A Thesis

entitled

An Investigation of the Polarity Effects in Small Field Based on the Orientation of the

Micro Ionization Chamber

by

Vidheesha Arora

Submitted to the Graduate Faculty as partial fulfillment of the requirements for the

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Biomedical Sciences: Medical Physics

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An Abstract of

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Purpose: Dosimetric quantities such as the polarity correction factor ($P_{pol}$) are important parameters for determining the absorbed dose and can influence the choice of dosimeter. $P_{pol}$ has been shown to depend on beam energy, chamber design, and field size. This study is to investigate the field size and detector orientation dependence of $P_{pol}$ in small fields for several commercially available micro-chambers.

Methods: We evaluated the Exradin A26, Exradin A16, PTW 31014, PTW 31016, and two prototype IBA CC-01 micro-chambers in both horizontal and vertical orientations. Measurements were taken at 10cm depth and 100cm SSD in a Wellhofer BluePhantom2. Measurements were made at square fields of 0.6, 0.8, 1.0, 1.2, 1.4, 2.0, 2.4, 3.0, and 5.0 cm on each side using 6 MV with both ± 300VDC biases. $P_{pol}$ was evaluated as described in TG-51, reported using -300VDC bias for $M_{raw}$. Ratios of $P_{pol}$ measured in the clinical field to the reference field are presented.

Results: A field size dependence of $P_{pol}$ was observed for all chambers, with increased variations when mounted vertically. The maximum variation observed in $P_{pol}$ over all chambers mounted horizontally was <1%, and occurred at different field sizes for
different chambers. Vertically mounted chambers demonstrated variations as large as 3.2%, always at the smallest field sizes.

**Conclusions:** Large variations in $P_{\text{pol}}$ were observed for vertically mounted chambers compared to horizontal mountings. Horizontal mountings demonstrated a complicated relationship between polarity variation and field size, probably relating to differing details in each chambers construction. Vertically mounted chambers consistently demonstrated the largest $P_{\text{pol}}$ variations for the smallest field sizes. Measurements obtained with a horizontal mounting appear to not need significant polarity corrections for relative measurements, while those obtained using a vertical mounting should be corrected for variations in $P_{\text{pol}}$. 
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List of Abbreviations

AAPM .................. American Association of Physicist in Medicine
DNA .................. Deoxyribonucleic acid
LCPE .................. Lateral charged particle equilibrium
IAEA .................. International Atomic Energy Agency
IMRT .................. Intensity modulated radiation therapy
PTV .................. Planning Target Volume
SRS .................. Stereotactic radiosurgery
SRT .................. Stereotactic radiotherapy
List of Symbols

$P_{pol}$ .......Polarity Correction Factor.
$M_{raw}$ ......Electrometer reading at negative polarity
$M^+_raw$ ....Electrometer reading at positive polarity
Chapter 1

Introduction

Radiation therapy makes use of high-energy radiation to kill cancer cells by damaging their DNA. There are different ways of treating cancer by using radiation, but the external photon beam irradiation technique is the most common method. Ionizing radiation not only harms cancer cells, but will also cause damage to healthy cells. Therefore, the radiation beam needs to be highly conformal around the planning target volume (PTV) to maximize the dose to the delineated target volume and minimize the dose to surrounding healthy tissue. Failure to do so will result in the patient receiving a radiation dose different from the prescribed dose. If the targeted cancer cells receive less than the prescribed dose, then the radiation therapy treatment may fail to control the cancer. On the other hand, if the delivered dose is greater than the prescribed dose, then there is an increased chance that the patient may develop radiation-induced complications. At present, treatment modalities like IMRT and SRS are increasingly being used in the
clinics all around the world. The improved local control and the reduced normal tissue dose associated with IMRT and SRS explains the extensive adoption of these techniques.

1.1 Intensity Modulated Radiation Therapy

Intensity modulated radiation therapy (IMRT) is a radiotherapy technique in which non-uniform intensity is delivered to the patient to optimize the composite dose distribution. This technique normally uses a number of smaller fields designed by the inverse plan to protect the normal tissue in the beam and often referred to as beamlets. During dose delivery, beamlets are shaped and controlled by the multileaf collimators of the linear accelerator. These beamlets are irradiated with non-uniform beam intensity levels, which implies different monitor units (MUs) are delivered with each beamlet to produce a modulated dose map. This dose map conforms tightly to the tumor shape. In small photon fields, determination of absorbed dose is a challenging task due to convergence of several dosimetric factors and several sources of error measurement. As such the finite size and type of detectors used for measurements become significantly important.

1.2 Stereotactic Radiosurgery/Radiotherapy

Stereotactic radiosurgery (SRS) is a radiotherapy procedure where multiple narrow beams are delivered in a single fraction using a combination of stereotactic apparatus and multiple isocentric arcs of coplanar or non-coplanar nature. If the dose is delivered across
multiple fractions it is known as stereotactic radiotherapy (SRT). This highly conformal therapy makes use of imaging and localization devices for the accurate delivery of the treatment. The most common field sizes used in SRS/SRT treatments are between 4-10 mm in diameter [21].

1.3 X-Ray interactions with the patient

X-rays produced by a linear accelerator are one of the most common sources of ionizing radiation used in radiation therapy. Electrons produced from an electron gun are accelerated along a waveguide. Upon exiting the waveguide, the electrons are focused by bending magnets onto a high-density tungsten target. The electrons interact in the target and produce Bremsstrahlung X-rays that are shaped to form a radiotherapy beam.

The different processes by which the radiation beam interacts with matter are Photoelectric, Compton and Pair Production. The type of interaction that a beam undergoes depends on the atomic number (Z) of the medium and the energy of the photon.
Fig 1.1: Graph showing the regions of relative predominance of the photoelectric effect, Compton effect and Pair Production [1].

Megavoltage energy photons that are used in radiotherapy will interact predominantly through Compton interactions. This occurs when a photon strikes an orbital electron with energy much greater than the binding energy of the incoming electron, causing it to be ejected from the atom. The ejected electron is highly energized and travels some distance through the tissue before losing all of its energy. Along its path, the electron deposits its energy via ionization and excitation of other orbital electrons. This deposited energy contributes to the absorbed dose (energy deposited per unit mass) to the patient. These electrons are capable of killing the cells either by direct or indirect interactions with the molecules in the DNA. Direct interactions take place when the electrons produced by the radiation beam directly ionize DNA molecules. Indirect interactions occur when the electrons ionize molecules within the tissue (e.g. water), which in turn produce, free
radicals. These free radicals are highly reactive and can subsequently interact with DNA molecules causing cell death.

1.4 Measuring X-ray Dose

The accurate determination of absorbed dose and dose distribution is crucial to the success of radiotherapy. There are many steps involved in the determination of absorbed dose (with units of J/kg or “Gray” (Gy)) in the patient. The dose delivered by a linear accelerator is calibrated through a process called absolute dosimetry. This is performed by using gas filled ionization chamber submerged in a water tank. The water is representative of a patient’s tissue and this process of dose measurement is known as dosimetry. The radiation causes ionization in the gas cavity of the ionization chamber; the ionization charge can then be collected and measured as a small current. The amount collected is proportional to the dose absorbed in the volume of the detector. Calibration dosimetry is usually performed under a single set of conditions (e.g. the radiation field is $10 \, \text{cm} \times 10 \, \text{cm}$, the depth of the detector in water is $10 \, \text{cm}$, and the distance from the X-ray target to the water surface is $100 \, \text{cm}$).

1.5 Bragg-Gray Cavity Theory

Absolute dosimetry of megavoltage photon beams using an ionization chamber is made possible by the use of the Bragg-Gray cavity theory. The theory states that the dose to
water can be calculated by measuring the dose to a small cavity of gas within the water and multiplying this value by the mass stopping power ratio of water to gas. Bragg-Gray cavity theory only works if the following conditions are satisfied: the range of the dose depositing electrons must be much greater than the cavity’s dimensions, charged particle equilibrium must exist, and the detector must not perturb the fluence of the dose depositing electrons.

Under standard measurement conditions for absolute dosimetry, the first two conditions mentioned above will be satisfied. However a gas cavity will always have a small effect on beam fluence. This effect must be taken into account by way of a correction factor. Also, an ionization chamber is not pure gas, but rather consists of a central electrode and an outer wall etc. These facts are also taken into account by applying additional correction factors.

1.6 Small Fields

1.6.1 Definition

While there is no clear consensus on the definition of small fields, they are generally defined as a field with dimensions smaller than $3 \times 3$ cm$^2$ in megavoltage photon dosimetry. According to a recent study [22], the threshold for very small field sizes was established by the measurement of output factors. The practical definition considered
field sizes less than 15 mm*15mm [22] to be small fields for a 6 MV photon beam because a change of more than 1% was observed in the output factor when the field size was changed by more than 1 mm on a side. This is attributed to the loss of lateral charged particle equilibrium at field sizes smaller than this. Similarly, for the theoretical definition [22] of small fields, field sizes less than 12 mm were considered to be very small because the output factor for such fields changed by more than 1% when the field size was changed by 1mm or more. In addition to loss of lateral charge equilibrium, source occlusion was another reason that led to the theoretical definition of small fields.

1.6.2 Small Field Problems

The accurate determination of absorbed dose is crucial to the success of radiotherapy. There are many different steps and several dosimetric challenges involved in the determination of absorbed dose in case of small fields. This is due to the fact that the conditions that hold good for classical field sizes begin to break down for small field sizes. There are three main causes for this breakdown: first, lateral charged particle equilibrium (LCPE) is lost because the size of the field becomes small compared to the range of the dose depositing electrons. Second, the finite size of the x-ray source means that it becomes relatively large compared to the field size. The result is that small fields have a very large percentage of the field made up by penumbra, making volume averaging within the detector problematic. Third, the finite size of the detector means that the perturbation of the radiation field by the detector becomes larger as the field size
decreases.

1.6.3 Formalism for reference dosimetry of small fields

In 2008 the International Atomic Energy Agency (IAEA) in conjunction with the American Association of Physicists in Medicine (AAPM) proposed a new formalism [14] for reference dosimetry of small and nonstandard fields. According to this new formalism, an additional sensitivity of detector factor is applied to the standard dosimetry protocol to account for two possible problems. The first is that a beam may not able to make a standard $(10 \times 10 \text{ cm}^2)$ field size (e.g. Cyber Knife), and the second is that many intensity modulated beams are delivered differently to a standard reference beam. That is, by way of many beamlets, which when combined might deliver a uniform dose, but separately may not have lateral equilibrium at any stage. Furthermore, an additional sensitivity correction factor may be required for specific non-reference fields. This is certainly the case for very small fields. Thus, this formalism presents a methodology where the detector response variation with field size can be corrected for by using a sensitivity correction factor. These correction factors have been obtained for various detectors.

1.6.4 Improving the accuracy of small field dosimetry

The response of detectors that are used for small field measurements can vary with small field size. The observed changes in sensitivity can be due to volume averaging or a difference in the physical density of the detector’s active volume to that of the phantom
material. Other components that make up the detector may also heavily perturb the particle fluence in small fields. With a large variety of radiation detectors marketed by various manufacturers covering all sizes (from mini to micro), types (ionization chamber, semiconductor, chemical, film, etc.), and shapes (thimble, spherical, plane parallel), the choice of suitable detector for small field dosimetry could be a challenging and rather confusing task without proper guidelines. It is not uncommon in clinical practice to compare measurements obtained with various detectors and choose the detector that yields the highest output for a given field size, or to select a measured value that is common to several detectors, without proper consideration of the possible perturbations and corrections for each of the detectors. Such approaches do not provide the scientific basis needed to achieve the confidence for dosimetric accuracy commonly set for clinical practices.

Cylindrical ionization chambers are the instruments of choice for use in photon calibration and dosimetry. For each ionization chamber, correction factors are needed to account for the many influences that affect the readings. Examples of correction factors in ionization chamber dosimetry are ambient air temperature, pressure, and humidity, applied chamber voltage and polarity, chamber leakage currents, and chamber stem effects. If the chamber is used under conditions that differ from the reference conditions, the measured signal must be corrected for these factors so that an accurate signal is obtained.
In addition, it has been shown that a detector with an active area of 1 mm$^2$ or less has negligible volume averaging at a typical linear accelerator field size of 5 mm$^2$. Therefore, by making the appropriate detector choice, small field dosimetry is possible at clinically relevant small field sizes.

### 1.7 Micro-ionization chambers for Small Fields

Ionization chambers are widely used in radiation therapy due to the comparatively small variation in their response to photon energy and dose rate. These chambers provide a direct measure of the absorbed dose since they are calibrated against a national laboratory standard (NIST). Additionally, ionization chambers are relatively inexpensive, readily available and come in many different shapes and sizes. Traditional farmer type ionization chambers are not suitable dosimeters for small fields because the active volume is often wider than the field itself; this results in extreme beam perturbations and unavoidable problems with volume averaging. To achieve a conformal dose distribution, IMRT plans use numerous subfields, many of them with small sizes. Small volume ionization chambers perform the best in low gradient regions and at low doses.

Typical volumes of small volume ionization chambers are between 0.015 and 0.03 cm$^3$. Six different dosimeters have been used in this study. If the chamber is used under conditions that differ from the reference conditions the measured signal must be corrected by using correction factors so that accurate measurements can be obtained.
The small volume of the chamber makes it more sensitive to radiation-induced leakage and charge multiplication; both are sources of error that are usually negligible for the large volume chambers.

When a chamber produces a measurable polarity effect, the true reading is taken to be the mean of the absolute value of the readings taken at the two polarities.

1.8 Polarity effects

It has been reported in the literature that under identical exposure conditions, the ionic charge collected by an ion chamber changes in magnitude as the polarity of the collecting volume is reversed. This phenomenon is known as the Polarity Effect. When the chamber is operating under saturation conditions, major causes of the polarity effects include the Compton current and the extra cameral current.

1.8.1 Compton current

When a chamber is irradiated, high-energy electrons such as Compton electrons are ejected from the central electrode due to the collisions of high-energy photons. These electrons constitute a current known as Compton Current, which is independent of gas ionization inside the cavity. This may add to or reduce the collector current, depending on the polarity of the collecting electrode. In addition to this, some of these Compton current electrons may stop in the collector but may not be entirely balanced by the ejection of recoil electrons from the collector. Charge imbalance in the collector electrode leads to
polarity effects in the ionization chambers. The true ionization current in these cases can be determined by taking the mean of measurements of the two currents obtained by reversing the chamber polarity.

1.8.2 Extra cameral Current

The extra cameral current collected outside the sensitive volume of the chamber may also contribute to the polarity effect. Such a current may be collected at inadequately screened collector circuit points. Also, irradiation of the cable connecting the chamber with the electrometer can cause both extra cameral current and Compton current. The errors caused by these sources can be minimized but not eliminated by reversing the chamber’s polarity and taking the mean of the collector current.

The polarity effect is very much dependent on chamber design and irradiation conditions. Many of the sources of the polarity effect and stem leakage can be minimized through the design of the chamber and the associated circuitry. Also, the adequacy of the chamber’s voltage is an important factor in minimizing some of the other polarity effects. Finally, it is recommended in TG-51A that the difference between the ionization currents measured at positive and negative polarizing potential should be less than 0.5% for any chamber to be used for absolute dosimetry [8].

One can eliminate the polarity effect by making measurements at two different polarities. The term “polarity effect” has been used to refer to the ratio of readings with
positive ($M_{\text{raw}}^+$) and negative ($M_{\text{raw}}^-$) polarity. $M_{\text{raw}}$ is the measurement taken with the polarity that was used during the chamber calibration process (either $M_{\text{raw}}^+$ or $M_{\text{raw}}^-$. The polarity correction factor according to TG-51 is defined as [4]

$$K_{\text{pol}} = \frac{[M_{\text{raw}}^+] + [M_{\text{raw}}^-]}{2[M_{\text{raw}}]}$$

### 1.9 Overall Aim of the Study

The overall objective of this research is to improve procedures involved in small field dosimetry by increasing the accuracy of measurements used in polarity correction factors for very small fields based on the orientation of the micro ionization chamber in the phantom. The dependence of the $P_{\text{pol}}$ factor on the orientation of the chamber has not been studied for the micro chambers, which are needed for dosimetry of small fields. The effect of reversing the voltage polarity applied to an ionization chamber has been investigated in photon beams for two different types of chamber orientation. This study concentrated on measuring the dependence of the polarity effect at various energies, field sizes, and ionization chamber combinations.
Chapter 2

Literature Review

2.1 Shimono et al.

Shimono et al. investigated seven different commercially available ionization chambers, but none of the ones that were used in this study. They measured the dependence of the polarity effect at various energies, and for various field sizes, ionization chamber and electrometer combination. They found the largest polarity effect for the small field sizes. They also noted that the magnitude of the polarity effect was strongly dependent on the material of the collecting electrode. Seven different ionization chambers were studied for the magnitude of the polarity effect in PTW 31005, PTW 23323, PTW 31015, PTW 31016, and PTW 31006 (PTW Co., Freiburg, Germany) and CC01 and CC04 (Wellhoffer Dosimetry, Schwarzenbruck, Germany). Two electrometers were used RAMTEC 1000D and RAMTEC 1000plus (Toyo medic, Tokyo, Japan) to determine the dependence of Polarity effect on the electrometer. Polarity effect was studied for field sizes of 10x10, 5x5, 3x3, 2x2 and 1x1cm². This study did not measure the polarity effect below 1 cm square field size. This study confirms that the polarity effect increased with depth up to 0.5dmax. Most chambers do
not exhibit polarity effects under conditions of electronic equilibrium. However, in the build-up region of a photon beam, polarity effect can be significant, depending on the design of the chamber. A possible chamber dependence of the polarity effect at low energies. They suggested that because of the field size dependence at the small ionization chambers, the polarity effect should be measured for different small ionization chambers. This work also found that there was no electrometer dependence on the Polarity effects.

### 2.2 Other works on Polarity Correction Factor

The development of intensity-modulated radiation therapy (IMRT) and stereotactic radiotherapy (SRT) has led to increased use of small-volume detectors for beam characterization and dose measurement. Small-volume ionization chambers (micro chambers) are a common option available to clinical physicists. Several authors have investigated the properties of these small-volume chambers for the purpose of reference dosimetry. These detectors have been shown to demonstrate several deviations from normal behaviors typically found in ionization chambers. Many investigations point to the increased impact of cable-induced currents (“stem effect”) because of the smaller ionization signal produced in the active volume.

Stasi et al.(7) reported variations in chamber response as a function of field size from 10×10 cm² to 1×1 cm². They noted variations on the order of 0.5% for the Exradin A16, and an almost constant $P_{Pol}$ value for the PTW 31002 PinPoint chamber. They concluded that the polarity response of these microchambers should be investigated, but offered no
explanation as to the cause of these differences. A larger polarity variance [10] with field size for the next generation of PinPoint chamber from PTW, citing variations as large as 1% for the PTW 31014. This was only for larger fields, as their investigation did not go below 2x2 cm². They also reported that the variation in \( P_{\text{Pol}} \) decreased with increasing energy, citing this as evidence that the polarity variation was caused by the increased impact of stem effect. This energy dependence was not observed during McEwen’s [17] investigation into the properties of multiple ionization chamber for reference dosimetry of therapy photon beams.

Snow et al [19] studied the suitability of microchambers for use in reference dosimetry of kV beams, including a full analysis of the polarity correction factors as a function of endpoint energy. They demonstrated that chambers with low-Z (\( Z \leq 13 \)) central electrodes, such as the PTW 31014, had stable polarity correction factors stable within 3% over the full range of investigated energies. Microchambers with high-Z electrodes (\( Z > 13 \)), such as the A16, showed polarity correction variations >50%. The A26, a subsequent chamber produced by Standard Imaging, incorporated the use of lower-Z material to help mitigate this effect.

Sarkar et al.[20] reported variations in measured PDD curves with multiple microchamber measurements, focusing on the A16. Their measured discrepancy was most influenced by the scanning phantom/controller/electrometer combination. They reject the possibility that their observed deviations are caused by polarity effects, highlighting that not every system used demonstrated the same magnitude of deviation.
for identical chambers. At this time, there is no accepted explanation for the cause of their observed differences.
Chapter 3

Materials and Methods

3.1 Radiation Source

All the measurements presented in this research were carried out on a Varian Truebeam Linear Accelerator (Varian medical systems, Inc., Palo Alto, CA) as a radiation source. The machine has been in clinical service at the Dana Cancer Center at University of Toledo Medical Center since 2013. Currently, it is used for the treatment of various types of cancers using special techniques like IMRT and SRS. This linac has two operating modes- the electron mode and the photon mode. It can be used as a source of high-energy electron beams with five different energies- 6 MeV, 9 MeV, 12 MeV, 16 MeV, and 20 MeV. In the photon mode it can be used with four different energies- 6 MV, 6 FFF, 10 MV, and 18 MV. The machine can form different small and large symmetrical and asymmetrical fields with maximum field size being 40x40 cm$^2$.

3.1.1 Phantom

A three-dimensional water scanning phantom, Blue Phantom$^2$ (IBA Dosimetry, Bartlett, TN), was used to acquire the required data. The phantom has dimensions of (675
mm $\times$ 645 mm $\times$ 560 mm) and a scanning volume with dimensions of (480 mm $\times$ 480 mm $\times$ 410 mm). This is considered to be the standard scanning phantom size for beam commissioning and annual QA, any smaller size phantom may not account correctly for the scatter contributions. The phantom was used in conjunction with the Omni Pro Accept software version 7.5 (IBA Dosimetry, Bartlett, TN) for acquiring data. The Blue Phantom\textsuperscript{2} is attached to a transport system, which helps to achieve stable, reproducible measurements with high positional accuracy of 0.1 mm. A hand pendant is attached to the phantom for setting up the ion chamber by making adjustments in x, y and z directions. Additionally, the system had a Common Control Unit (CCU) attached to it. The control unit integrates a controller and two independent electrometers which were used to take measurements. It also has built-in pressure and temperature sensor interfaces which automatically corrects for the $K_{sp}$ correction factor.

### 3.1.2 Detectors

The selection of detectors was based on their physical dimensions, their availability for clinical use, their suitability for use in small fields and their performance characteristics. A total of six detectors were used for the purpose of this research. The first ion chamber that we used was an Exradin A16 (Standard Imaging, Middleton, WI). This chamber has good spatial resolution and is suitable for small field dosimetry. The outside diameter of the shell is 3.4 mm and the inner diameter of the shell is 2.4 mm. A small, silver plated and copper clad steel wire acts as the chamber’s collector. It is covered with a coating of air equivalent C552 Shonka conductive plastic (physical density of 1.76 g/cm$^3$, and
relative electron density to water of 1.58, chemical composition of 2.52 % Hydrogen, 50.01% carbon and 47.47% Fluorine). The second chamber that was used was an Exradin A26 ion chamber (Standard Imaging, Middleton, WI). This chamber also had a small silver plated and copper clad steel wire that acts as the chamber collector and it also has a coating of air equivalent C552 Shonka. The chamber has a sensitive volume of 0.015cm$^3$ and it has shown to have stable and reproducible measurements. The third ionization chamber used was PTW 31014(PTW-Freiburg, Germany). The central electrode for this detector is made of aluminum and it has a sensitive volume of 0.015 cm$^3$. The fourth detector included in our research was another PTW model: PTW 31016(PTW-Freiburg, Germany). The sensitive volume for this detector is 0.016 cm$^3$ and the central electrode material for this detector is aluminum. The last two detectors used in this research were manufactured by IBA: the CC01 13401 and CC01 11533(IBA Dosimetry, Schawarzenbruck, Germany). Both of these ionization chambers have a sensitive volume of 0.01cm$^3$ and have a central electrode material constructed with steel, (which has an atomic number of 26). The characteristics of all of these detectors are summarized in the table below.
Table 3.1: Sensitive volume and central electrode material of the detector used for the purpose of measurements.

<table>
<thead>
<tr>
<th>Detector</th>
<th>Sensitive Volume(cc)</th>
<th>Manufacturer</th>
<th>Central Electrode Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exradin A16</td>
<td>0.007</td>
<td>SI</td>
<td>Silver-plated(Z=47), Copper-clad(Z=29)Steel(Z=26) with C552 Coating</td>
</tr>
<tr>
<td>Exradin A26</td>
<td>0.015</td>
<td>SI</td>
<td>Silver-plated(Z=47), Copper-clad(Z=29)Steel(Z=26) with C552 Coating</td>
</tr>
<tr>
<td>31014</td>
<td>0.015</td>
<td>PTW</td>
<td>Aluminum(Z=13)</td>
</tr>
<tr>
<td>31016</td>
<td>0.016</td>
<td>PTW</td>
<td>Aluminum(Z=13)</td>
</tr>
<tr>
<td>CC 01 13401</td>
<td>0.01</td>
<td>IBA</td>
<td>Steel(Z=26)</td>
</tr>
<tr>
<td>CC 01 11533</td>
<td>0.01</td>
<td>IBA</td>
<td>Steel(Z=26)</td>
</tr>
</tbody>
</table>

### 3.2 Method

All of the measurements for our experiment were acquired in the photon mode of the Varian Truebeam Linear Accelerator with gantry angle and collimator angle set to zero degrees. The IBA Blue Phantom\(^2\) was filled with distilled water and the tank was left to stand for some time to let the water and the room temperature equilibrate. The SSD to the surface was set to be 100 cm by using the ODI and the front pointer. Chambers were mounted vertically and horizontally to the beam’s direction at a depth of 10 cm in the Blue Phantom\(^2\). Detectors were aligned using the visual light field and verified using point wise scans in a 1×1 cm\(^2\) field size. This ensured proper centering and minimized the volume averaging effect. Both inline and crossline scans were acquired; scanning in
both directions eliminates any error that may be caused by the rotation of the tank. Three different energies were used for this research- 6 MV, 10 MV and 18 MV and all of the measurements were taken using the maximum dose rate. Measurements were made using field sizes of 5, 3, 2.4, 2, 1.8, 1.6, 1.4, 1.2, 1.0, 0.8 and 0.6 cm were measured using both polarities. These square field sizes were defined by using the jaws of the collimator. A special tri-axial connector was used to connect chambers to an electrometer capable of providing the positive and the negative bias with a nominal operating voltage of 300V. Measurements were taken for both polarities for each field size. The on-board electrometer from the CCU controller (IBA, Schwarzenbruck, Germany) was used, as well as an external SuperMaxx (Standard Imaging, Middleton, WI) electrometer to eliminate any electrometer dependence. Before more data was collected after a polarity switch, a beam with 3000 MU and a field size of 10×10 cm² was shot into the phantom. This was done so that sufficient amounts of charge could be collected, restoring the system equilibrium. An appropriate amount of time was given between each change in polarity to allow the chamber/cable/electrometer system to equilibrate, and the electrometer was zeroed following this period before any measurements were taken. The Omni Pro software was used to collect the measurements. Changes in the polarity correction factor were relative to a reference field of 5x5 cm². Measurements were repeated on multiple days to estimate the impact of setup uncertainties on the final value of $P_{pol}$. $P_{pol}$ was evaluated as described in TG
$P_{pol}$ values are reported using the raw measurements and the ratio of $P_{pol}$ measured in the clinical field to that measured in the reference field.
Chapter 4

Results and Conclusions

4.1 Orientation comparison for IBA CC01-11533 micro ionization chamber

Fig 4-1: Horizontal orientation of the IBA CC01-11533 micro chamber.
Fig 4-2: Vertical orientation of the IBA CC01-11533 micro chamber.

Figures 4.1 and 4.2 above shows the variation of the ratio of polarity correction factor with field size and energy for the IBA CC01-11533 micro ionization chamber (IBA Dosimetry, Schawarzenbruck, Germany) at 10 cm reference depth. These parameters were studied for the horizontal and vertical orientations of the micro ionization chamber. As seen, the variation in polarity correction factor was less in the horizontal direction in comparison to the vertical direction. The polarity effect tended to decrease with increasing field size. A sharp increase in the polarity correction factor was noticed at 2x2cm² field size in the horizontal direction with the maximum polarity factor being 0.992 for 18 MV energy. This sharp increase was observed for all the three energies that were studied. This might be attributed to the construction of the chamber. As for the
energies, the 6 MV showed least variation for all field sizes in both the vertical and the horizontal direction whereas the maximum variation was shown by the 18 MV beam. Thus, in case this chamber is used in the vertical direction polarity correction factor might have to be taken into account.

4.2 Orientation comparison for IBA CC01-13401 micro ionization chamber

![Horizontal Orientation of the IBA CC01-13401 micro chamber](image)

Fig 4-3: Horizontal Orientation of the IBA CC01-13401 micro chamber
Figures 4.3 and 4.4 above shows the variation of the ratio of polarity correction factor with field size and energy for the IBA CC01-13401 micro ionization chamber (IBA Dosimetry, Schawarzenbruck, Germany) at 10 cm reference depth. This is a prototype chamber by IBA and showed less variation in polarity effect as compared to IBA CC01-11533. Similar to the trend shown by previous chamber, a sharp increase was observed at 2x2cm² field size for all energies in the horizontal direction. The maximum variation was found to be 0.993 for 10 MV energy. The 6 MV energy continued to show least deviation for both the horizontal and vertical orientation of the micro ionization chamber whereas 18 MV energy showed maximum deviation in the vertical direction. In the horizontal
direction, 10 MV showed the maximum variation as against the expected by 18 MV energy.

4.3 Orientation comparison for SI Exradin A16 micro ionization chamber

Figure 4-5: Horizontal orientation for SI Exradin A16 micro chamber
Figures 4.5 and 4.6 above shows the variation of the ratio of polarity correction factor with field size and energy for the SI Exradin A16 (Standard Imaging, Middleton, WI) micro ionization chamber at 10 cm reference depth. With a sensitive volume of 0.007 cc, this chamber had the smallest sensitive volume out of all the chambers that we included in our studied. The horizontal orientation showed less variation in polarity correction factor as compared to the vertical orientation. In the horizontal direction the 6 MV showed the maximum variation of 0.994 in comparison to other energies whereas in the vertical direction it showed the minimum variation of 0.986 which was minimum as compared to other energies. The 10 MV and 18 MV energies have nearly the same

Figure 4-6: Vertical orientation for SI Exradin A16 micro chamber
correction factor in the horizontal direction whereas in the vertical direction 18 MV has the maximum variation in the polarity correction factor. The chamber tends to have nearly the same polarity correction factor at 3x3cm² field size for all the energies in both the vertical and the horizontal direction.

4.4 Orientation Comparison for SI Exradin A26 micro ionization chamber

Figure 4-7: Horizontal orientation of the SI Exradin A26 micro chamber
Figures 4.5 and 4.6 above shows the variation of the ratio of polarity correction factor with field size and energy for the SI Exradin A26 (Standard Imaging, Middleton, WI) micro ionization chamber at 10 cm reference depth. This chamber did not show much variation in the polarity correction factor in the horizontal direction for all the three energies that were studied, whereas in the vertical direction it showed greater variation for the 18 MV energy and least variation for the 6 MV energy. In spite of less variation in the horizontal direction a correction factor would still be required for this chamber. The maximum correction factor was 0.992 for the smallest field size of 0.6x0.6cm$^2$ and for 6 MV energy. For the same orientation, no variation was observed beyond the 2x2cm$^2$ filed size for all the energies.
4.5 Orientation comparison for PTW 31014 micro ionization chamber

Fig 4-9: Horizontal Orientation for the PTW 31014 micro chamber
Figures 4.9 and 4.10 above shows the variation of polarity correction factor with field size and energy in the horizontal and vertical direction for the PTW 31014 micro ionization chamber (PTW, Freiburg, Germany) at 10 cm reference depth. As with most chambers, horizontal orientation showed less variation as compared to the vertical orientation for all the field sizes. Smaller field sizes had greater polarity effect and this decreased as the field size increased. The largest polarity effect was found to be 0.997 in the horizontal direction whereas the same was 0.994 for the vertical direction. For the horizontal orientation, 10 MV showed the maximum variation at smaller field sizes. For the vertical orientation, 18 MV seems to have shown the maximum variation in the polarity correction factor for the smaller field sizes whereas the same energy showed least variation in the horizontal direction in comparison to other energies.
4.6 Orientation comparison for the PTW 31016 micro ionization chamber

Figure 4-11: Horizontal orientation for PTW 31016 micro chamber
Figures 4.11 and 4.12 above shows the variation in polarity correction factor with field size and energy in the horizontal and vertical direction for the PTW 31016 micro ionization chamber (PTW, Freiburg, Germany) at 10 cm reference depth. At smaller field sizes the horizontal direction showed less variation in comparison to the vertical orientation. In both the orientations of the micro chamber 10 MV showed the least variation in polarity correction factor. As with the IBA chambers, anomalous behavior was seen in this chamber in the horizontal direction at 2.4cm square field size. The maximum variation was found to be 0.995 by the 18 MV energy. Same trend for polarity correction factor was found with the field sizes in the vertical direction with greater polarity effect at smaller field sizes as compared to larger field sizes.
### 4.7 Conclusions

Table 4.1: Measured $P_{pol}$ values for various micro-ionization chambers for the smallest (0.6x0.6cm$^2$) field size in the vertical and the horizontal orientation.

<table>
<thead>
<tr>
<th>Chamber/Energy</th>
<th>6 MV</th>
<th>10 MV</th>
<th>18 MV</th>
<th>6 MV</th>
<th>10 MV</th>
<th>18 MV</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC01 11533</td>
<td>0.999</td>
<td>0.998</td>
<td>1.003</td>
<td>0.979</td>
<td>0.970</td>
<td>0.971</td>
</tr>
<tr>
<td>CC01 13401</td>
<td>1.000</td>
<td>0.999</td>
<td>1.000</td>
<td>0.982</td>
<td>0.974</td>
<td>0.976</td>
</tr>
<tr>
<td>Exradin A16</td>
<td>0.997</td>
<td>0.996</td>
<td>0.998</td>
<td>0.993</td>
<td>0.974</td>
<td>0.979</td>
</tr>
<tr>
<td>Exradin A26</td>
<td>0.994</td>
<td>0.996</td>
<td>0.995</td>
<td>0.991</td>
<td>0.980</td>
<td>0.982</td>
</tr>
<tr>
<td>PTW 31014</td>
<td>1.000</td>
<td>0.998</td>
<td>0.996</td>
<td>0.995</td>
<td>0.993</td>
<td>0.992</td>
</tr>
<tr>
<td>PTW 31016</td>
<td>1.009</td>
<td>1.010</td>
<td>1.010</td>
<td>0.992</td>
<td>0.983</td>
<td>0.983</td>
</tr>
</tbody>
</table>

According to TG-51A $P_{pol}$ values should be expected between 0.996 and 1.004 for chambers to be considered for absolute dosimetry. The maximum recommended variation in $P_{pol}$ with energy is 0.5%. Chambers having values within this range does not need any polarity correction factor whereas for chambers that exhibit polarity effect beyond this range, a polarity correction should be applied for the correct measurement of absorbed doses. Variations in $P_{pol}$ have been documented before, but without investigating any dependence on orientation. In this study the variation of polarity correction factor was studied with field size and energy for different orientations of six different micro ionization chambers. A dependence on field size was observed for all chambers, with all the chambers showing the maximum variation in polarity effect at smaller field sizes. The values in the above table shows the polarity correction factor obtained for the smallest
field size of 0.6x0.6cm² for micro-ionization chambers in the horizontal and the vertical orientation. The maximum deviation at the smallest field size was shown by the PTW 31016 ion chamber in the horizontal direction whereas in the vertical direction CC01-11533 chamber showed the maximum deviation. For all the chambers that were studied the horizontal orientation of the chamber showed less deviation as compared to the vertical deviation. Horizontal mountings demonstrated <1% variation in the polarity correction factor from 5x5cm² to 0.6x0.6cm². Vertical mountings increased the measured polarity correction factor variation up to 3.2% for the smallest field size. The increase in $P_{pol}$ shows some energy dependence; with the highest variation occurring at 18 MV for most of the chambers in both orientations. The only exception to this energy dependence were the CC01-13401 chamber by IBA and Exradin A26 ion chamber by SI in the horizontal direction where maximum variation was shown by the 10 MV energy although the difference was not very significant. In addition, it was noted that three micro ionization chambers PTW 31016, IBA CC01-11533, and CC01-13401 that we included in our study showed anomalous behavior. It is interesting to note that in spite of anomalous behavior shown by the PTW 31016 chamber, the polarity correction factor will still not be required as the variation was found to be within the limits defined in Tg-51A.

The A16 and A26 ion chambers demonstrate comparable variations for the vertical mounting. Horizontal mountings of these chambers demonstrate negligible variation between fields of 5x5 cm² and 0.6x0.6 cm². In this research it was found that the A16 and
A26 have much larger variations (2-3%) when oriented vertically compared to when the chamber is mounted horizontal (~0.8%). The same effect is shown to a lesser extent by the 31014 chamber, with a maximum variation of 0.6% in the vertical orientation for an 18 MV beam. In addition, the horizontal variation was found to be consistent with the levels of variation previously reported in the literature for the A16 and 31014.

Based on the above observations we can say that most of the micro ionization chambers studied do not require polarity correction factor for small fields in the horizontal orientation whereas a polarity correction factor would be required in the vertical orientation of the micro-ionization chambers. Also in this study it was found that the PTW 31014 showed least variation for all the field sizes and energies studied for both the vertical and the horizontal direction. It was found to be the only chamber for which polarity correction factor was not required in the vertical direction for all fields and energies.
Chapter 5

Discussion

In this study it was found that vertically mounting the chamber increased the measured polarity effect. A larger area of stem is exposed with this orientation, which leads to greater collection of charge. The amount of the chamber’s stem and triaxial cable irradiated will vary as a function of the radiation field size. Due to the small size of the micro ionization chamber, the charge collected is significantly less than larger volume chambers. Furthermore, the relative contribution to the chamber response due to extra cameral effects, such as stem and cable irradiations, is larger. It was also found that the sensitive volume of the ionization chambers studied affects the polarity correction factor. The A16 has a sensitive volume of 0.007 cc, whereas the 31014 chamber has a sensitive volume of 0.015cc. The 0.015cc PTW 31014 chamber showed less variation in the polarity correction factor as compared to the A16 ion chamber.

It was found that the chamber construction plays an important role in the magnitude of $P_{pol}$. Longer sensitive volumes with smaller radii may lead to decreases in polarity correction factors, but further studies are required to support this conclusion. The magnitudes of polarity measurements were found to be related to field size for certain chambers. The CC01 prototype chamber showed anomalous behavior in the horizontal
orientation for field sizes around 2 cm, and the PTW 31016 showed similar behavior for fields of about 2.4 cm in size. The abnormal performances of these chambers is believed to be due to an electrical connection in the ion chamber, but the construction of these ion chambers must be investigated for a more thorough explanation. It has also been reported in the literature [9] that the design of the central electrode plays an important role in the prominence of the polarity effect. This was found to be true in our research, as the chambers with central electrodes of higher-Z materials, such as steel, demonstrated greater variations in $P_{\text{pol}}$ values than those with lower-Z electrodes. The A16 and A26 both contain a silver-plated, copper-clad steel collector ($Z=47, 29, 26$), whereas the collector of the 31014 and 31016 is aluminum ($Z=13$). The central electrode of the CC01 chamber is made of steel ($Z=26$). As expected, $P_{\text{pol}}$ values varied the most with A16 and A26 and varied the least with the 31014 and 31016. The effect of central electrode design was found to hold true for both of the orientations of the micro ionization chamber. Polarity effect dependence was observed for the ionization chambers and field sizes studied which was consistent with the literature. The polarity effect was largest for small field sizes due to the loss of lateral charged particle equilibrium (LCPE). The effect may be significant in the buildup regions of megavoltage photon beams. Accurate measurements of polarity correction factors make it possible to measure the exposure (absorbed dose) with a desired accuracy of +/-5%. The literature suggests that there is no electrometer dependence associated with polarity effects, so measurements presented in this thesis are averaged results obtained with two electrometers.
5.2 Future Works

The results presented in this thesis may be a good starting point for other studies. Testing the effect of dose rate on polarity correction factors in various micro ionization chambers will be a study of great importance. For example, data can be collected at different polarities for a variety of dose rates and the significance of polarity correction factor can be evaluated. Using this data we could find dose rates minimize the variation of the polarity correction factor for a given micro chamber.

Anomalous behavior was exhibited by certain micro ionization chambers. The design of these chambers could be studied, including an analysis of the effect that the ratio of the length and radius of the sensitive volume has on measurements. The above future projects should be feasible with the equipment available at present, but would require the collection of a large amount of data as well as a big time investment. The work presented in this thesis, along with the ongoing small field research at University of Toledo, would serve as an excellent base for new studies.
References


