POLARITY AND ION RECOMBINATION CORRECTION FACTORS OF A THIMBLE TYPE IONIZATION CHAMBER WITH DEPTH IN WATER IN THE MEGAVOLTAGE BEAMS

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When the PDD (percentage depth dose) in the megavoltage beams is measured in the water phantom, the polarity and ion recombination effects of ionization chambers with depth in water are not usually taken into consideration. We try to investigate if those variations with depth should be taken into consideration or could be ignored for the thimble type semi-flex ionization chamber (PTW 31010™, SN 1551). According to the recommendation of IAEA TRS-398, the 4 representative depths of d_s, $d_{\max}$, d_{90} and d_{50} were used for the electron beams. For the photon beams, the 4 depths were arbitrarily chosen for the photon beams, which were d_s, $d_{\max}$, d_{10} and d_{20}. For the high energy photon beam both polarity and ion recombination factors of the chamber with depth in water gives the good agreements within the maximum ±0.2%, while the C_{pol}s with depth came within the maximum ± 0.4% and the C_{IR}s within the maximum ±0.6% in every electron beam used. This study shows that PDI (percentage depth ionization) could be a good approximation to PDD for the chamber used.

Keywords : Polarity Effect, Ion Recombination Effects, Ion Chamber, PDD, PDI

I. INTRODUCTION

When the PDD (percentage depth dose) in the megavoltage beams is measured in the water phantom using the dosimetry system, the polarity and ion recombination effects of ionization chambers with depth in water are not usually taken into consideration. The polarity and ion recombination effects may vary depending on the radiation type and spectrum, which vary with depth in water [1-4]. If those effects with depth could be ignored, the PDI (percentage depth ionization) curve could be a good approximation to the PDD curve, while those effects, if not, should be applied to every depth for the correction of the PDI curve.

For most chamber types the polarity effect will be negligible in photon beams, while the effect may be significant in charged particles, particularly electrons. For plane-parallel chambers the polarity effect is usually more pronounced in low energy electron beams. However, for certain chamber types it has been shown that the polarity effect increases with energy [4]. For this reason the polarity effect should always be investigated at all electron energies. The polarity effects of ionization chambers are relatively more prominent in the electron beam than in the photon beam. Moreover, this effect increases with the lower energies of electron beams and therefore this effect should be determined at various depths in water especially in the electron beams.

In electron beams, the PDD should be measured to determine R_{50}, the half-value depth in water, used as the beam quality index for electron beams. Ion recombination and polarity corrections are required at all depth. Instead

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of measuring at all depth, IAEA TRS-398 Code of Practice recommends to use the four representative depths which are near the surface, the ionization maximum and the depth corresponding to 90% and 50% of the ionization maximum [5].

The commercial dosimetry systems have the software which converts the PDI curve into the PDD one but the software doesn't take into consideration the polarity and ion recombination effects with depth in water. It is usually assumed that the variations of those effects with depth wouldn't be too large to be considered and so could be ignored. The commercial dosimetry systems are commonly accompanied by the small volume of a pair of cylindrical chambers, the reference chamber and the field chamber, for the routine measurement of the beam data such as PDDs and Profiles. Even if the software includes the data of the polarity and ion recombination effects of the field chamber, users can replace the chamber with any another chambers according to the situations given.

In this study the variations of the polarity and ion recombination effects with depth in water for the semiflex ion chamber commonly used as the reference chamber for the beam data analysis will be investigated for the high energy photon beam and several electron beams. We try to investigate if those variations with depth should be taken into consideration or could be ignored in the calculation of the PDDs.

2. THEORY AND METHODS

2.1 The Percentage Depth Dose Curve *PDD* from the Depth Ionization Curve *PDI*

When a detector is inserted into water at any depth to measure the absorbed dose to water at the same depth, the absorbed dose to water D_w is related to the charge collected in the cavity volume of the detector and the stopping power ratio of water and air according to Brag-Gray cavity theory [6].

$$D_w = \frac{Q}{m}\left(\frac{W}{e}\right)_{air}\left(\frac{S}{\rho}\right)_{air}^{w} \tag{1}$$

The *PDD*(percentage depth dose) is defined as the ratio of the absorbed dose to water at any depth d to the absorbed dose to water at the depth of maximum dose $d_{\max}$ at an *SSD* of 100cm

$$PDD \equiv \frac{D(d)}{D(d_{\max})} \tag{2}$$

Substituting the formula (1) into the formula (2) gives the equation for *PDD* in terms of *PDI* (depth ionization curve) and stopping power ratio.

$$PDD = \frac{\left[\frac{Q_d}{m}\left(\frac{W}{e}\right)_{air}\left(\left(\frac{S}{\rho}\right)_{air}^{w}\right)_d\right]}{\left[\frac{Q_{\max}}{m}\left(\frac{W}{e}\right)\left(\left(\frac{S}{\rho}\right)_{air}^{w}\right)_{d_{\max}}\right]} = \frac{Q_d}{Q_{\max}}\frac{\left(\left(\frac{S}{\rho}\right)_{air}^{w}\right)_d}{\left(\left(\frac{S}{\rho}\right)_{air}^{W}\right)_{d_{\max}}} = PDI\frac{\left(\left(\frac{S}{\rho}\right)_{air}^{w}\right)_d}{\left(\left(\frac{S}{\rho}\right)_{air}^{w}\right)_{d_{\max}}} \tag{3}$$

The percentage depth ionization *PDI* in the equation (3) is defined as the ratio of the charge at any depth to the charge at the maximum depth.

$$PDI = \frac{Q(d)}{Q(d_{\max})} \tag{4}$$

The charge in the equation (4) is the one corrected for the influence quantities such as temperature, air pressure, polarity effects and ion recombination effects. The equation (4) is then rewritten including those influence quantities.

$$PDI = \frac{Q_d}{Q_{d_{\max}}} = \frac{\left(Q_0 C_{TP} C_{pol} C_{IR}\right)_d}{\left(Q_0 C_{TP} C_{pol} C_{IR}\right)_{d_{\max}}} \tag{5}$$

where Q_0 is the uncorrected charge reading, C_{TP} the temperature and pressure correction factor, C_{pol} the polarity correction factor, and C_{IR} the ion recombination correction factor. Since measurements are performed over a short period of time and C_{TP} is irrelevant to depth, air temperature and pressure corrections with depth need not be made and the equation (5) is now reduced to

$$PDI = \frac{\left(Q_0 C_{pol} C_{IR}\right)_d}{\left(Q_0 C_{pol} C_{IR}\right)_{d_{\max}}} \tag{6}$$

In the protocol of AAPM TG-51 measurements of depth ionization curves ignore any variations in C_{pol} and C_{IR} with depth and for electron beams they also ignore variations in the electron fluence correction factor [7]. Since well-guarded plane-parallel chambers minimize these variations, they are preferred for measuring electron beam depth ionization curves. In the Code of Practice IAEA TRS-398 for the photon beam variations of C_{pol} and C_{IR} are treated negligibly with depth and for the electron beam.

Ion recombination and polarity corrections are required at all depths. These may be derived from a reduced set of representative measurements, for example near the surface, the ionization maximum and depths corresponding to 90% and 50% of the ionization maximum.

The thimble type chambers of about 0.1 cm^3 volume are usually used in the commercial dosimetry systems to measure the beam data such as *PDD* and the variations of C_{pol} and C_{IR} with depth in water are negligible and ignored both for the megavoltage beams. The *PDD* is in this case approximated to the ratio of the charge at any depth to the one at the maximum depth.

$$PDD \cong PDI_{app} = \frac{Q_0(d)}{Q_0(d_{max})} \tag{7}$$

If the variations of C_{pol} and C_{IR} with depth be negligible, the equation (7) will be a good approximation. However, if C_{pol} and C_{IR} shows the physically meaningful difference with depth, the equation (6) should be used to determine the *PDD*.

2.2 The Correction of the Polarity and Ion Recombination Effects

When a chamber is used in a beam that produces a measurable polarity effect, the true reading is taken to be the mean values of the absolute values of readings taken at both polarities.

$$C_{pol} = \frac{|M_+| + |M_-|}{2M} \tag{8}$$

where M is the electrometer reading obtained with the polarity adopted for the routine use of the chamber and so used to calibrate the chamber in the standards laboratories.

Two voltage techniques (V_1/V_2) are usually used to determine ion recombination correction C_{IR}, where V_1 is equal to $2V_2$.

$$C_{IR} = a_0 + a_1\left(\frac{M_1}{M_2}\right) + a_2\left(\frac{M_1}{M_2}\right)^2 \tag{9}$$

Where constants a_0= 2.337, a_1=3.636, and a_2= 2.299 are used for pulsed beams when the voltage V_1 is half the voltage V_2.

2.3 Experimental Setup

The MP3 system, Therapy Beam Analyzer of PTW FREIBURG, provides with a pair of semiflex ionization chambers with measuring volume of 0.125 cm^3 and the inner radius of 0.3 cm for the analysis of the therapy beams such as PDD(the percentage depth dose) and Profiles. Fig. 1 shows the semiflex chamber (PTW 31010™, SN 1551) and the electrometer PTW UNIDOS (SN 10001) used. The certificate of the chamber says that it has the polarity effect less than 1.0% at the ^{60}Co beam. The chamber was irradiated by the linear accelerator (SIEMENS ONCOR) to evaluate the polarity and ion recombination effects of the chamber.

According to the recommendation of IAEA TRS-398, the 4 representative depths of d_s (near the surface), d_{max} (the ionization maximum), d_{90} (the depth corresponding to 90% of the ionization maximum), and d_{50} (the depth corresponding to 50% of the ionization maximum) were used for the electron beams. For the photon beams, however, there are no recommendations for such depths. In this work, the 4 depths were arbitrarily chosen for the photon beams, which were d_s (near the surface), d_{max} (the ionization maximum), d_{10} (10 cm from the surface), and d_{20} (20 cm from the surface).

Fig. 2 shows the setup of those depths for both photon and electron beams. The depths used, the beams used, and the conditions of measurements are listed in Table 1. ***SSD*** (the source to surface distance) was taken to be **100 cm** both in the photon and electron beam. The **10 × 10 cm^2** for the photon beam and the **10 × 10 cm^2** Cone for the electron beam were used as the field sizes in this work, which are the reference field size in the calibration of the beams.

The **0.5 cm** were given same to all $\boldsymbol{d_s}$s, the depth near the surface, while the other 3 depths ($\boldsymbol{d_{max}}$, $\boldsymbol{d_{90}}$, and $\boldsymbol{d_{50}}$) in

(a) Semiflex ionization chamber

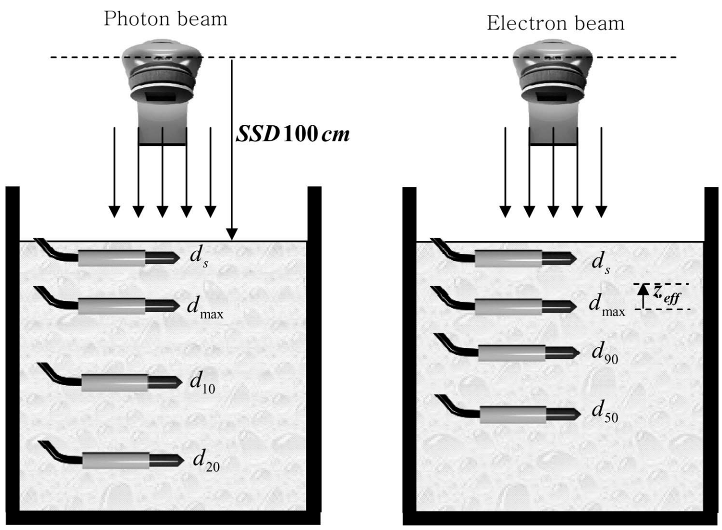
(b) UNIDOS electrometer

Fig. 1. The electrometer and ionization chamber used in this work.

Table 1. The beams used and the conditions of measurements. These beams were generated from the linear accelerator (SIEMENS ONCOR).

Beam Type	Photon beam	Electron beam		
Nominal energy	6 MV	6 MeV	12 MeV	18 MeV
Beam quality* (R_{50}[cm])	$TMR_{10}^{20} = 0.672$	$R_{50} = 2.25$	$R_{50} = 4.63$	$R_{50} = 7.32$
Depth of measurements [cm]	$d_s = 0.5$	$d_s = 0.5$	$d_s = 0.5$	$d_s = 0.5$
	$d_{\max} = 1.6$	$d_{\max} = 1.2$	$d_{\max} = 2.50$	$d_{\max} = 2.25$
	$d_{10} = 10.0$	$d_{90} = 1.66$	$d_{90} = 3.57$	$d_{90} = 5.40$
	$d_{20} = 20.0$	$d_{50} = 2.25$	$d_{50} = 4.63$	$d_{50} = 7.32$
Field Size	10cm × 10cm	10cm × 10cm	10cm × 10cm	10cm × 10cm
SSD [cm]†	100.0	100.0	100.0	100.0

* $\boldsymbol{R_{50}}$ and $\boldsymbol{TMR_{10}^{20}}$ are the indices of the beam quality commonly used in the Code of Practice(or Protocol) based on the absorbed dose to water calibration factor.
† ***SSD*** represents the distance from the source to the water surface.



(a) Photon beam (b) Electron beam

Fig. 2. Schematic drawing of the setup for experimental measurements. For the (a) photon beam the 4 depths of d_s, $d_{\max}$, d_{10}, and d_{20} were chosen, while for the (b) electron beam the 4 depths of d_s, $d_{\max}$, d_{90}, and d_{50} were used. The **0.5** $\boldsymbol{r_{cyl}}$ (the inner radius of the chamber) were used as the effective point of measurements $\boldsymbol{z_{eff}}$ in the electron beam and the **100 cm** was set up as the source to the surface distance ***SSD***.

the electron beams have different values depending on the beam qualities (given in the Table1). The effective point of measurements $\boldsymbol{z_{eff}}$ was not applied in the photon beam in consistency with the absorbed dose to water based protocols like IAEA TRS-398 where the effective point of measurements is not used for the photon beam calibrations, while **0.5** $\boldsymbol{r_{cyl}}$ (the inner radius of the chamber) were used as the effective point of measurements $\boldsymbol{z_{eff}}$ in the electron beams.

3. RESULTS AND DISCUSSION

The polarity and ion recombination effects were calculated using the equations (8) and (9), respectively. Five readings were taken with one polarizing voltage and the standard deviations of the readings with one setting of polarizing voltage was observed to be ±0.13%. Every reading of the charges were corrected for the temperature and air pressure to the reference temperature (**22 ºC**) and air pressure (**101.325** ***kPa***). The correction factor $\boldsymbol{C_{TP}}$ for the temperature and air pressure was calculated from the following equation.

$$C_{TP} = \frac{P_0}{P} \cdot \frac{(273.2 + T)}{295.2} \qquad (10)$$

where $\boldsymbol{P_0}$ represents the reference air pressure of **101.325**

Table 2. Polarity and ion recombination correction factors (C_{pol} and C_{IR}) of a semi-flex ionization chamber (PTW 31010™, SN 1551) with depth in water in the megavoltage beam with the uncertainty of ±0.13%.

Influence quantity	Depth	Photon beam	Electron beam		
		6 MV	12 MeV	6 MeV	18 MeV
C_{pol}	d_s	1.00485	1.00693	1.00724	1.00487
	d_{max}	1.00657	1.00907	1.00739	1.00552
	d_{90}	1.00612	1.01040	1.00637	1.00676
	d_{50}	1.00628	1.00707	1.00858	1.00965
C_{IR}	d_s	1.00434	1.01174	1.00297	1.00618
	d_{max}	1.00267	1.00554	1.00597	1.00833
	d_{90}	1.00353	1.00467	1.00727	1.00500
	d_{50}	1.00229	1.00326	1.00121	1.00720

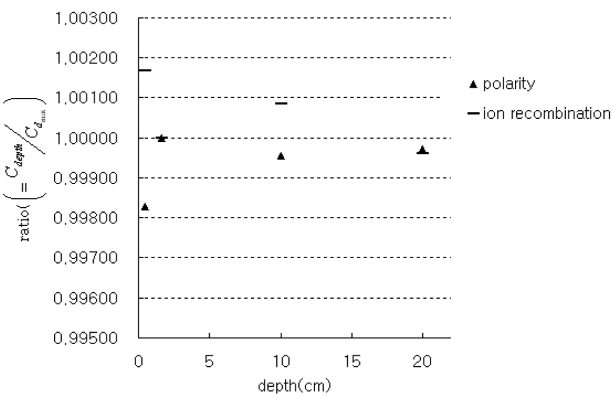


Fig. 3. Polarity and ion recombination effects of a semiflex chamber (PTW 31010™, SN 1551) with depth in water for the photon-6 MV beam. The correction factors on the y-axis are normalized to the factor at the d_{max}, the depth of the maximum dose because the PDDs are the quantities normalized to the maximum dose depth d_{max}.

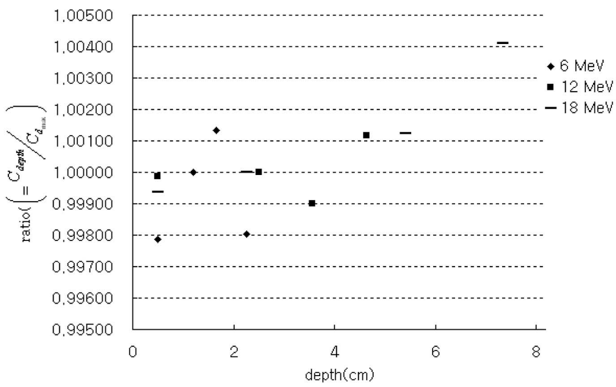


Fig. 4. Polarity effects of a semiflex chamber (PTW 31010™, SN 1551) with depth in water for the electron-6 MeV, 12 MeV, and 18 MeV beams. The correction factors on the y-axis are normalized to the factor at the d_{max}, the depth of the maximum dose because the PDDs are the quantities normalized to the maximum dose depth d_{max}.

kPa and ***P*** and ***T*** the air pressure of the room and the temperature of the water phantom, respectively.

The results of the polarity and ion recombination correction factors (C_{pol} and C_{IR}) of a semi-flex ionization chamber (PTW 31010™, SN 1551) are shown in Table 2 with depth in water in the nominal 6 MV photon beam and the electron beams with the nominal energies from 6 MeV to 18 MeV.

Fig. 3 shows the polarity and ion recombination correction factors of the semiflex chamber normalized to the factor at the d_{max}, the depth of the maximum dose, with depth in water for the nominal potential 6 MV photon beam. For the megavoltage photon beam both polarity and ion recombination factors of the chamber with depth in water gives the good agreements within the maximum ±0.2% compared with those at the maximum dose depth d_{max}.

In a Fig. 3 ratios near the surface are bigger than those at the other depths, which shows that it is a little bit more difficult to evaluate the factors within the buildup region. The ratios near the surface are, however, are not too big to affect the correction of the PDI curves. It's reasonable to expect that the same trends observed here will appear in the other photon energy beams. So there will be no need of giving the corrections of the polarity effects C_{pol} and ion recombination effects C_{IR} with depth in water to the PDI curve in the high energy photon beams for the cylindrical types of chambers. That is to say, the equation (7) can be thought to be a good approximation for the evaluation of the PDD curve.

Fig. 4 shows the polarity effects C_{pol} and Fig. 5 shows the ion recombination effects C_{IR} of the same chamber with depth in water for the electron-6 MeV, 12 MeV, and 18 MeV beams. The correction factors on the y-axis are normalized to the factor at the $\boldsymbol{d_{max}}$, the depth of the maximum dose. The variations of the C_{pol} with depth in water came within the maximum ± 0.4% and those of the C_{IR} within the

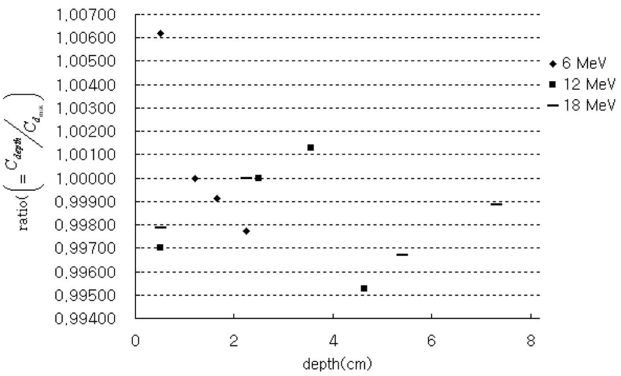


Fig. 5. Ion recombination effects of a semiflex chamber (PTW 31010™, SN 1551) with depth in water for the electron-6 MeV, 12 MeV, and 18 MeV beams. The correction factors on the y-axis are normalized to the factor at the d_{max}, the depth of the maximum dose because the PDDs are the quantities normalized to the maximum dose depth d_{max}.

maximum ± 0.6% in every electron beam used.

It demonstrates that much the same as the photon beam the chamber evaluated have a good performance for the analysis of the electron beam data without giving any corrections to the polarity effects C_{pol} and ion recombination effects C_{IR} with depth in water. From these observations it seems that the equation (7) can be thought to be a good approximation for the evaluation of the PDD curve even in the electron beams as well as the photon beams for cylindrical types of chambers like the semiflex chamber used in this work.

4. CONCLUSION

The results for the semiflex chamber used in this work say that the equation (7) be a good approximation for the evaluation of the PDD curve both in the megavoltage photon and electron beams. From these observations it can be guessed that any cylindrical types of ionization chambers can be used to evaluate the PDD curve without giving any corrections to the polarity effects C_{pol} and ion recombination effects C_{IR} with depth in water under the assumption that the chambers have such a normal performance as certified by the manufacturer.

Any (types of) chambers as well as the chambers routinely given as the reference chamber for the beam analysis by the manufacturer can be used for such a beam analysis as PDD curves. Moreover, the performance of chambers might vary from types to types and from chambers to chambers, which insists that the chambers should be checked before the use with regard to the possibility of the variations of both C_{pol} and C_{IR} with depth in water. We, in conclusion, recommend that every chamber should be checked ahead of the use for the beam analysis because the malfunction unexpected in the chamber might lead to the wrong analysis of the beam data.

In this study only a cylindrical type of an ionization chamber were evaluated but next time the same kind of observations will be performed on the plane parallel types of chambers.

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