulated values takes into account the field size, beam spectrum, photon cross sections and the chamber wall and central electrode dimensions.

The correction factors obtained at the BIPM with their kilovoltage beam primary standard are consistent with those calculated in this study.

CONCLUSIONS

The aim of this study was to determine radiotherapy kilovoltage beam ionization chamber correction factors through MC simulations and water calorimetry measurements.

A discrepancy at the $k = 1$ level can be seen in figure 1 for the certain beam qualities.

The ratio of the MC chamber simulations and the chamber measurements carried out at PTB are close to unity (within the standard uncertainties). This demonstrates the accuracy of the chamber MC simulations with respect to the chamber measurements and that the discrepancy between the calculated and measured correction factors in figures 2 and 3 are due to the discrepancies between the calculated and measured $D_{w,z=2cm}/K_a$ values.

Due to these discrepancies, a re-evaluation of the water calorimeter measurements and uncertainties may be carried out.

At this time, no recommendations are being made as to which set of values to use.

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