# Photon Contamination Analysis (Bremsstrahlung tail) of Electron Beams in Small Fields

**[1]Sadip Barua, [2]M.A. Hasnat, Samiul Alim, [2]Fatema Tuz Zohra, [2]Priyanka Poddar, [2]M Rafiqul Islam, [3]S.C.B. Sarma, [1]Santunu Purohit, [1]Mohammad Nasirul Hoque, [2]M M Ahasan**

[1]Department of Physics, University of Chittagong, Chattogram, Bangladesh

[2]Institute of Nuclear Medical Physics (INMP), AERE, Savar

[3]National Institute of Nuclear Medicine and Allied Sciences

**Correspondence Address :** Md. Abul Hasnat, Senior Scientific Officer, INMP, AERE, Savar. E-mail: hasnat.phy@gmail.com

## ABSTRACT

Intensity-modulated radiotherapy, volumetric arc radiotherapy, and stereotactic radiosurgery are three modern radiotherapy applications that commonly use dosimetry of small fields. Field sizes ranging from 1 × 1 cm² to 5 × 5 cm² are taken for analysis. Varian Clinac IX SN6298 was utilized for both 6 and 12 MeV electron beams, using the TRS-398 and IAEA Technical Reports Series No. 483 procedure as the standard. The beam profile and the percentage of depth dosage (PDD) were finally ascertained in a water phantom. Various percent dosages and Bremsstrahlung tail regions were experimentally measured from the PDD curves. With an increase in field size (s), R100, R90, R80, R50, and Rp all rose for the medical linear accelerators. In the CC13 chamber, this held true for both 6 MeV and 12 MeV electron beams. The area of the bremsstrahlung tail grows as energy increases. This may result in modifications to the penumbra region's dosage distribution. Beam profiles revealed that dose was scattered more in small fields than in intermediate sizes. The interactions between the radiation beam, detector, and surrounding materials make small-field dosimetry difficult. Additionally, none of the beam symmetries exceed 2%.

***Keywords:*** Radiotherapy, Bremsstrahlung tail, Percentage of depth dosage, Electron Beam

Bangladesh J. Nucl. Med. Vol. 28 No. 1 January 2025

**DOI: https://doi.org/10.3329/bjnm.v28i1.79545**

## INTRODUCTION

Modern radiation therapy aims to tailor a high dosage zone exactly to the target while organs at risk (OARs) and healthy tissue are preserved to the greatest extent possible. This leads to an efficient treatment of the tumor with decreased adverse effects. With the advent of image-guided radiation therapy (IGRT), the accuracy of patient placement, target localization, and the treatment itself may be enhanced. However, whether employing computed tomography (CT) or x-ray radiography as imaging modalities, restrictions on imaging frequency and duration are necessary to minimize the patient's exposure to extra ionizing radiation.

External beam radiotherapy (EBT) is a technique for treating a patient's tumor using high-energy x-rays or gamma rays. In this method, radiation is produced outside of the patient (often using a linear accelerator) and directed towards the tumor location. EBT may be used to alleviate symptoms in people with advanced or metastatic cancer. For example, breast cancer, lung cancer, and colorectal cancer.

Brachytherapy (internal beam radiation therapy) involves the placement of radioactive sources inside the body in order to eradicate cancer cells and decrease tumors. This permits the clinician to employ a greater total radiation dosage to treat smaller cancer lesions in less time. Such include the prostate, cervix, head and neck, and skin.

These days, around sixty percent of cancer patients are also given a prescription for radiation in addition to surgical treatment and chemotherapy. The final result of radiation is heavily reliant on accurate dosimetry for the computation of the Treatment Planning System (TPS), which should not be more than ±5% of the authorized dosage, taking into account all types of uncertainties (1,2). Separately and occasionally in combination, high-energy electron beams and photon beams are utilized to treat various cancer cells found in various organs. These beams may be either employed alone or in combination.

As an electron travels through a medium, it interacts with atoms by a variety of processes. The processes are: (i) (i) inelastic collisions with atomic shell electrons (ionization and excitation), (ii) elastic collisions with atomic nuclei, (iii) inelastic collisions with atomic nuclei (bremsstrahlung), and (iv) elastic collisions with nuclei.

A traveling electron in a material loses energy due to collisional and irradiative processes.

In the collisional processes, the rate of energy loss depends on the electron density of the medium. The rate of energy loss per gram per cm squared, which is called the mass stopping power, is greater for low atomic number (Z) materials (3,4).

Radiation Losses (Bremsstrahlung): Bremsstrahlung radiation, also known as braking radiation or deceleration radiation, is a form of electromagnetic radiation created when a charged particle, such as an electron, slows down or is deflected by another charged particle, such as a nucleus. The transfer of energy from the charged particle's kinetic energy to its electromagnetic field, caused by its deceleration, results in the emission of electromagnetic radiation (5).

Bremsstrahlung radiation may be regarded from a quantum mechanical viewpoint as the product of momentarily produced and absorbed virtual photons by the charged particles. These virtual photons may become actual photons that move over space as electromagnetic radiation as the charged particle slows down (6,7).

The rate of energy loss per cm is approximately proportional to the electron energy and to the square of the atomic number. Moreover, the probability of radiation loss compared to the collisional loss increases with the kinetic energy of the electron and with atomic number (Z) (7).

Dosimetry is the science of measurement of ionizing radiation and the assessment of the amount of radiation energy absorbed by matter, specifically biological tissue. The goal of dosimetry is to quantify the amount of radiation dose received by an individual and to evaluate the associated health risks and biological effects. This information is used to optimize radiation therapy, to assess radiation exposure in occupational settings, and to monitor and control public exposure to ionizing radiation (6, 8).

In the clinical setting (Intensity-Modulated Radiotherapy (IMRT), Image-Guided Radiotherapy (IGRT), Stereotactic Arc Radiosurgery (SRS), and Volumetric Arc Radiotherapy (VMAT)), various measurements are performed under non-reference (small field) conditions in which the calibration coefficient is not required. Dosimetry of different radiation fields (values compared to the reference field, output factors), wedge filter factor (ratio between readings done with and without filter for the same geometry), and measures of depth dose are examples of relative measurements (normalized to the values obtained at the maximum dose point for that specific radiation field and type of beam) (9).

Dosimetry of small fields is not an easy task due to the lack of charged particle equilibrium in the measured radiated region due to these factors: the volume-averaging effect of the monitoring chambers, focal spot difficulties, source occlusion effect, difficulties in positioning of the chamber, difficulties in chamber choosing, etc. (10).

## MATERIALS AND METHODS

An electron linear accelerator is typically used in the medical field. For this study we used Varian Clinac IX SN6298 (Figure 1) at the Institute of Nuclear Medical Physics, which can accelerate precisely and effectively deliver accurate dosage to the target. The IBA Blue Water Phantom 2 (484841) with accessories is used for the measurements.

**Figure 1: Dosimetric Setup for Small Field Dosimetry at INMP**

This chapter actually encompasses the technical procedure of machine adjustment and performing experimental set up or present study. The technical procedure for the measurements is performed in to several sessions. Main procedure techniques are as follows:

a. Preparing electron cutouts
b. Startup session
c. Setting up session
d. Adjustment of RAF
e. Adjustment of electrometer
f. PDD measurement using myQA accept software.

After all setup, we measured PDD curves for 4 × 4, 3 × 3, 2 × 2, 1 × 1 cm2 field sizes using CC13 (ionization chamber) chamber. All measurement was done in accordance with IAEA TRS 483 (International Code of Practice Dedicated to the Dosimetry of Small Static Fields Used in Radiotherapy).

## RESULT AND DISCUSSION

***Measuring PDD using IBA ionization chamber:***

The experimental values of PDD are measured with an IBA ionization chamber (CC13). The PDD of 6 and 12 MeV electron beams measured for a field size of 1 x 1, 2 x 2, 3 x 3, 4 x 4 cm2 keeping SSD (source to surface distance) at 100 cm, using a blue water phantom 2 which are shown in Figure 2(a, b).

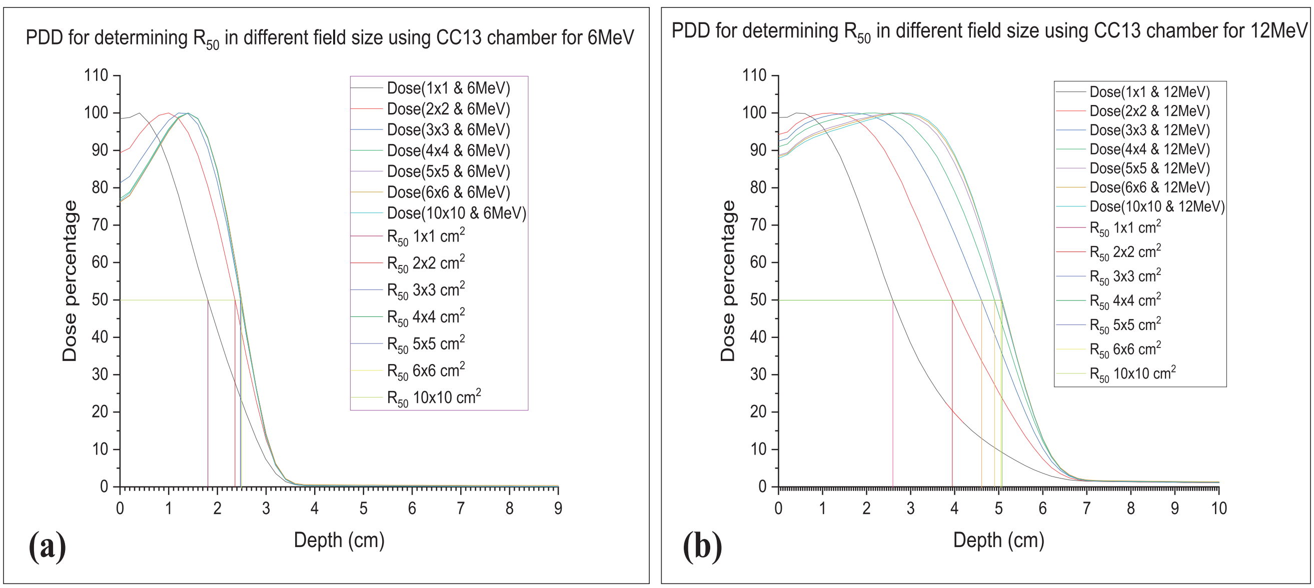


**Figure 2: Pictorial representation of percentage of depth dose (PDD) for CC13 Ionization chamber in different fields and determination of fifty percent depth dose, R50, in 6 MeV (a) and 12 MeV (b)**

**Bremsstrahlung tail area of different field size:**

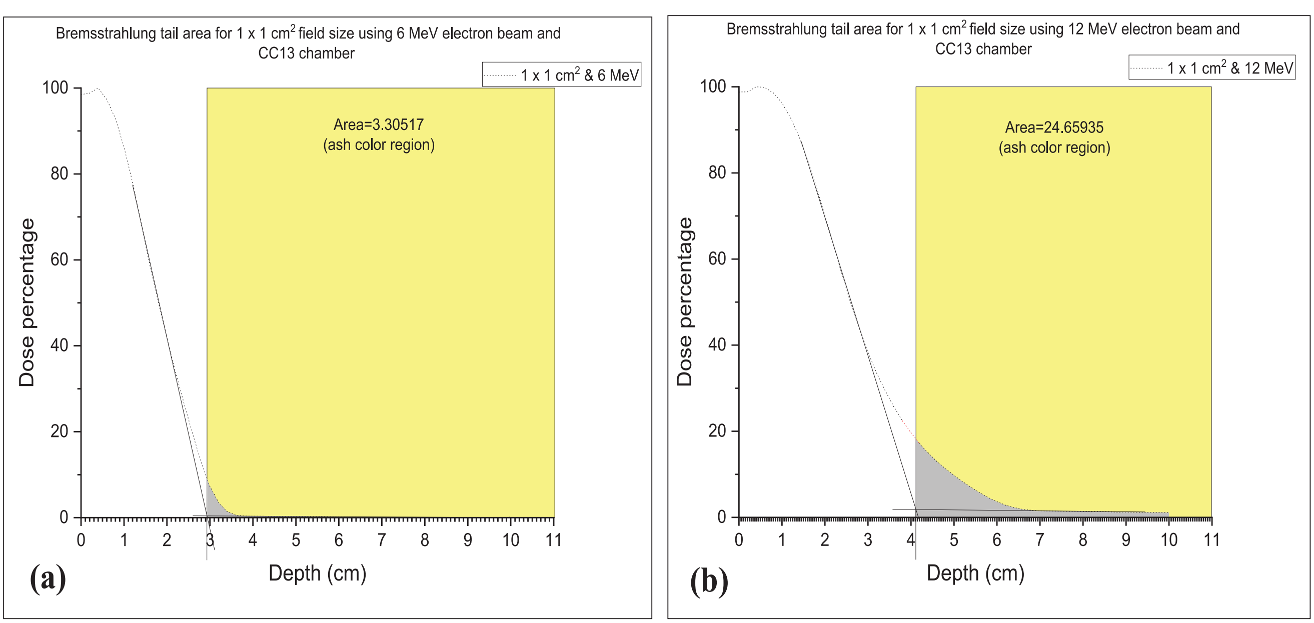


**Figure 3: Bremsstrahlung tail area of 1 x 1 cm2 field size for 12 MeV (a) and 6 MeV (b) electron beams.**

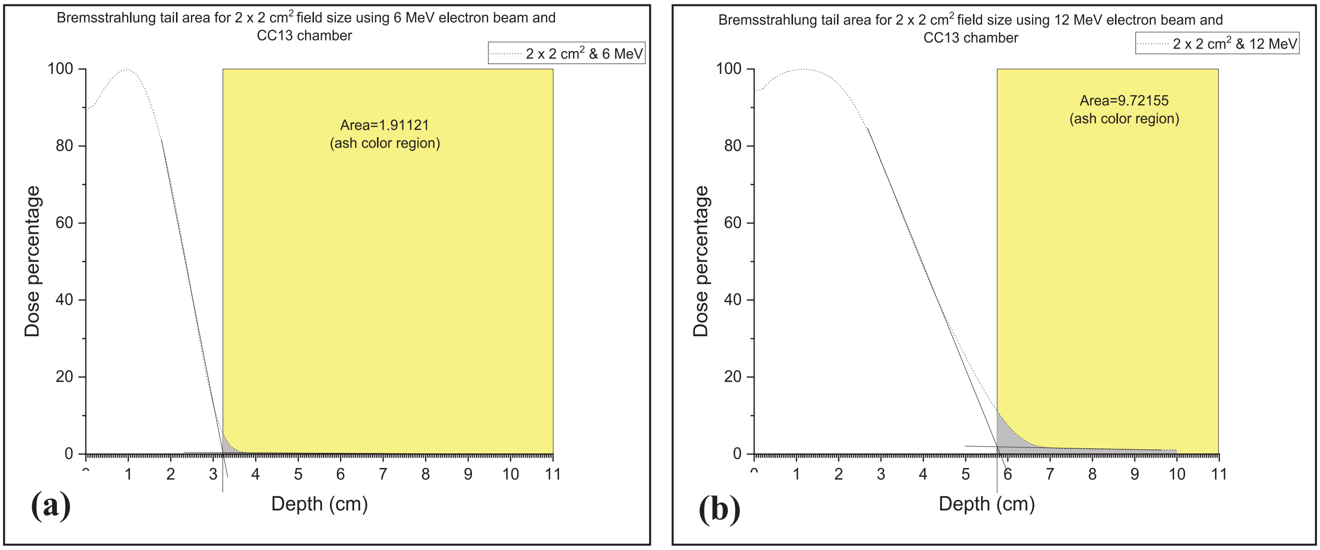


**Fig. 4: Bremsstrahlung tail area of 2 x 2 cm2 field size for 6 MeV (a) and 12 MeV (b) electron beams.**

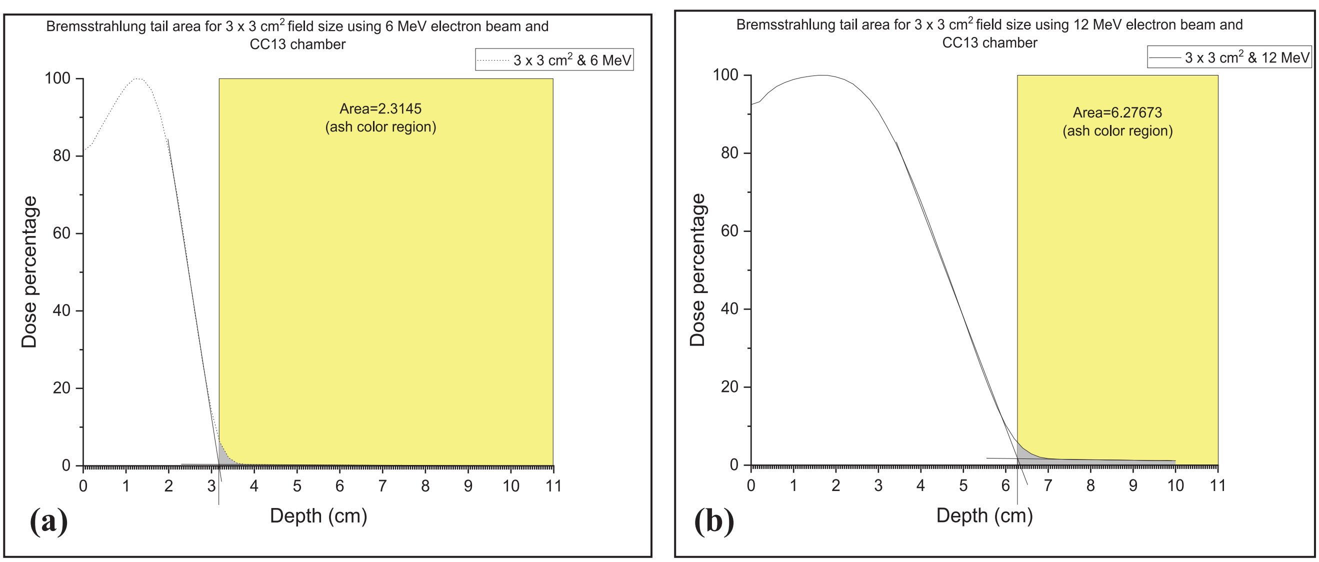


**Figure 5: Bremsstrahlung tail area of 3 x 3 cm2 field size for 6 MeV (a) and 12 MeV (b) electron beams.**

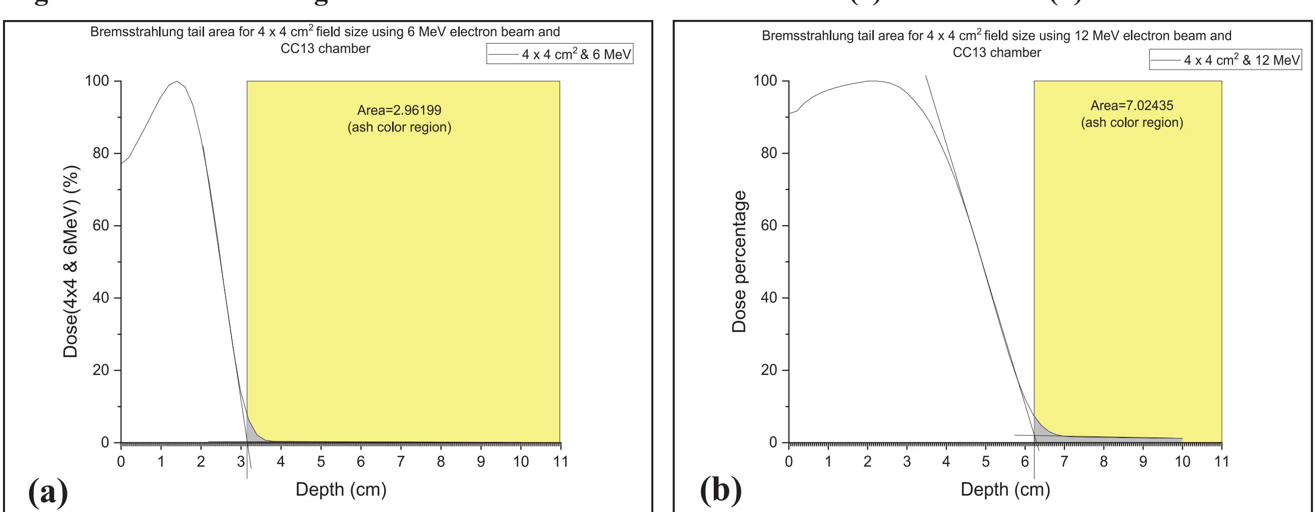


**Figure 6: Bremsstrahlung tail area of 4 x 4 cm2 field size for 6 MeV (a) and 12 MeV (b) electron beams.**

**Table 1: Comparison between Bremsstrahlung tail area for 6MeV and 12 MeV electron beams.**

| Field size(s) | Area for 6 MeV electron beam | Area for 12 MeV electron beam |
|---|---|---|
| $1 \times 1$ cm$^2$ | 3.30517 | 24.65935 |
| $2 \times 2$ cm$^2$ | 1.91121 | 9.72155 |
| $3 \times 3$ cm$^2$ | 2.31450 | 6.27673 |
| $4 \times 4$ cm$^2$ | 2.96199 | 7.02435 |

From Figure 2 to Figure 6 and Table 1, it can be said that for the same field size, higher energies have greater depth of maximum dose and higher entrance dose. Bremsstrahlung tail region increases with energy. Bremsstrahlung tail region can be problematic for small field dosimetry. The Bremsstrahlung photons can scatter multiple times before depositing their energy, which can lead to significant lateral electron disequilibrium in the surrounding materials. This can cause changes in the dose distribution in the penumbra region, which can be difficult to accurately measure and account for.

**DISCUSSION**

From the above Table and Figures it can be concluded that small field dosimetry can be challenging for a few reasons, particularly when it comes to measuring the PDD and beam profile curve for small fields. Here are some factors that contribute to this challenge:

Field size dependency: For small fields, the dose distribution is strongly influenced by the field size. The beam profiles can change rapidly in the penumbra region, and this can make accurate measurements difficult to obtain. This is because small field can be influenced by a variety of factors, such as collimator design, detector size, and positioning, that can lead to significant variations in dose.

Detector characteristics: Small field dosimetry requires high spatial resolution detectors, which can be sensitive to changes in orientation, position, and radiation quality. This sensitivity can lead to measurement uncertainties and variability in the data.

Beam Scattering: Small fields can exhibit high levels of beam scattering, particularly at the interfaces between different materials. This scattering can lead to changes in the beam profile, dose distributions, and PDD curves, which can be difficult to account for in the measurement process.

Dose perturbation: In small field, the presence of detector can perturb the dose distribution, which can affect the accuracy of the measurements. This perturbation can be particularly significant in the penumbra region, where small changes in the detector position can lead to large variations in the measured dose.

Overall, small field dosimetry can be challenging due to the complex interactions between the beam, detector, and surrounding materials. Careful attention to measurement technique, detector selection, and data analysis is necessary to ensure accurate and reliable dose measurements.

Again, if we compare small field dosimetry and large field dosimetry, here are some of the key differences:

PDD: In small field dosimetry, the PDD can exhibit significant changes with depth particularly in the buildup region. This is because small fields can experience a greater influence from lateral electronic disequilibrium, which can lead to steep dose gradients in the buildup region. In contrast, in large field dosimetry, the PDD typically shows a smoother decrease with depth, as the lateral electronic equilibrium is more established.

Beam profile curve: Small field tend to have steeper dose gradients and sharper penumbra regions compared to large fields. This can result in more significant changes in the beam profile curve, particularly in the penumbra region. This can lead to a more gradual transition between the field and surrounding areas, which can be more challenging to measure accurately.

Detector Selection: The type of detector used in small and large field dosimetry can differ as well. Small field dosimetry requires detectors with high spatial resolution, such as Razor Nano diode chamber, due to the steep dose gradients and sharp penumbra regions.

Output factors: Output factors are a measure of the dose rate of a given radiation field compared to a reference field. In small field dosimetry, output factors can exhibit more significant variations compared to large fields, due to complex interactions between the beam and the detector. Accurate measurement of output factors is critical for an accurate dose calculation in small field treatments.

So, small and large field dosimetry differ in terms of the complexity of the dose distribution, the required detector spatial resolution, and the accuracy required for output factor measurements. Careful attention to measurement technique, detector selection, and data analysis is necessary for both small and large fields dosimetry to ensure accurate and reliable dose measurements.

It is important to be very careful when working with small field dosimetry when measuring the PDD and beam profile curve, due to the following reasons:

High sensitivity to field size and detector position: Small fields can exhibit rapid changes in the dose distribution and steep dose gradients, particularly in the penumbra region. This can make small field dosimetry highly sensitive to variations in field size and detector position, which can lead to significant uncertainties in the measured data. Small changes in the detector position can lead to large variations in the measured dose, particularly in regions of steep dose gradients.

Dose perturbation: The presence of a detector in the radiation field can perturb the dose distribution, particularly in the penumbra region. This can affect the accuracy of the measured data, and can lead to errors in dose calculation and treatment planning.

Beam scattering and electron disequilibrium: Small fields can exhibit high levels of beam scattering and lateral electron disequilibrium, particularly at interfaces between materials. These effects can lead to changes in the beam profile curve and PDD, which can be difficult to account for in the measurement process.

Detector limitations: Small field dosimetry requires detectors with high spatial resolution, which can be sensitive to changes in orientation, position, and radiation quality. This sensitivity can lead to measurement uncertainties and variability in the data.

Small field dosimetry can be challenging. Any errors or uncertainties in the measurement process can lead to errors in dose calculation and treatment planning, which can have significant consequences for patient outcomes.

## CONCLUSION

Small field dosimetry is an essential part of radiation therapy treatment planning. However, it is also a challenging field due to the complex interactions between the radiation beam, detector, and surrounding materials.

The PDD and beam profile curve measurements are critical components of small fields dosimetry, as they provide information about the dose distribution of the radiation beam in the patient. However, these measurements can be highly sensitive to variations in field size, detector position, dose perturbation, and beam scattering. This sensitivity can lead to significant uncertainties in the measured data, which can have profound impact on the accuracy of dose calculation and treatment planning.

The Bremsstrahlung tail region in electron beam small field dosimetry can also contribute to measurement uncertainties, particularly in the penumbra region of the beam. The Bremsstrahlung photons have a broad energy spectrum and can scatter multiple times before depositing their energy, leading lateral electron disequilibrium in the surrounding materials.

To mitigate the effects of these challenges, careful attention to measurement technique, detector selection, and data analysis is necessary. The selection of a suitable detector with high spatial resolution is essential, as is the positioning of the detector close to the edge of the field to minimize the effects of the Bremsstrahlung photons. Monte Carlo simulations can also be used to model the effects to the Bremsstrahlung tail region and validate the measurement technique.

Small field dosimetry requires careful attention to detail to ensure accurate and reliable dose measurements. The potential for measurement uncertainties and errors underscores the need for quality assurance and quality control measures in radiation therapy treatment planning. By addressing these challenges and implementing appropriate safeguards, the accuracy and precision of small field dosimetry can be improved, leading to improved patient outcomes and more effective cancer treatment.

## REFERENCES

1. F. M. Khan. The Physics of Radiation Therapy, Fourth Edition, Lippincott Williams & Wilkins, Philadelphia.
2. K.A. Paskalev, J.P. Seuntjens. H.J. Patroeinio, and E.B. Podgorsak, Med. Phys. 30(2), 111 – 118 (2003), https://doi.org/10.1118/1.536290
3. S. Sathiyan, M. Ravikumar. Absolute dose determination in high-energy electron beams: Comparison of IAEA dosimetry protocols. J Med Phys. 33(3).108-13 (2008).doi: 10.4103/0971-6203.42754. PMID: 19893700; PMCID: PMC2772041.
4. M.M.H. Manna. Reference dosimetry for small megavoltage photon beam on standard system. M.S. Thesis. Department of medical Physics and Biomedical Engineering, Gono Bishwabidyalay, Savar, Dhaka (2015).
5. E.B. Podgorsak. Radiation Oncology Physics: A Handbook for Teachers and Students. IAEA in Austria, STI/PUB/1196 (2005).
6. J.U. Wuerfel. DOSE MEASUREMENT IN SMALL FIELDS. Med. Phys. J. 1(1), 81-90 (2013).
7. D.T. BURNS, G.X. DING, D.W.O. ROGERS. R50 as a beam quality specifier for selecting stopping-power ratios and reference depths for electron dosimetry, Med. Phys. 23, 388-388 (1996).
8. ICRU INTERNATIONAL COMMISION ON RADIATION UNITS AND MEASUREMENTSM, Stopping Powers for Electrons and Positrons, ICRU Report 37, Bethesda. MD: ICRU (1984)
9. J.M. FERNANDEZ-VAREA, P. ANDREO, T. TABATA. Detour factor in water and plastic phantoms and their use for range and depth-dose scaling in electron beam dosimetry. Phys. Med. Biol. 41, 1119-1139 (1996).
10. https://www.iba-dosimetry.com/product/myqa-accept#benefitimage-661 March 2023