ASSESSING THE ACCURACY OF SURFACE AND BUILD-UP DOSES CALCULATED FROM BEAM COMMISSIONING OF BREAST TECHNIQUE USING EDGE^{TM} DETECTOR

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Thesis
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ABSTRACT

This study was intended to investigate whether the commissioning beam data by an EDGE^{TM} detector can improve the accuracy of dose calculation at the surface and buildup region from AAA algorithms version 8.9 in the tangential breast technique. The percentage depth dose (PDD) of 6 MV photon beams was measured with an EDGE^{TM} detector for field sizes ranging between 2×2 and 40×40 cm^2 for open and wedge fields. Gafchromic EBT 2 film was used for a reference measurement comparison at the surface and the buildup region dose. There were 2 calculation sets. The first and second sets were the calculation from the commissioning beam data measured with an EDGE^{TM} detector and a photon field diode detector (PFD),respectively.Thestudy consisted of 2 techniques: The first one employed a direct angle for open field sizes of 10×10 and 15×15 cm^2. Solid water phantoms were used to vary the depths in thebuildupregion.The second technique used clinical tangential wedge fields with various thicknesses of Superflab placed on a CIRS thorax phantom. The EBT2 film measurement of both techniques were compared with the TPS from the first (EDGE^{TM}) and second (PFD) set of commissioning beam data.In the direct angle of both field sizes, at the surface dose, it noticeably showed that both calculations from the first and second setwere larger than the measurement. However at 2 mm and 5 mm depths, the EDGE^{TM} commissioning beam data set provided a superior agreement with the EBT2 film than the PFD data set.The % differences between EBT2 film and both sets of data at both depths and field sizes were in the range 1.4% - 5.5% for the first set and 3.2%-17% for the second set. In the tangential technique, both of TPS sets (PFD and EDGE^{TM}) obtained a very much higher dose at the surface than the measurement. Nevertheless, both TPS sets calculated small differences at other depths of within ±5% on average compared with the EBT2 film.In this study, the commissioning beam data set of the percentage depth dose measured with an EDGE^{TM}detector obtained comparable results with those measured by PFD for buildup dose calculation. However, selecting the appropriate detectors for the TPS beam commissioning is still important to improve the accuracy of TPS for dose calculation.

KEY WORDS: COMMISSIONING BEAM DATA /BEAM CONFIGURATION/ AAA ALGORITHM/SURFACE DOSE/ BUILDUP REGION / EDGE^{TM} DETECTOR / GAFCHROMIC EBT2 FILM

74 pages

การประเมินความถูกต้องในการคำนวณปริมาณรังสีบริเวณผิวและส่วนลึกลงไปจากการเก็บข้อมูลลำรังสีพื้นฐานโดยการใช้หัววัดรังสีไดโอดชนิดเอชในเทคนิคการวางแผนการรักษามะเร็งเต้านม

ASSESSING THE ACCURACY OF SURFACE AND BUILD-UP DOSES CALCULATED FROM BEAM COMMISSIONING OF BREAST TECHNIQUE USING EDGE^{TM} DETECTOR

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คณะกรรมการที่ปรึกษาวิทยานิพนธ์:พวงเพ็ญ ตั้งบุญดวงจิตร, Ph.D. (MEDICAL RADIATION PHYSICS), นวลเพ็ญ ดำรงกิจอุดม, Ph.D. (MEDICAL RADIATION PHYSICS)

บทคัดย่อ

การศึกษานี้จัดทำขึ้นเพื่อตรวจสอบข้อมูลลำรังสีพื้นฐานจากการใช้หัววัดรังสีไดโอดชนิด EDGE^{TM} เพื่อปรับปรุงความถูกต้องในการคำนวณปริมาณรังสีบริเวณผิวและส่วนลึกลงไป(build-up)ในอัลกอริทึม AAA เวอร์ชั่น 8.9 สำหรับการฉายรังสีเต้านมในเทคนิค tangential field ในการทดลองนี้มีการเก็บข้อมูลปริมาณรังสีในส่วนลึก (PDD) ที่พลังงานลำรังสีโฟตอน 6 MV พื้นที่รังสีขนาด 2×2 ถึง 40×40 ตารางเซนติเมตรสำหรับ open และ wedge field ใช้ฟิล์มRadiochromic (EBT2)ในการวัดปริมาณรังสีเปรียบเทียบกับการคำนวณของคอมพิวเตอร์วางแผนการรักษา (TPS)ที่มีข้อมูลลำรังสี 2 ชุด โดยชุดแรกเป็นข้อมูลลำรังสีพื้นฐานจากใช้หัววัดรังสี EDGE^{TM} และชุดสองเป็นข้อมูลจากการใช้หัววัดรังสีไดโอด PFD ศึกษาปริมาณรังสีใน 2 เทคนิค ได้แก่ direct angle ในพื้นที่รังสีขนาด 10 × 10 และ 15×15 ตารางเซนติเมตรโดยวัดที่ระดับความลึกต่างๆในบริเวณbuild-upทดสอบในtangential technique โดยใช้ CIRS phantom โดยใช้ความหนาของ Superflabกำหนดระดับความลึกที่ทดสอบ ฟิล์ม EBT2 นำมาใช้วัดปริมาณรังสีใน 2 เทคนิค เปรียบเทียบกับการคำนวณของคอมพิวเตอร์วางแผนรักษาจากการใช้ข้อมูลลำรังสีจากชุดแรก (EDGE^{TM}) และจากข้อมูลชุดสอง (PFD) ผลการทดลองพบว่าใน direct angleของทั้งสองขนาดพื้นที่ลำรังสี ปริมาณรังสีที่ผิวที่ได้จากการคำนวณของ TPS ของทั้งสองชุดมีค่ามากกว่าการวัด อย่างไรก็ตามที่ระดับความลึก 2 และ 5 มม.การคำนวณของ TPS (EDGE^{TM}) ให้ค่าใกล้เคียงกับการวัดของ EBT2 มากกว่าการคำนวณของ TPS (PFD) โดยมีเปอร์เซนต์ความแตกต่างระหว่างการวัดอยู่ในช่วง 1.4%-5.5% ของ TPS (EDGE^{TM}) และ3.2% - 17% ของ TPS (PFD) ผลการทดลอง tangential technique พบว่า การคำนวณปริมาณรังสีที่ผิวของ TPS ทั้งสองชุด มีค่าสูงกว่าการวัด และการคำนวณของ TPS (EDGE^{TM}) ให้ค่าใกล้เคียงกับการวัดมากกว่า TPS (PFD) อย่างไรก็ตามการคำนวณของทั้งสองชุดมีค่าใกล้เคียงกันที่ความลึกอื่นๆ การศึกษานี้พบว่าการคำนวณของ TPS จากการใช้ข้อมูลลำรังสีพื้นฐานในส่วนของ PDD จากการใช้ EDGE^{TM}และ PFD ในการคำนวณบริเวณ build-upให้ผลไม่แตกต่างกันอย่างไรก็ตามควรเลือกใช้หัววัดรังสีที่เหมาะสมในการเก็บข้อมูลลำรังสีพื้นฐานเพื่อปรับปรุงความถูกต้องในการคำนวณของ TPS

74 หน้า

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (cont.)

LIST OF FIGURES (cont.)

LIST OF ABBREVIATIONS

Abbreviation	**Term**
cGy	Centigray
cm	Centimeter
cm^2	Square centimeter
cm^3	Cubic centimeter
d	Depth
d_{max}	Depth of maximum dose
mm	Millmeter
mm^3	Cubic millimeter
MLC	Multileaf collimator
MU	Monitor Unit
MV	Megavolt
OD	Optical Density
PDD	Percent depth dose
PFD	Photon diode detector
S_{cp}	Total scatter factor
SD	Standard Deviation
SAD	Source to axis distance
TMR	Tissue maximum ratio
TPS	Treatment planning system
% Diff	The percentage difference
AAA	Analytical Anisotropic Algorithm
MC	Monte Carlo

CHAPTER I
INTRODUCTION

In radiotherapy, an accuracy and precision of calculation of radiation dose is the most important which can affect to the patient treatment especially when tumor is closed to the surface/skin such as head and neck or breast cancer. It might lead to dose reduction of tumor dose which increases risk of recurrence or it might cause over dose which can increase side effect to the skin. In generally, radiation for breast cancer case will be done after the operation to get rid of the rest of cancer cell and decrease the chance of recurrence at chest wall area in case of mastectomy. Most of treatment plan for breast cancer use tangential technique as an oblique beam to adequate and uniform surface dose. The treatment planning system (TPS) must be investigated for the dose calculation accuracy in order to avoid unnecessary skin reactions or under dosing of near surface tumor.

Researchers have been studying about the accuracy of surface dose and build up region and found that the dose calculation is different from dose measurement.

Chung *et al* [1] studied the accuracy of surface dose and build regions for IMRT technique by using radiochromic film to measure dose at head and neck area from tissue equivalent. They found that calculating dose from pinnacle and corvus TPS were higher than measurement dose about 7.4% - 18.5%.

Dogan *et al* [2] studied the buildup dose by comparing measurement dose using parallel plate chamber and EDR2 film in flat phantom with calculating dose from convolution/superposition. It was shown that the calculated dose at surface area and 1mm deeper from the surface gave higher dose than that from the measured dose as 25% and 5%, respectively.

Akino *et al* [3] studied the dose accuracy at 3 mm depth for tangential technique at breast cancer. They found that the calculated dose was 15%-30% lesser than the actual dose

Many researchers found that the calculated doses at the surface and build up region using computer treatment planning are different from the measured dose which can be affected by many parameters such as limitation of calculating dose, incorrectly commissioning and limitation of choosing grid size in TPS.

For the megavoltage photon beam, the source of surface and buildup dose usually depend on machine configuration including the primary photon beam, backscattered radiation and electron contamination from accelerator head and air volume. The radiation dose contamination relies on machine head configuration, energy, depth, field size, air gap, and incident angle. An electron contamination is usually added to the convolution based three dimensional model in TPS accounting for dose contributed by electron contaminations in the buildup region. In the Anisotropic Analytical Algorithm (AAA) on Eclipse treatment planning system (TPS), the configuration model is based on pre-calculated Monte Carlo (MC) calculations using basic physical parameters and then adjusted to fit the beam data measurement. Therefore, accurate measured data impacts to the accurate dose calculation in the surface and buildup region. However, there are limitations in obtaining such accurate data from using detectors for beam commissioning which might give an over response at the surface and buildup regions due to perturbation in the contamination electron originated from different detector designs.

The sensitivity of EDGE™ detector is high due to brass composition and it contains very small active size of silicon diode and its position is closed and paralleled to the phantom's surface which is different from the photon diode detector (PFD). These are suggested that it might be a proper detector for measuring radiation dose in small area and also suitable for using in beam commissioning. Hence researcher aims to study the accuracy of treatment planning system to calculate dose at surface and build up region. By using the beam data measured by EDGE™ detector, the researcher expects to obtain the better accuracy of dose calculation when compared with Gafchromic®EBT2 film.

CHAPTER II
OBJECTIVE

The main objective of this research is to investigate whether the commissioning beam data using EDGE^{TM} detector can improve the accuracy of dose calculation at the surface and the buildup region from AAA algorithms version 8.9 in a tangential breast technique.

CHAPTER III
LITERATURE REVIEWS

3.1 Basic knowledge

3.1.1 Megavoltage photon beams

In radiotherapy treatment , high energy photon beams have some of the characteristics of photon beams such as surface dose, buildup region, D_{max} (the maximum dose), d_{max} (the depth of maximum dose) and the percentage depth dose (PDD) which are important to radiation treatment planning system. Figure 3.1 shows some of the characteristics of photon beams from a general percentage depth dose curve [4].

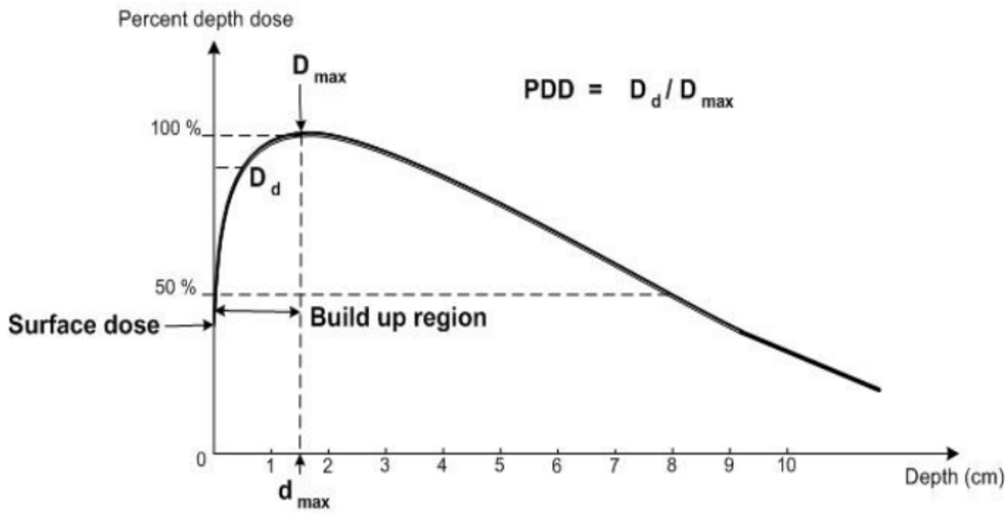


Figure 3.1 The percentage depth dose curve, 6 MV photon beams.

3.1.2 Surface dose

The surface dose is defined as the dose deposited at the boundary between the air and the phantom [5].The skin dose in an incident megavoltage photon beam consists of 2 components. The first component is from electrons created from photon interaction in the patient which of most electrons are scattered in a forword direction and the second component comes from electrons created from interaction prior to the phantom called electron contamination. It created from the head of accelerator or air column above phantom.The dose deposited on the surface depend on the amount of the scatter radiation. For example, a larger of field size will increase surface dose than a smaller field due to more scatter radiation of electrons and photons from the interaction of treatment machine configuration. However the surface dose decreases when energy increases because of the decrease of scattered radiation.

3.1.3 Build-up region

The build-up region is a region near the surface where the high dose gradient which is dose rapidly increase within the first few millimetres and get to its maximum value at the depth of the maximum dose as displayed in Figure 3.1. The result of dose build-up region was called a “skin sparing” effect. The higher energy, the greater skin-sparing effect with the maximum dose deposited at a depth related to energy of the photon beams. The build-up dose is comprised of the primary photon beam, backscattered radiation from the patient and contamination electrons.

3.1.4.Analytical Anisotropic Algorithm (AAA)

The AAA algorithm was implemented in the Eclipse (Variance Medical system) treatment planning system for the calculation of dose distributions for photon beams. The AAA was created to improve the dose calculation accuracy, in particular heterogenous media. It calculates total dose deposition as the superposition of the dose deposited by primary, secondary photon source and electron contamination source. This algorithm is a three dimensional pencil beam convolution/superposition algorithm where the configuration model used bases on pre-calculated Monte Carlo basic physical parameters which are adjusted to the measure beam data by the user. The photon dose is calculated as Monte Carlo precalculated scatter kernels, scale according to electron density metrix. For the configuration of AAA, the parameters are determined by characterizing the multiple source model from optimizing agreement between the calculated and measured depth dose curves and profile for the basic beam data.[6,7]

3.2 AAA calculation of Surface & build up dose in tangential field

Panettieri *et al* [6] studied the accuracy of calculation dose of AAA and PBC in commercial TPS Eclipse and used Monte Carlo (MC) for comparing in build up dose. The first step, they studied the effect of different beam data from different detectors to configure the AAA and PBC of TPS modeling. They found that the absorbed dose of PBC algorithm obtained the beam data using a plane parallel chamber showed lower dose than that of the PBC algorithm using RK chamber up to 80% in build up region due to the effect of small volume detector. But, for the AAA algorithm, the beam data for beam configuration found only insignificant difference in the calculated absorbed dose in build up region. This result was due to the AAA beam modeling from the primarily based on precalculated data from MC simulations for the accelerator model to use in calculation. After that, using a cylindrical phantom to approximate the breast contour of the patient. Calculation of the absorbed dose were performed for four different angles and field sizes. Moreover, a breast patient case was created with two opposed 6 MV photon beams and the AAA and PBC calculation were used to compare with MC simulation. The result of cylindrical phantom and patient cases for 6 MV photon beams showed that both of AAA and PBC algorithm tended to underestimate the absorbed dose compared to the MC result in build up region. It was concluded that the results of absorbed dose in the surface and build up region might fairly changed depending on the type of the algorithm and commercial TPS employed. It is important for assessing the limitations of each algorithm.

Akino *et al* [3] studied the accuracy of radiation dose in breast cancer with the assumption that the treatment planning system might not be able to give accurate dosimetry in the buildup region. The investigation was performed in various treatment techniques and compared with Gafchromic EBT2 film measurement. A humanoid acrylic phantom with layer of superflab bolus was used in the measurement. Treatment plans were created using four techniques with two different grid sizes which were of 1×1 and 2.5×2.5 mm^2. EBT2 films were placed at different depths and exposed with selecting techniques. Comparison of the calculated and measured dose profiles were separated by check point which were marked on the film before radiation. The results showed that the measured dose at a 3 mm depth was higher than that of TPS calculation by 15-30% for all techniques. In contrast, at deeper depth than 3 mm (6-11 mm depths), EBT2 film measurement showed good agreement with the TPS calculation. For tangential wedge field, using 1×1 mm^2 grid size showed a smaller different than 2.5×2.5 mm^2 grid size compared to the EBT2 film measurement.

James C. L. Chow *et al* [8] studied evaluating dose calculation of AAA and CCC algorithm using tangential photon beams and phantom geometry. Monte Carlo (MC) simulation was used to test performance of the TPS calculation with field sizes of 4×4, 10×10 and 20×20 cm^2 in 6, 15 MV photon beams with gantry rotated in 5º and 45ºanti-clockwise. For the gantry angle of 0^0, it was found that both the AAA and CCC overestimated dose at the surface phantom compared to the MC simulation with various field sizes and photon beam energies. The mean dose of skin profile difference are 10.5% ± 1.3% and 3.4% ± 0.9% for the AAA and CCC when comparing with the MC, respectively. The agreement between the AAA/CCC and MC becomes better when the field size of beam is 10×10 cm^2. The mean depth dose difference are 7.6% ± 2.6% and 2.1% ± 1.3% for the AAA and CCC at 6 MV photon beams, respectively. For oblique photon beams, it was found that the mean depth dose difference at 5º in both the AAA and PBC underestimated the phantom skin profile. This study was concluded that there are dosimetric deviation of the AAA and CCC when compared to the MC, especially in the tangential field technique. In particular, both AAA and CCC cannot accurately predict dose at depth less than 2 mm in which that location is important in radiation treatment site for breast chest wall and sarcoma.

Task Group 106 (TG-106) [9] recommended that the selection of detectors for commissioning beam data should be cautious in order to obtain the correcting beam data for beam configuration and the accuracy of dose calculation. This report studied the effect of the volume of various detectors for measuring dose at the surface and build up region for 10×10 cm^2 field size of 6 MV photon beams. The result was found that the relative dose value at those region were varied with different volume sizes of the detectors as shown in Figure 3.2.

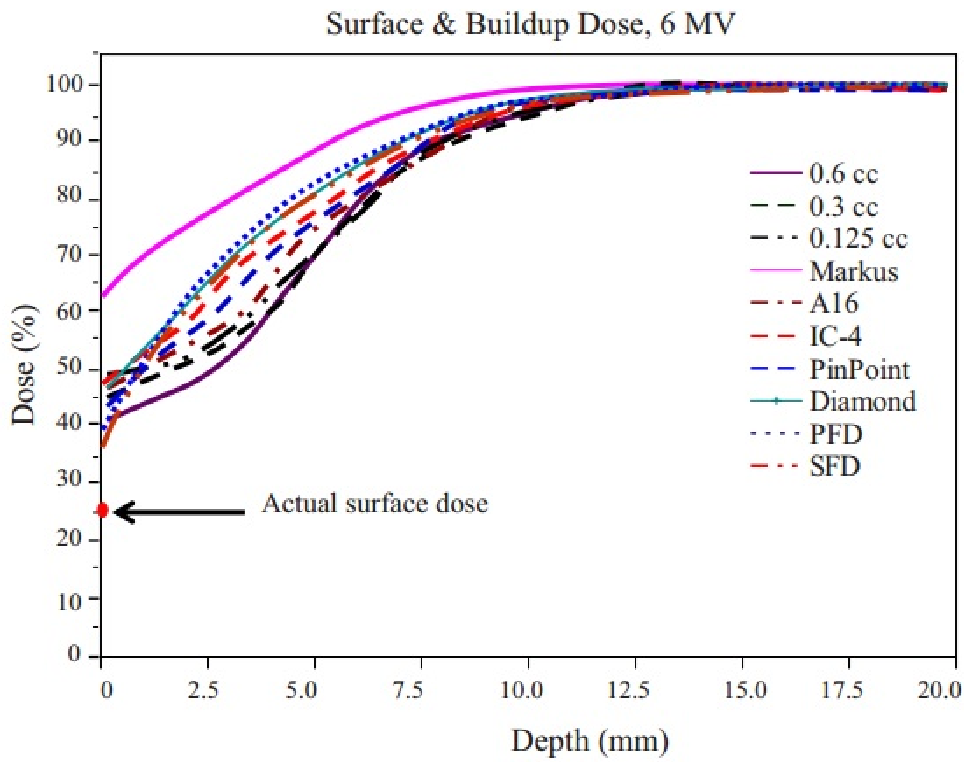


Figure 3.2 Surface and build up dose for 10×10 cm^2 field size of 6 MV photon beams with various detector.

At Ramathibodi Hospital, we have EDGE^{TM} detector which is claimed that it can be used to measure dosimetry in small field technique. With its characteristics which made from diode with sensitive volume of 0.0019 mm^3, the author is skeptical that whether or not it can improve the accuracy of the beam data measurement especially in the build up region which can lead to better accuracy of dose calculation for TPS in that area.

CHAPTER IV
MATERIALS AND METHODS

4.1 Materials

4.1.1 Linear accelerator

The Linear accelerator used in this experiment was ClinaciX which is manufactured by Varian Oncology System Palo Alto, CA as shown in Figure 4.1. It is a dual photon beam energies as 6 MV and 15 MV, field sizes range from 0.3x0.3 cm^2 to 40x40 cm^2 at 100 cm source to surface distance and six electron beam energies of 4, 6, 9, 12, 16, and 20 MeV. There are five stationary therapy dose rates range from 100-600 monitor units per minute and there are 120 tungsten MLC leaves. For this experiment, only 6 MV photon beam was used [10].

Figure 4.1 The Varian ClinaciX linear accelerator

4.1.2 Water phantom tank

Figure 4.2 shows the Bluephantom^2 (ScanditronixWellhoferDosimetric, Schwarzenbruc, Germany) made from acrylic. It has the scanning volume of 48×48×41 cm^3 and having the control by OmniPro-Accept 7.2 Software.The blue phantom consists of the control unit (CU 500E) with a three – dimensional servo and optional detector array.The control unit combines the controller and two channel electrometer. Several detectors can be used with the Bluephantom^2 such as the semiconductor detectors, cylindrical and plane parallel ionization chamber. This phantom is a device which is used to collect and analyze beam data of Linear accelerator and used to perform the percentage depth dose measurement in this study.TheOmniPro-Accept is a software which is used to control for collecting beam data input to the treatment planning system and analyze dose distribution for quality assurance [11].

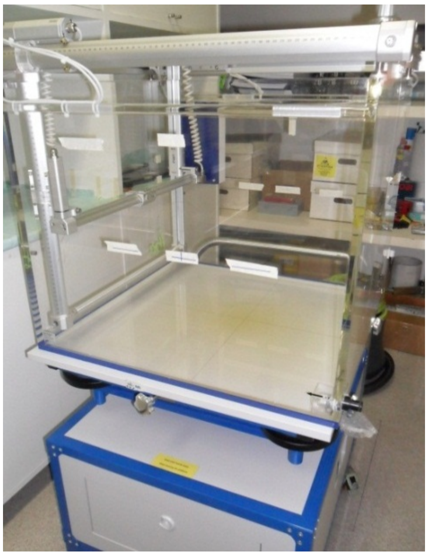


Figure 4.2 The Blue Phantom^2 (ScanditronixWellhoferDosimetric,Schwarzenbruc, Germany)

4.1.3 EDGE^{TM} detector

Figure 4.3 shows the EDGE^{TM} detector of Sun Nuclear corporation. It consists of brass housing wall 0.13 mm thickness. Its has a sensitive volume of 0.0019 mm^3 and active dimension of 0.8x0.8 mm with 0.3 mm from top and 4.3 mm from end.The detector has sensitivity of 32 nC/Gy,impendance> 200 Mohm at 10 mV reverse bias.The active element of this detector is a radiation-hardened silicon diode. This detector is waterproof. The construction detail of EDGE^{TM} detector is shown in Figure 4.4. The EDGE^{TM} detector is a device to measure beam data in radiotherapy such as beam profiles and PDD curves for dose modeling in the treatment planning system.The detector was used to measure the radiation beam data in any water tank scanning system and in this study it was used to collect the PDD curves for beam modeling [12].

Figure 4.3 EDGE^{TM} detector

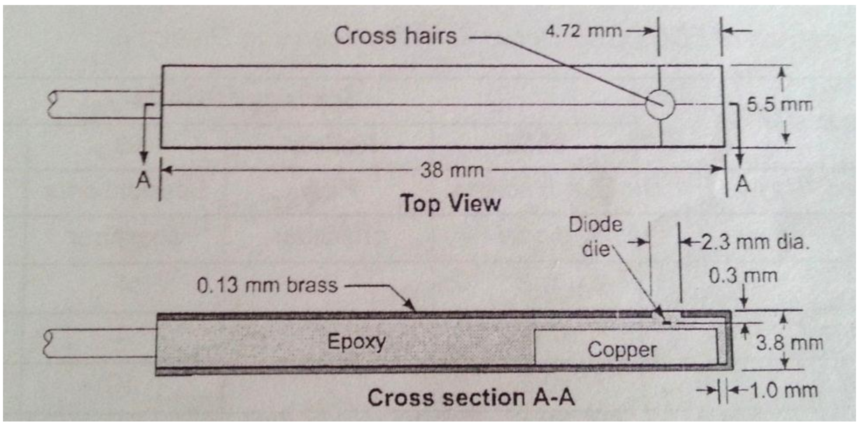


Figure 4.4 Construction detail of EDGE^{TM} detector

4.1.4 Photon Field Diode detector (PFD)

Figure 4.5 displays the Photon Field Diode detector (PFD) of ScanditronixWellhofer.Thedetector has a sensitive volume of 0.2-0.3 mm^3. The diameter of an active area detector is 2 mm and thickness of active volume 0.06 mm with circular shape.The detector is a p-type silicon detector with effective measurement point 0.5±0.15 mm, chip size (side/thickness) 2.5/0.5 mm. It was used for collecting the percentage depth dose as a reference to compare with that measured with EDGE^{TM} detector [13].

Figure 4.5 Photon Field Diode detector (PFD)

4.1.5 Solid water phantom

The solid water phantom material (Gammex RMI) is made of epoxy resins and powder control density and a radiation property with the density of 1.030 g/cm^3 and 5.96 effective atomic numbers. Its physical form is a square slab of 30x30 cm^2 with various thickness of 0.2 , 0.5, 1, 2, and 5 cmas shown in Figure 4.6 [14].

Figure 4.6 RMI solid water phantoms

4.1.6 Gafchromic®EBT2 film

Figure 4.7 shows Gafchromic® EBT2 film (International Specialty Product,Inc., Wayne, NJ) which is a radiochromicdosimetry film that has been developed specifically to use in dosimetryradiotherapy.This film is two-dimensional dosimeter with high spatial resolution (<0.1mm), near tissue equivalent (Z eff =6.84), water proof film ,low energy dependence (minimal response difference from 100 keV into the MV range).The EBT2 film is a self- developing film that changes color directly in response to radiation and does not require chemical processing .The film has minimal daylight sensitivity which can be handled in lightroom.The component of Gafchromic® EBT2 film is shown in Figure 4.8.The EBT2 film is consisted of a a single active layer with thickness of 30 μm and 5 micron-thick topcoat. It has the clear 175 μm polyester substrate and 50 μm polyester over-laminated to coat the active layer in order to protect the active layer.The EBT2 film has dose range of 0.01-8 Gy. The Gafchromic®EBT2 film used in this measurement was lot # A09271201. The expire date is in September, 2014. In this study, the EBT2 film was used for point dose measurement at the surface and buildup region [15].

Figure 4.7 GafChromic®EBT2 film

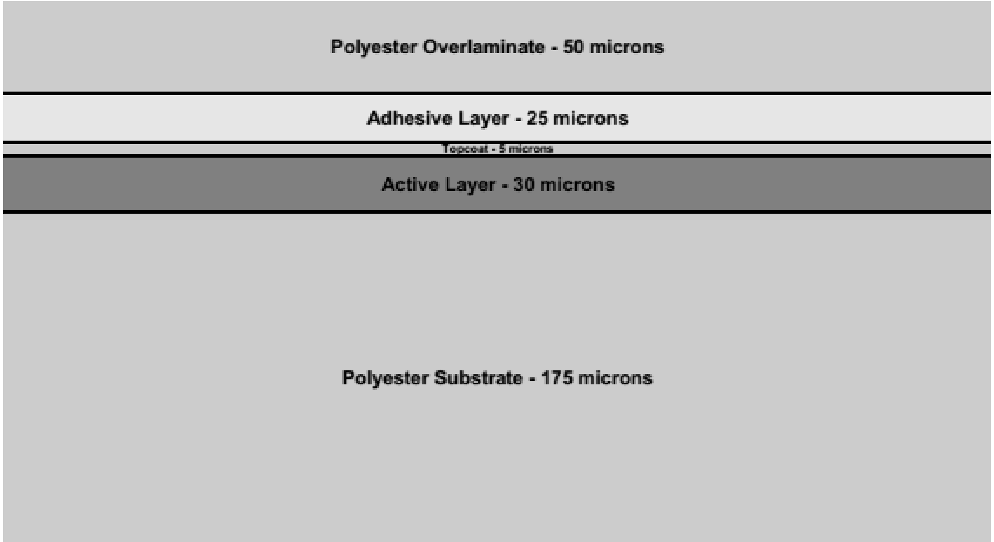


Figure 4.8 Components of the Gafchromic EBT 2 film

4.1.8 Film digitizer with OmniProI'mRT software

Figure 4.9 shows the VIDAR's DosimetryPROAdventage (Red) (Vidar systems Corporation, Herndon,VA USA). It is a film digitizer which was used for dosimetry in this measurement. This scanner has scanning resolutions of 71 ,75,142,150,285,300 dpi ,available bit depths of 8,12,16 ,32 bpp and optical density ranges from 0 to 4.0. The scanner uses a long light source to illuminate film and image on film is projected on 2- dimension CCD array. This scanner has red LED light source with maximum emission of 627 nm which is closely matched to the absorption peak of EBT2 film at 636 nm. In this study,the films was scanned with 16 bit grayscale and spatial resolution of 71 dpi. The OmniProI'mRT is a software to verify treatment plan and quality assurance of IMRT ,IGRT and Rotation treatment.This software compares TPS planed data with measured data to verify quality assurance and it can be used multiple profile analysis [16].

Figure 4.9 VIDAR's DosimetryPROAdventage (Red)

4.1.9 CIRS phantom

As shown in Figure 4.10, the CIRS Model 002LFC IMRT Thorax Phantom with size of $30\times30\times20$ cm^3 consists of tissue equivalent eproxy materials . This phantom is elliptical in shape and represents a human torso in two dimensional structure. The dose measurement can be done by placing an ionization chamber into the rod provided for point dose measurement. In this study, the EBT2 film was used to place on the surface of this phantom for verification treatment planning [17].

Figure 4.10 CIRS Model 002LFC IMRT Thorax phantom

4.1.10 Eclipse^{TM} Treatment Planning System

Eclipse^{TM}TPS (Varian ,Palo Alto,USA) is a window based operating system. Anisotropic Analytical Algorithm (AAA) version 8.9 was used to generate photon dose distribution in this study. The AAA is the 3D pencil beam convolution/superposition algorithm which uses separate Monte Carlo to derive modeling and use the commissioning beam data from measurement for beam configuration.

4.1.11 CT simulator

The Discovery CT590 RT, CT simulations 16 slice (GE Healthcare) was used and shown in Figure 4.10. It is a spiral computed tomography system which creates the cross-sectional imaging for radiation therapy planning. The gantry aperture is 80 cm diameter to support the patients with immobilization device. The true size scan field of view is 60 cm.

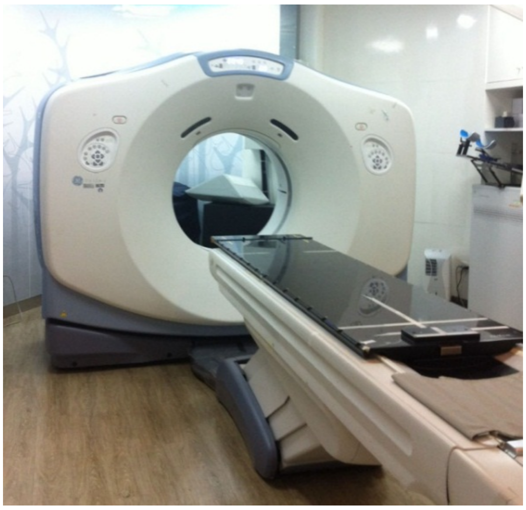


Figure 4.11 The Discovery CT590 RT (GE Healthcare)

4.1.12 Superflab Bolus Material

Superflab Bolus Material is made of synthetic oil gel having specific gravity of 1.02.This slab is a tissue equivalent bolus substance which is elastic and quite flabby. It is a sheet of flexible plastic material which can be applied to the surface of a patient to avoid the skin sparing effect of megavoltage photon beams and some mgavoltage electron fields.This bolus can be used to compensate for an irregular patient contour to adjust flat isodose line and to prevent hot spot on the patient surface. Superflab Bolus Material has various thicknesses which provide maximum dose buildup for photon energies. In this study,this bolus was used to create depths in the buildup region for measuring buildup dose.

4.2 Methods

The methods of this study are consisted of three main procedures. There are a collection of the beam data, beam configuration which performed in the AAA 8.9 algorithm on the Eclipse treatment planning system and verification of the treatment planning system with the dose measurement.

4.2.1 Collection of the beam data

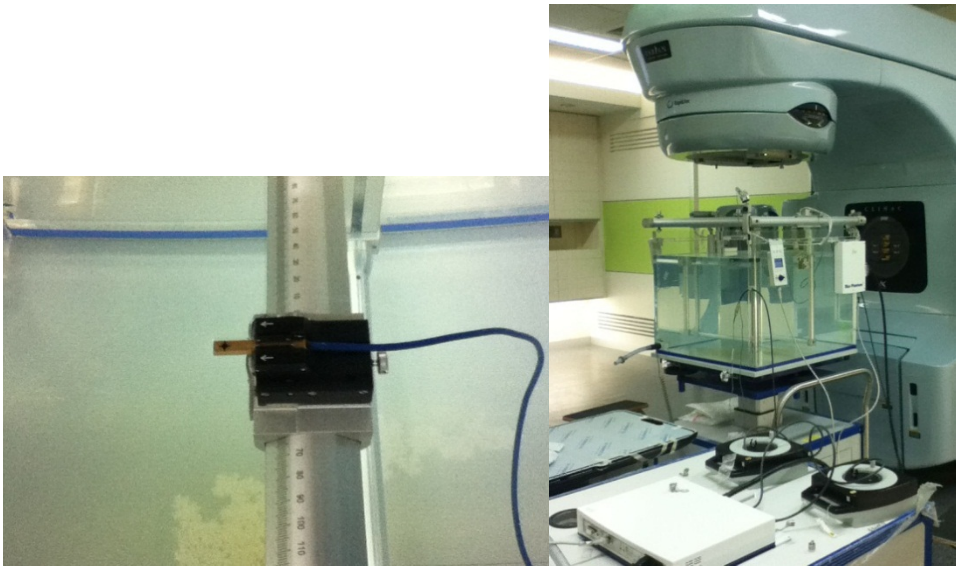
The AAA algorithm is used for dose calculation which is modeled from Eclipse beam configuration task. According to the Beam Configuration Reference Guide, it requires specific measured beam data for 6 MV photon beams and parameters from linear accelerator's machine data for beam configuration. The commissioning beam data includes percentage depth dose (PDD), output factor, and beam profile which were measured directly by users. In this study, there were two beam data sets measured from two different detectors to configure two modelings of 6 MV photon beams in the TPS. For the first set, the EDGE^{TM}detector was used to measure the PDD of 6 MV photon beams for open and wedge fields. The output factor and beam profile were measured with the photon field diode detector (PFD). For the second set, the PFD was used to collect all beam data. Also the process of measurement was the same as that of the first set. At this point, it is worth mentioned that the Division of Radiation Oncology, Ramathibodihospital has been currently using the second set of beam data for treatment planning in the clinic for 4 years. Therefore, the second set was not configured by the author.

4.2.1.1 Measurement of the percentage depth dose (PDD)

The EDGE ^{TM} detector was used to measure the depth dose curves for completing the first set of beam data. For open fields, the depth doses were measured on 2x2, 3x3, 4x4, 5x5, 6x6, 8x8, 10x10 ,12x12, 15x15, 20x20, 25x25, 30x30, 35x35 and 40x40 cm^2. They were performed at 100cm SSD in the Blue phantom^2. The field sizes ranging between 2x2 and 5x5 cm^2 were collected depth doses in "the step by step" mode with 2 mm step width due to the limitation to place a reference detector in the field. Other field sizes used the continuous mode. For wedge fields, wedge 30° was used to measure depth doses with field sizes of 2x2, 3x3, 4x4, 5x5, 6x6, 8x8, 10x10, 12x12,15x15, 20x20, 20x40 cm^2. For wedge field collection method, the “step by step” mode on field sizes less than 5 cm^2 were also used and other field sizes used the continuous mode. The EDGE ^{TM} detector was scaned to a maximum depth of 310 mm. Depth dose curves for all field sizes were normalized to the same depth of maximum dose (d_{max}) which was 1.5 cm.

i. Setup Blue phantom^2 and EDGE^{TM} detector

The Blue phantom^2 was adjusted so that the cross hairs of this phantom in the X and Y direction were overlaped to the cross hair of the light field at the maximum field size. At the isocenter, it showed the intersection point of the cross hair. Next, water was filled in the phantom and the SSD of 100 cm was set at the water surface. To check the water level in x,y and z directions, a spirit level was used. The Common Control Unit (CCU) was connected between the detectors and a PC with Omnipro-Accept version 7.2 by the Ethernet cable. The EDGE^{TM} detector was placed in a holder of the phantom. The detector was set to the isocenter of the beam. Its axis was set perpendicular to the central axis. A small spririt level was used for checking the detector level. The detector was moved along x,y,z directions in order to check whether the center of the detector aligns to the crosshair. After that, the detector was moved to the central axis at the surface. The effective point of measurement of EDGE^{TM} detector is 0.3 mm which was placed exactly at the water surface controlled by the Omnipro-Accept software. Figure 4.12 shows the setup of Blue phantom^2 and EDGE^{TM} detector.



a) b)

Figure 4.12 Setup the EDGE ^{TM} detector at the surface (a) and the Blue phantom^{2} was setup to measure the depth doses with Variance ClinaciX linear accelerator (b)

ii.Setup program

The Omnipro-Accept version 7.2 is used for beam scanning by setting the parameters which were used to define radiation device, field size, depth, energy, detector, phantom and SSD. The depth dose was selected to measure depth dose which is along the Z axis. The EDGE^{TM} detector was used to measure depth dose at 6 MV photon beams and set the effective point of measurement of detector at 0.3mm. For open field, the step by step for a scan mode was selected for field sizes ranging between 2×2 and 5×5 cm^{2} and with wedge 30 degree for field sizes less than 5×5 cm^{2}. The step type was selected as an Equidistant. The scaning step distance as 0.5 mm and scan speed as 1.0 mm/s were used. For other field sizes of both open and wedge fields, the continuous mode was chosen for scaning mode.The accuracy of position of the scanning is ±0.1 mm per axis and its reproducibility is ±0.1 mm. All fielid sizes of beam data depth doses were normalized to the depth of maximum dose.

4.2.2 Beam configuration of the Anisotropic Analytical Algorithm (AAA)

The AAA configuration program requires a specific measured beam data and parameter values which are the measurement geometry and physical characteristics of the beam. In this study, the TPS from the first set beam data was used for beam configuration previously mentioned in 4.2.1 of both open fields and wedge fields. The beam data for the first set was consisted of depth doses measurement by the EDGE^{TM} detector, beam profiles, output factors and diagonal profiles in which all beam data were converted into ASCII file format before imported to the beam data library of configuration processing. The followings are the the steps of beam configuration. Firstly, starting Eclipse application and selecting the beam configuration. After that the user selected the treatment unit and enegy photon beams. This study used the Linac 2 #5288 at 6 MV photon beams. Next, clicking the energy list and selecting the AAA calculation model and creating the new beam data. Then, selecting general parameters and defining nominal energy, source axis distance, source phantom distance, smallest and largest open beam, number of profiles and depths. Selection of parameter to fill the absolute calibration values in the table which showed in display. Next, highlighting the therapy unit name and selecting New Add-on for selection the Open field Add-on type. When the user highlighted the open field that can import the diagonal profiles data, depth dose data, profiles data and output factors which all beam data is w2cad format. Finally, selecting “calculate beam data” for calculation of AAA modeling. This AAA required the quality assurance process to determine the accuracy of the calculation that seem the trend of calculation compared with the measure beam data.The modeling verification is analyzed by criteria for acceptability of comparison the calculated and measured data.In this study, the accurate calculation of TPS predicted the depth dose was done in open field on field sizes of 5×5, 10×10 and 20×20 cm^2. The acceptance criteria are usually shown as the dose deviation and distance to agreement (DTA) in a geometrical concept, low and high dose gradient region. The DTA was defined as the distance between a reference data point and the nearest point in the same dose value and the deviations (δ) referred to the comparisions of dividual calculated and measured points. The criteria of acceptability for the deviations (δ) according to Venselaar *et al*.[18].

4.2.3 Comparision and verification of the treatment planning system

This method is performed by the following steps:

4.2.3.1 Treatment planning

Two techniques, direct angle and tangential techniques were performed in the TPS. Two commissioning beam data, from EDGE™ and PFD detector were used for TPS beam calculation. The grid size at 1×1 mm^2 and 2.5×2.5 mm^2 were set for the dose calculation.

i. Direct angle

The solid water phantom was used to verify in this technique. Various thicknesses of solid water phantom were used to vary depth of 7 sets for verification namely 0, 2, 5, 10, 20 and 50 mm. Each set thickness of solid water phantom always contains 15 cm thickness of solid water phantom placed under the depth of verification to fulfil full back scattering. The EBT2 film of 3×3cm^2 were cut from the sheet of film that were placed at the center of the phantom at depth for verification mentioned previously. After that the solid water phantom of seven sets were taken into CT scanning as shown in Figure 4.13. The CT images of seven set image were imported to the TPS in which the treatment plans were created by using direct angle for field sizes of 10×10and 15×15 cm^2 and 200 MU was prescribed at depth 5 cm for 6 MV photon beams, 100 cm SAD technique. The number of plans in this technique contained fourteen plans. The example of the direct angle plan of field size 10×10 cm^2, 2 mm thickness of solid water phantom for depth verification is displayed in Figure 4.14.

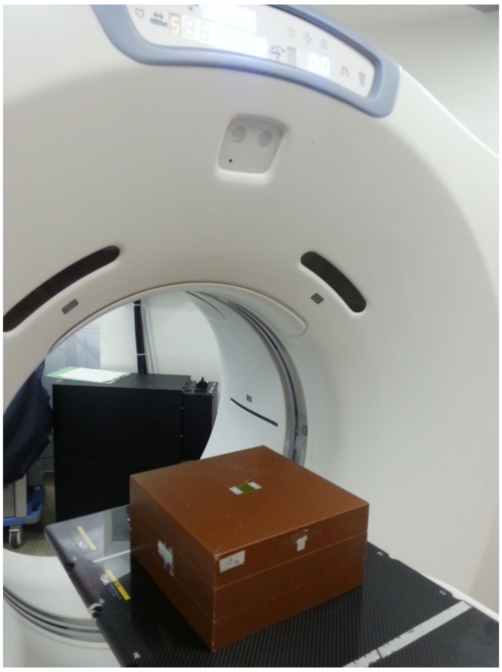


Figure 4.13. Setup of the solid water phantom with EBT2 film placed at the surface for CT scanning.

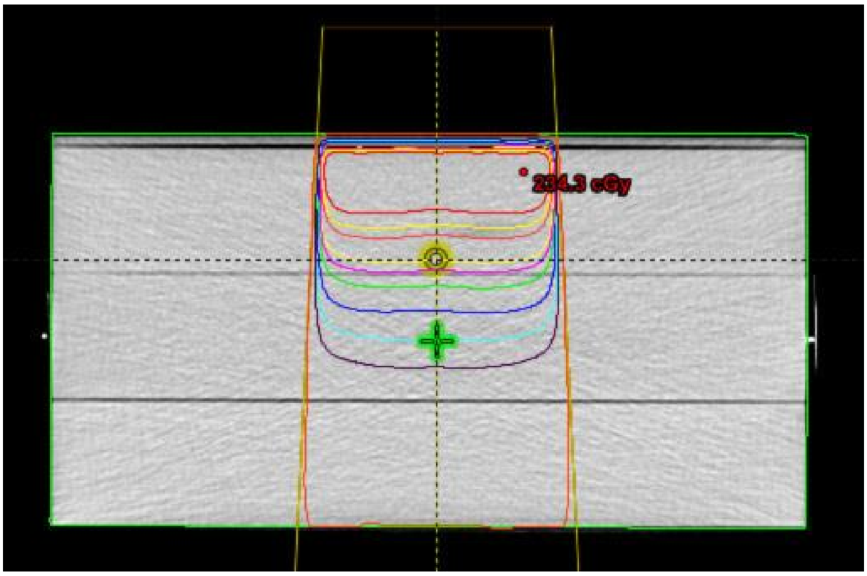


Figure 4.14. Isodose distribution of 10×10 cm^2 field size was generated on the solid water phantom of 2 mm depth for verification, 200 MU was prescribed at depth 5 cm, 100 cm SAD technique for 6 MV photon beams.

ii.Tangential technique

The CIRS phantom was used to investigate in this technique. Various Superflab^{TM} thicknesses mimicking breast tissue were placed on the CIRS phantom to form the buildup region.Three sheets of Superflab boluses were spread on the CIRS phantom; two sheet of 3 mm thickness and another one sheet of 5 mm thickness.The EBT2 filmwas cut into 3×25 cm^2 strips for 4 strips which were put between the Superflab^{TM} bolus layer to represent the depths in breast for dose verification at surface, 3, 6 and 11 mm as shown in Figure 4.15. The CT images of the phantom were transferred to the TPS and the treatment plan was then created using tangential two opposed beams (50.6° and 224.9°) with 30°wedge as shown in Figure.4.16. The plans were delivered to Varian ClinaciX of 6 MV photon beams for irradiating of the film measurement.

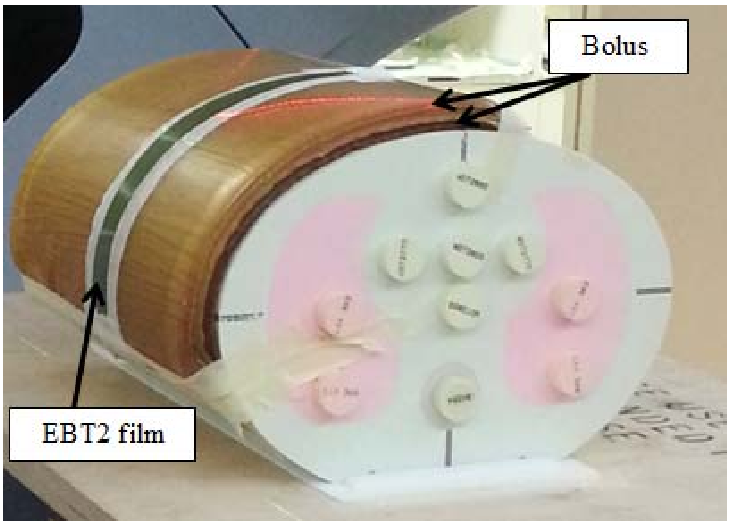


Figure 4.15.Superflab bolus were spread onto the CIRS phantom to simulate the breast tissue at thickness of 3, 6, and 11 mm and EBT2 film strips with size of 3×25 cm^2 were placed on the bolus surface and also between bolus and phantom surface at depth 3, 6, and 11 mm.

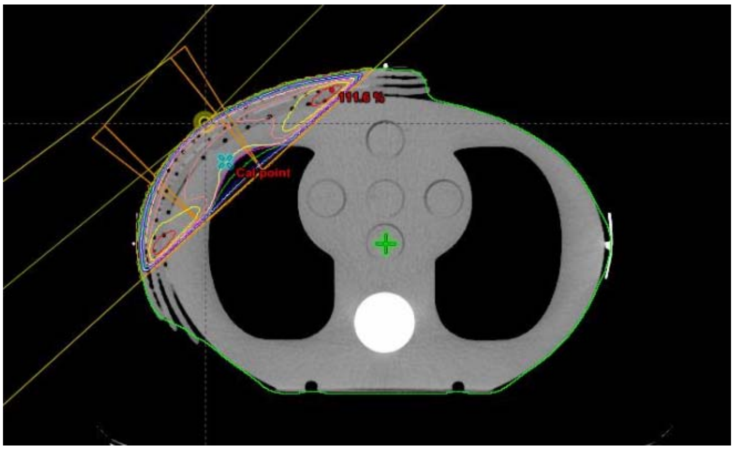


Figure 4.16. Isodose distribution of tangential planning using CIRS lung phantom with Superflab bolus sheets to represent dose at surface and buildup region.

4.2.3.2 EBT2 Film measurements

i.Calibration curve

In this study, all the EBT2 films from the same batch were used for experiment and calibration procedure. The calibration curve for dose versus pixel values was taken as the day of experiment. The EBT2 film was prepared for the calibration film by cutting each film into 3×3 cm^2 square pieces for 16 pieces. Pieces of EBT2 film were placed on the solid water phantom perpendicular to the central axis of the beam and irradiated by 6 MV photon beams with known absorbed dose given to each film by using SAD technique at depth 1.5 cm. The radiation output was calibrated to be 0.7780 cGy/MU for field size 10×10 cm^2 at depth 10 cm, 100 cm SAD technique. Pieces of EBT2 film were put on the solid water phantom at depth 1.5 cm with 10×10 cm^2 field size.The range of dose was 0-400 cGy. Table 4.1 shows the MU setting for exposing films in the experiment for calibration curve at depth 1.5 cm. However, in this study, comparing between the calibration curve of EBT2 film at 1.5 cm and 5 cm depth with 10×10 cm^2 field size found that dose measurement of both calibration curves shows no differernce of each other. All the EBT2 films were scaned at least 24 hours after film exposure. The Vidar film digitizer was used to scan all the films. It was operated with pixel resolution of 71 dpi(dot per inch) and Bit depth 16 bpp. The red colour channel was extracted for the scanning and processed using commercial software OmniProI'mRT. This software was taken to analyze point dose of the film measurement in this study.

The MU setting for calibration film measurement using SAD technique were calculated by

$$MU = \frac{PD}{D_0 * S_{cp} * TMR} \quad (1)$$

PD =Prescribed Dose (cGy)\

D_0 =0.778cGy/MU at depth 10 cm, 100 cm SAD technique

S_{cp} =Output factor

TPR =Tissue phantom ratio is equal 1.2853 for field size $10\times10cm^2$, depth 1.5 cm

Table 4.1 The MU setting for exposing the films in calibration curve measurement for open field size of $10\times10\ cm^2$ at depth 1.5 cm.

Dose (cGy)	MU	Dose (cGy)	MU
0	0	180	180
25	25	200	200
50	50	220	220
75	75	240	240
100	100	280	280
120	120	320	320
140	140	360	360
160	160	400	400

ii.Measurements

1) Verification of EBT2 film with NACP detector

In this study, NACP detector was used to compare the absoluted dose point with EBT 2 film measurement in order to make sure that the of EBT2 can be used as a reference detector in this study. NACP detector is plane parallel chamber. It is made from mylar foil and graphite with active volume size of 0.16 cm^3. NACP detector was used in the solid water phantom and water phantom. The calibration factor of NACP detector was obtained from the cross calibration with the CC 13 chamber at depth of 10 cm for field size of 10×10 cm^2 at SAD technique for 6 MV photon beams. After that, to compare with film measurement, by exposing 200 MU at depth of 5 cm, 100 cm SAD technique for 6 MV photon beams, NACP detector was placed at depth of 0, 2, 5, 10, 15 and 20 mm one at a time with 10×10 ,15×15 cm^2 field sizes in both solid and water phantom to obtain point dose.

2) The measurement of direct angle

A point dose of the film measurement was used to validate the accuracy of dose calculation of two TPS modeling which performed on both of the measured beam data measured by EDGE^{TM} and PFD. The EBT 2 film was cut into 42 pieces with dimension 3×3$cm^2$of both field sizes 10×10 and 15×15 cm^2 treatment plans to verify point dose with dose calculation in TPS. For this method, the conventional treatment plan were verified in seven sets of depth at surface and build up region, namely at surface, 2 ,5, 10, 15, 20, and 50 mm. The treatment plans with grid size for dose calculation of 2.5×25 mm^2 were transferred to the Clinac iX linear accelerator for verification with measurement. The phantom has a thickness of 15 cm which was placed under the film to fulfil the full back scatter radiation. For the measurement, each set of depth for this treatment plan were measured by EBT2 film piece placed at the center of solid water phantom between the slab of depth in each set and 15 cm solid water phantom. This method repeated three films in each set. The Vidar DosimetryPro was used to scan all the films after irradiated 24 hr. Point dose was analysed and compared between phantom measurement and dose of TPS. Figure 4.17 shows the film measurement of solid water phantom in buildup region at 20 mm depth, field size of 10×10 cm^2.

Figure 4.17. The measurement of direct angle at depth of 20 mm verification and field size of 10×10 cm^2.

3) The measurement of the tangential technique

For tangential beam measurement, the CIRS phantom was coverd by different thicknesses of Superflab layer to simulate depth in buildup region. EBT2 film was cut into 3×25 cm for 4 sheets which placed on the CIRS phantom at surface and 3 , 6, 11 mm in between Superflab bolus sheets. This method was measured three times to obtain an average point dose in each position on the film. The ClinaciX Linear accelerator was used for irradiation. Before irradiation, the gantry and the position of the central axis of both angles were marked in order to refer to the same position of the tangential plan. After irradiation 24 hr, all films were scanned in the same manner as in calibration curve process. Figure 4.18 shows the measurement of tangential technique in lateral field with beam angle of 224.9 degree.

Figure 4.18. The measurement of tangential technique in lateral field with beam angle of 224.9 degree.

CHAPTER V
RESULTS AND DISCUSSION

5.1. The percentage depth dose measurement

The EDGE™ detector was used to measure the percentage depth dose for AAA beam modeling in this study.The percentage depth dose was measured for open field sizes of 2×2, 3×3, 4×4, 5×5, 6×6, 8×8, 10×10, 12×12, 15×15, 20×20, 25×25, 30×30, 35×35 and 40×40 cm^2,for wedge field sizes of 2×2, 3×3, 4×4, 5×5, 6×6, 8×8, 10×10, 12×12, 15×15, 20×20, and rectangular field of 20×40 cm^2. For the surface dose, the percentage depth dose using EDGE™ detector showed lower number than using PFD for all field sizes, up to -10.3% and -10.7% in both open and wedge field, respectively. The example of PDD obtained from using EDGE™ and PFD detector in 10×10 cm^2as shown in Figure 5.1 and percentage surface dose for all field sizes as displayed in Table 5.1.It is because of the effect of the volume of the detector. The PFD detector has bigger volume than the EDGE™ leading to dose from PFD was averaged. According to AAPM report of TG-106 [9], it recommends that the selection of the detector is essential. The different volume of the detector can result in the different surface and build up dose.

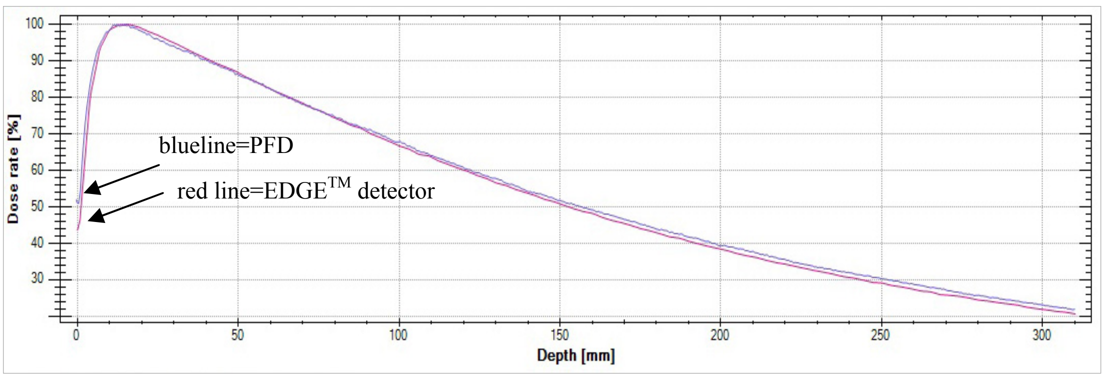


Figure 5.1 The percentage depth dose obtained from using the EDGE™ detector and PFD with field size of 10×10 cm^2 open field.

Table 5.1 The percentage surface dose obtained from using EDGE^{TM} and PFD detector for all field sizes in open field (a) and wedge field 30^0 (b).

Field size (cm^2)	**%Surface dose**		**Diff**
	EDGE^{TM}	**PFD**	
2×2	37.3	47.6	-10.3
3×3	39.1	47.9	-8.8
4×4	40.9	48.7	-7.8
5×5	40.3	49.4	-9.1
6×6	39.5	46.2	-6.7
8×8	41.4	47.7	-6.3
10×10	43.8	49.4	-5.6
12×12	45.7	51.1	-5.4
15×15	48.3	53.5	-5.2
20×20	53.7	57.4	-3.7
25×25	57.4	60.9	-3.5
30×30	60.9	63.7	-2.8
35×35	63.9	66.4	-2.5
40×40	66.5	68.6	-2.1

(a) Open field

Field size (cm^2)	**%Surface dose**		**Diff**
	EDGE^{TM}	**PFD**	
2×2	32.8	43.5	-10.7
3×3	34.1	43.6	-9.5
4×4	35.1	44.2	-9.1
5×5	35.2	41.9	-6.7
6×6	36.3	42.9	-6.6
8×8	38.5	44.4	-5.9
10×10	40	46.1	-6.1
12×12	42.2	47.8	-5.6
15×15	45.4	50.4	-5
20×20	49.6	54.8	-5.2
20×40	56.3	60.6	-4.3

(b) Wedge field

5.2 The results of beam configuration

The AAA beam modeling needs to be evaluated for the performance of the algorithm before using in the calculation in treatment plans for this study. To evaluate the beam configuration using the criteria for acceptability of dose calculation model in the TPS, Venselaar's criteria was used. In beam configuration task, it was found that deviations between results of calculated and measured data can be expressed as the following equation:

$$\delta = 100\% \times (D_{calc} - D_{meas}) / D_{meas} \quad (2)$$

Different tolerances of δ are suggested for different regions in the beam which can be discriminated according to the paper of Van Dyk et al[19] and the report of AAPM Task Group 53[20], as:

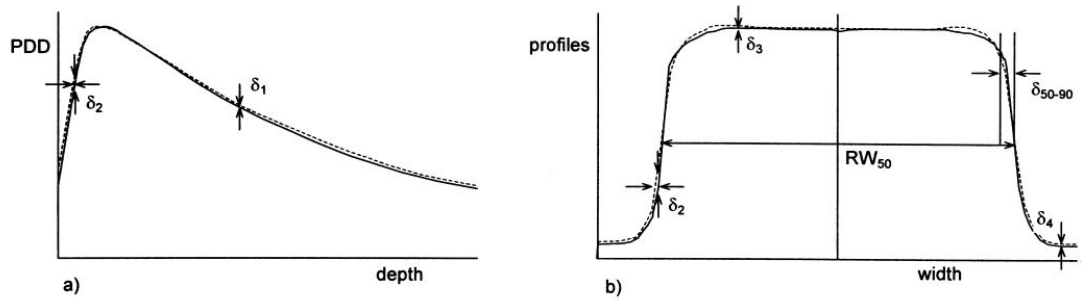
δ_1 = for data points on the central beam axis beyond the depth of d_{max}

δ_2 = for data points in the build up region

δ_3 = for data points beyond d_{max}, within the beam but outside the central beam axis

δ_4 = for data points off the geometrical beam edges

The regions of validity of the previously mentioned criteria are shown in Figure 5.2. The criteria of acceptability for δare followed from Vanselaar et al [18] as shown in Table 5.2.



(a) (b)

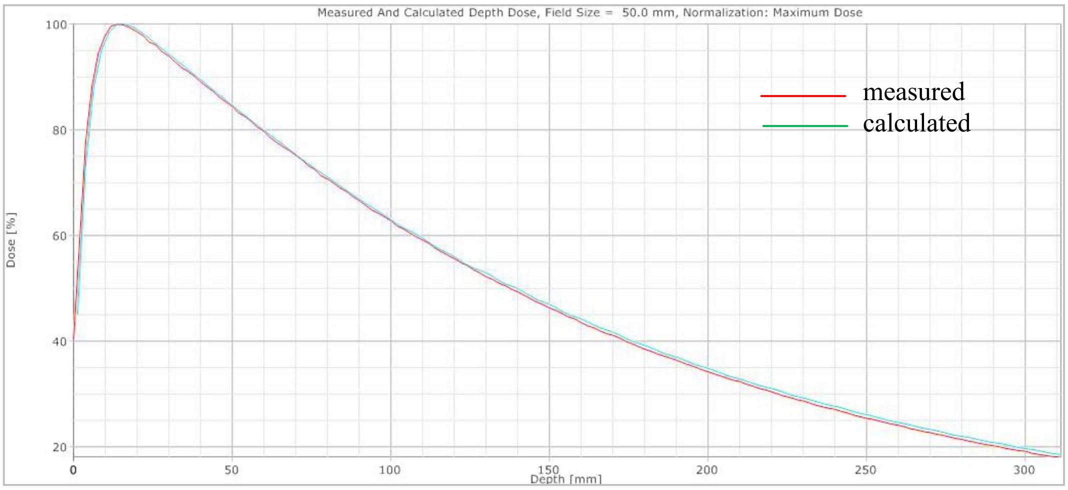
Figure 5.2 Region of validity of criteria δ_1 - δ_4 to compare between the calculated and measured depth dose(PDD) curves (a) and beam profiles (b).

Table 5.2 Proposed values of the tolerances for δ for application in different test configurations [18]

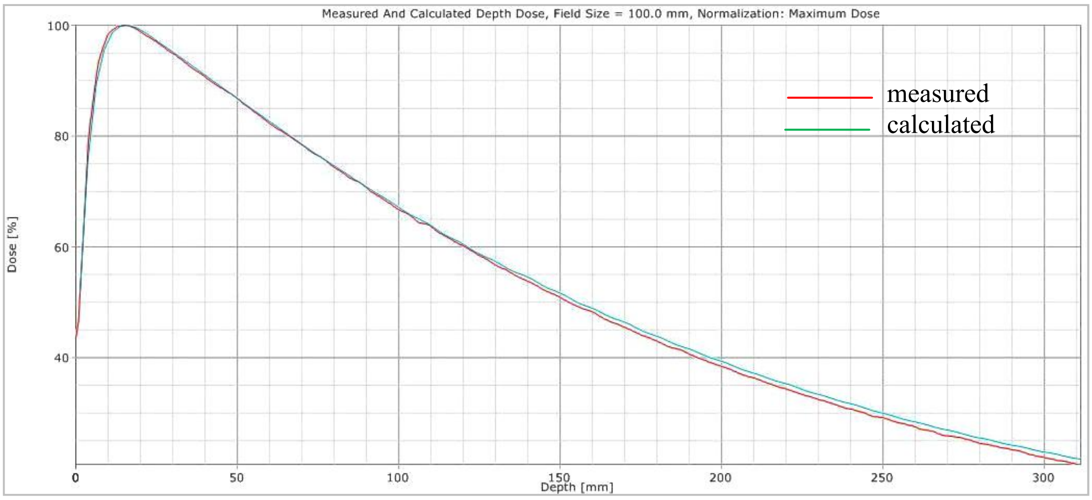
Tolerance	Homogeneous, simple geometry
δ_1 (central beam axis data)	2%
δ_2 (build-up region of central beam data)	2 mm or 10%
δ_3 (outside central beam axis region)	3%
δ_4 (outside beam edges)	3%
RW_{50} (radiological width)	2 mm
$\delta_{50\text{-}90}$ (beam fring)	2 mm

In the beam configuration, only the comparison between the calculated and measured PDD was performed to check whether the AAA modelled by EDGE^{TM} detector measured data was accepted or not, for field sizes of 5×5, 10×10, 20×20 cm^2 for both open fields and wedge field in TPS modeling as shown in Figure 5.3 (a,b,c,d,e,f). The results of depth dose validation in all field sizes are displayed in Table 5.3.

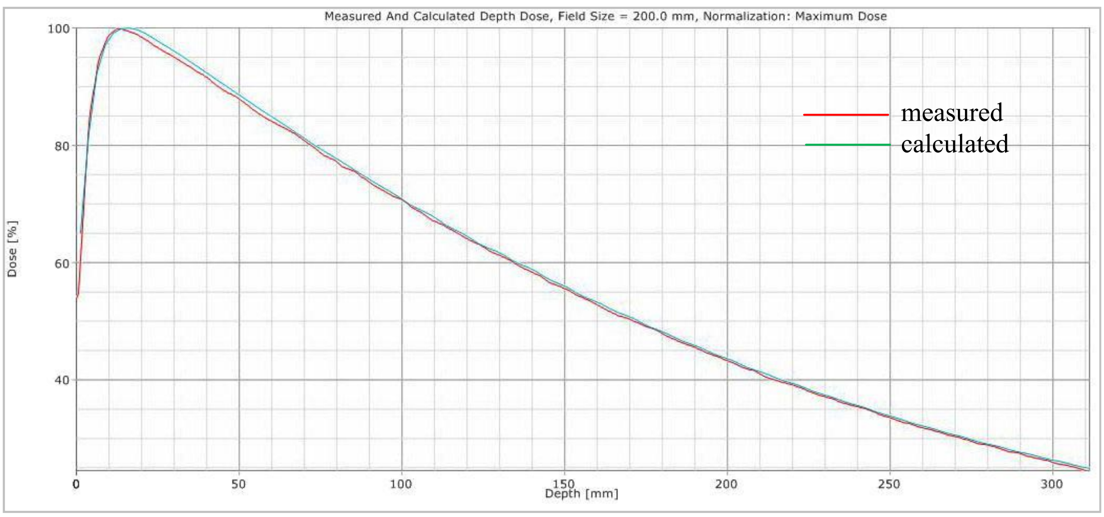
According to Table 5.3,it was found that the AAA modeled by the beam data obtained from EDGE^{TM} detector is efficient enough to calculate dose in treatment planning.



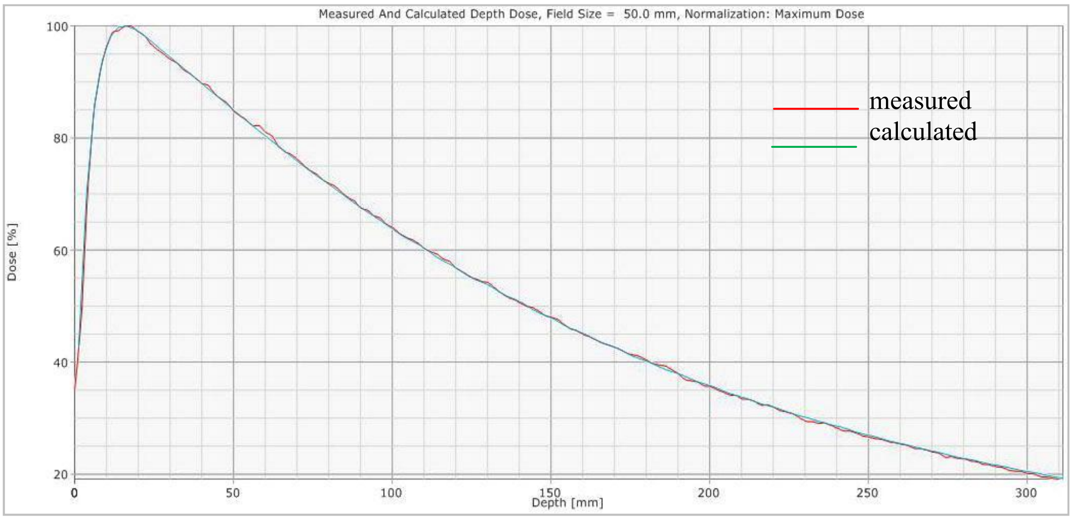
(a) field size 5×5 cm^2, open field



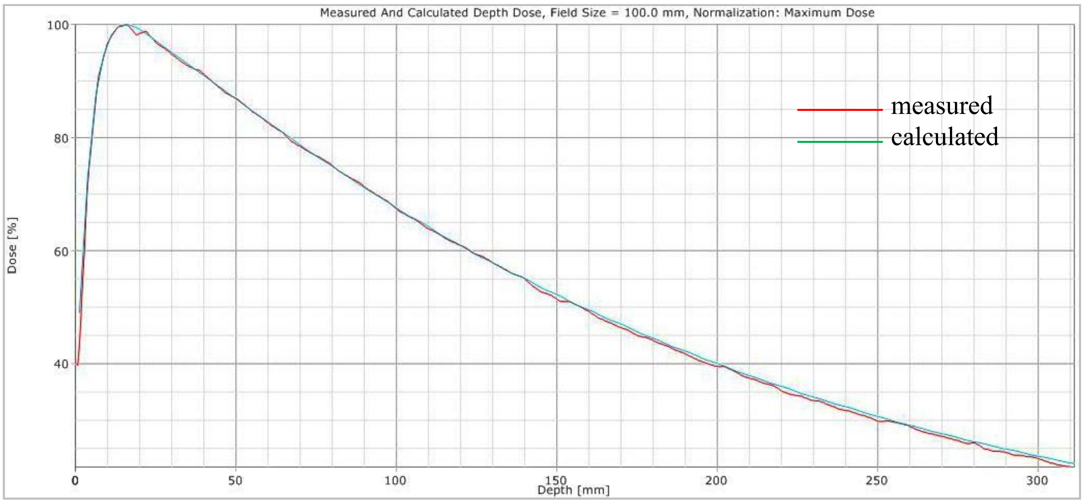
(b) field size 10×10 cm^2, open field



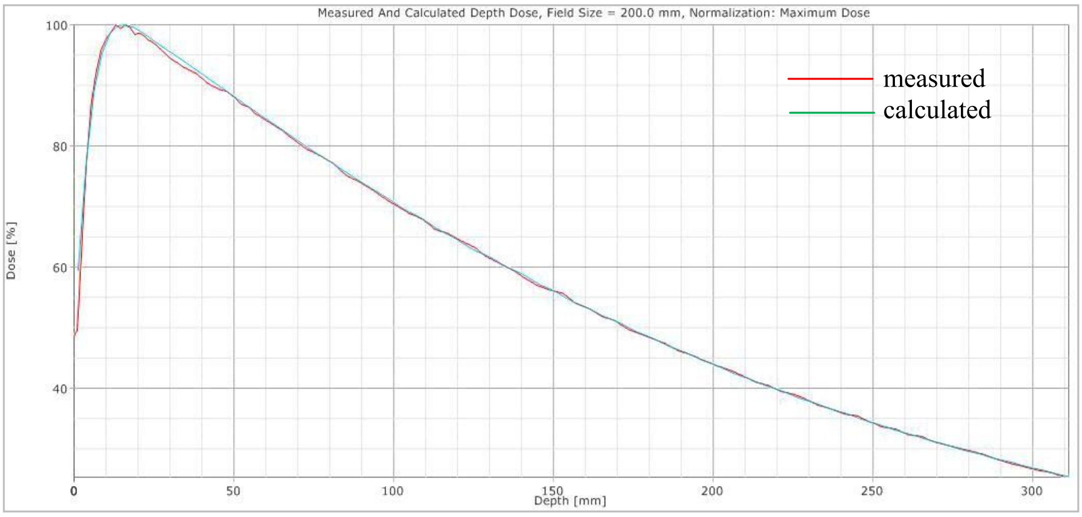
(c) field size 20×20 cm^2, open field



(d)field size 5×5 cm^2, wedge field



(e)field size 10×10 cm^2, wedge field



(f) field size 20×20 cm^2, wedge field

Figure 5.3. The percentage depth dose (PDD) curves compared between the measured and calculated depth dose in the beam configuration task for open fields a) field size 5×5 cm^2, b) field size 10×10 cm^2 c) field size 20×20 cm^2 , for wedge field d)field size 5×5 cm^2,e) field size 10×10 cm^2, f) field size 20×20 cm^2.

Table 5.3 The results of depth dose validation between modeled and measured depth dose from EDGE™ detector in the beam configuration task for open and wedge fields.

Field types	**Beam data set (cm^2)**	**δ_1 (%)**	**δ_2 (mm)**
Open field	5×5	0.109	1.957
	10×10	0.450	2.562
	20×20	-0.03	0.993
Wedge field	5×5	-0.283	0.427
	10×10	0.205	0.453
	20×20	0.258	1.091

*Recommended values for the tolerances of depth dose verification are 2% for for data points on the central beam axis beyond the depth of d_{max} (δ_1) and 2 mm and 10% for data points in the build up region (δ_2)

5.3 Verification of treatment planning system (TPS)

5.3.1 Calibration curve of Gafchromic® EBT2 film

The calibration curves of EBT2 film irradiated with photon energy 6 MV at depth of 1.5 cm with field size of 10x10 cm^2 at 100 cm SAD technique in OmniProI'mRT software as shown in Figure 5.4. The optical density were plotted against dose ranges from 0 cGy to 400 cGy. The dose conversion from optical density (OD) to dose was fitted to a second order polynomial and the linear correlation coefficient values (R^2) was 0.991.

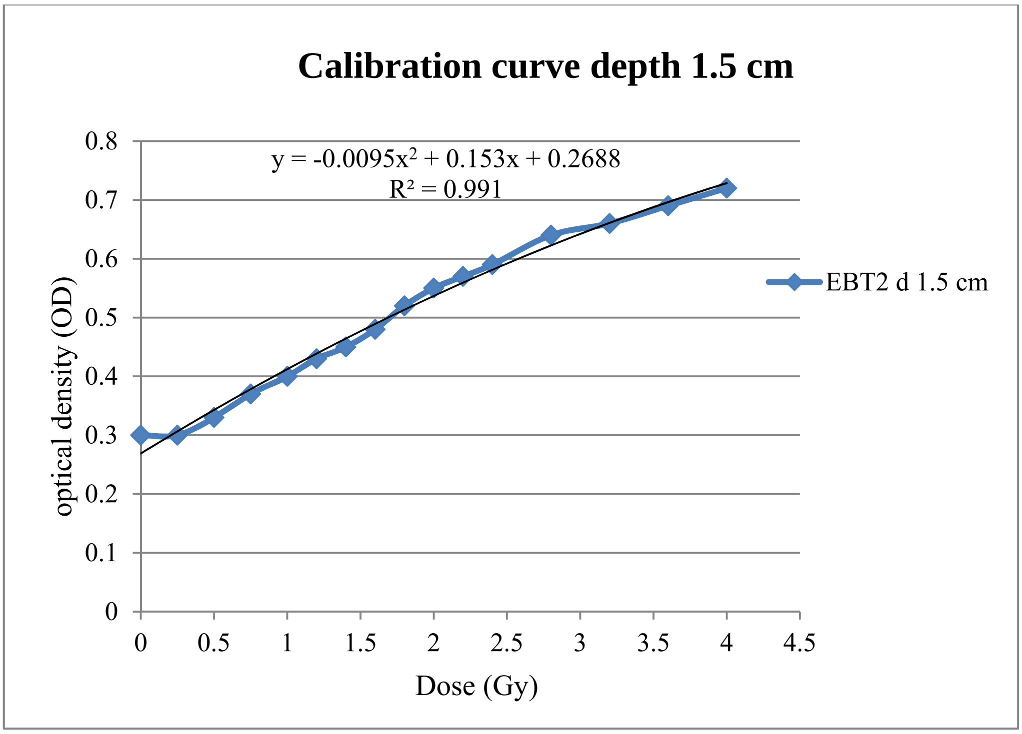


Figure 5.4 The calibration curve of EBT2 film for 6 MV photon beams,10x10 cm^2 open field size at depth of 1.5 cm, 100 cm SAD technique.

5.3.2 Verification the EBT2 film with NACP detector

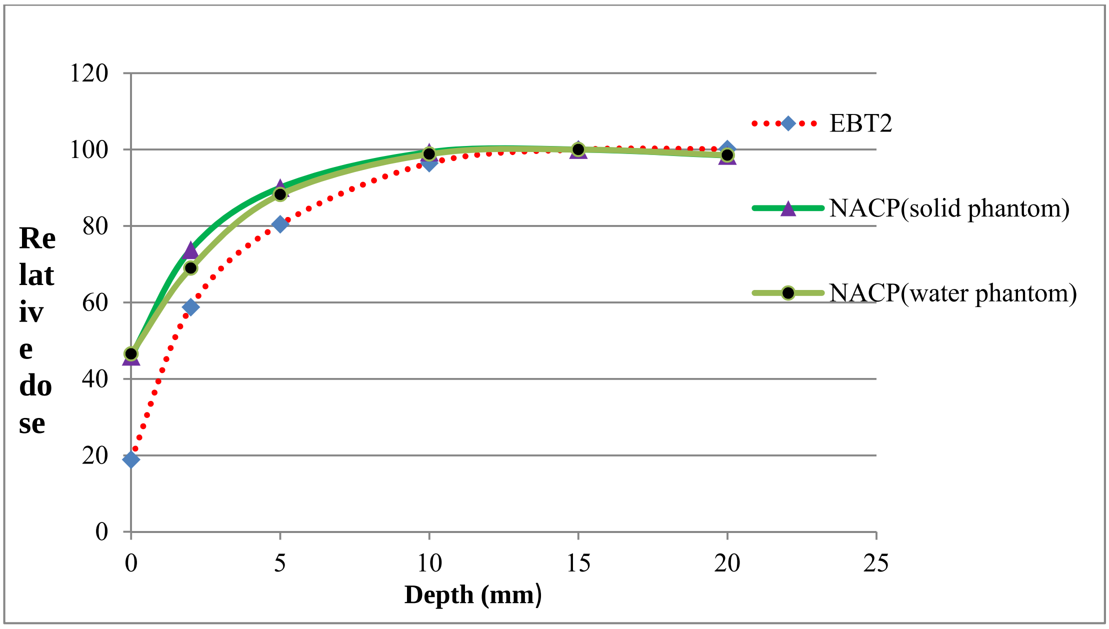
Table 5.4 shows the absolute dose for the EBT2 measurement using calibration curve at depth of 1.5 cm and the NACP detector was used to measure the absolute dose in solid water phantom and water phantom. Figure 5.5 shows comparison of the relative dose (normalize dose at depth 1.5 cm) between EBT2 and

NACP detector for field size of 10×10 cm^2 (a) and field size of 15×15 cm^2 (b). It was found that there are quite compromised agreement starting from 10 mm depth for both field sizes especially in water phantom.

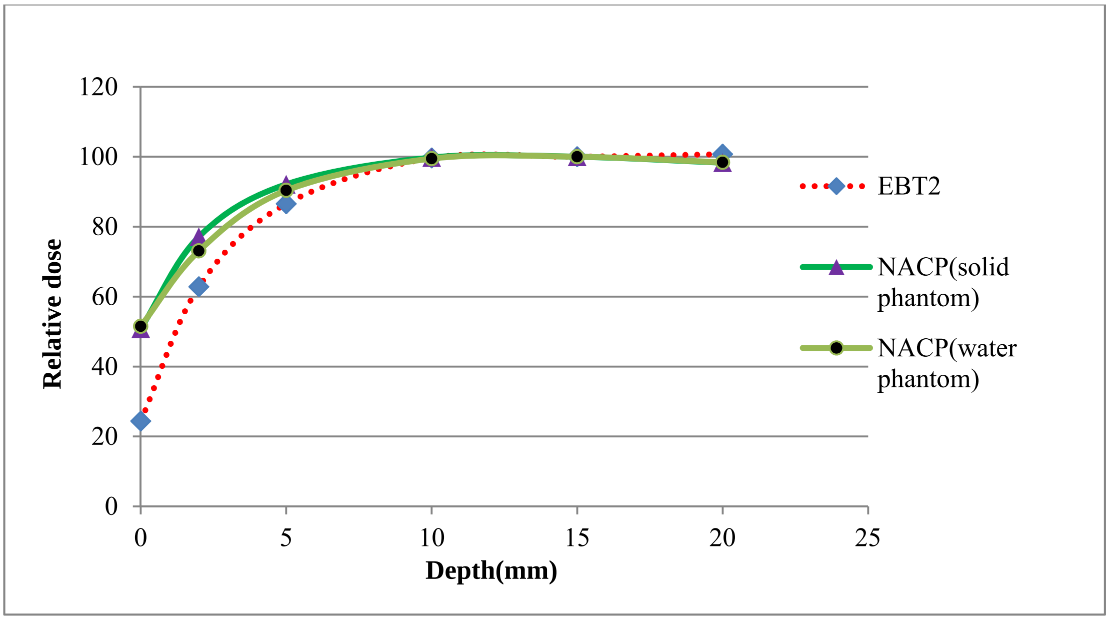
However, a number of studies reported that the Gafchromic EBT2 film was found to be suitable for surface and near surface dose measurement in megavoltage photon beams due to its energy independence, good water-equivalence, little angular dependence and high sensitivity.The standard uncertainty of using EBT2 film measurement for surface or near surface dose measurement was derived from IAEA TRS-398 dosimetry protocol about 3.3%. Therefore the EBT2 was used for a reference standard instrument to compare with the TPS calculation for evaluating the TPS modeling in this study.

Table 5.4 The absolute dose of EBT2 film measurement and using NACP detector in depth verification for field sizes of 10×10 and 15×15 cm^2.

Field size (cm^2)	Depth (mm)	EBT2 film (CGy)	NACP (cGy)		%Diff (EBT2 – a)/a*100	%Diff (EBT2 – b)/b*100
			solid phantom (a)	water phantom (b)		
10×10	0	40.2±0.2	98.44	99.53	-59.2	-59.6
	2	125.2±0.2	158.28	147.53	-20.9	-15.1
	5	171.42±4.5	193.11	188.69	-11.2	-9.2
	10	205.5±1.4	213.04	211.32	-3.5	-2.8
	15	213.1±4.5	214.45	213.87	-0.6	-0.4
	20	213.35±4.2	211.09	210.7	1.1	1.3
15×15	0	53.76±0.2	112.42	113.64	-55.4	-55.9
	2	138.52±0.3	170.5	161.19	-20.8	-16.2
	5	190.8±4.5	203.66	199.3	-10.4	-8.5
	10	219.7±5.5	220.61	219.39	-0.9	-0.4
	15	220.5±2.2	221.13	220.56	-0.9	-0.6
	20	222.1±4.5	217.39	217.07	1.6	1.8



(a) Field size10×10 cm^2



(b) Field size 15x15 cm^2

Figure 5.5 Comparision the relative dose between EBT2 and NACP detector measured in solid water phantom and water phantom.

5.3.3 Comparing the direct angle technique of EBT2 measurement and TPS calculation

Figure 5.6 shows the example of isodose distribution for direct angle at 10 mm of depth verification for field size of 10×10 cm^2, 100 cm SAD technique and 200 MU (185 cGy) was prescribed at depth 5 cm.

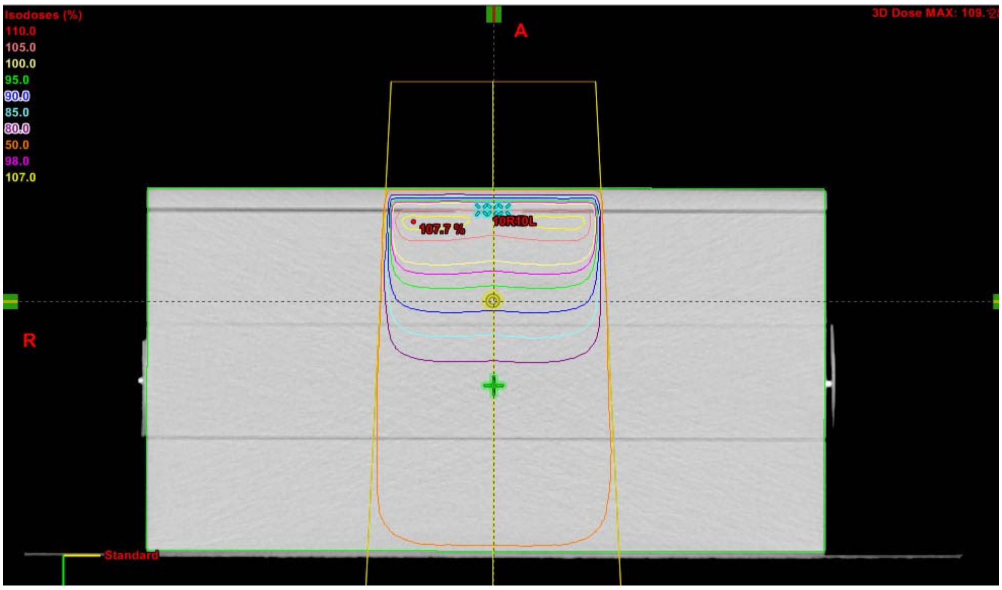


Figure 5.6. The example of isodose distribution for direct angle at 10 mm depth verification.

For the results of the direct angle technique, the EBT2 film measurement used the calibration curve at depth of 1.5 cm in this study. Comparing the point dose at the central axis of beam in solid water phantom between the calculation of both TPS (PFD and EDGE^{TM}) is shown in Figure 5.7 for field size of 10×10 cm^2 and Figure 5.8 for field size of 15×15 cm^2. The 2 different dose grid sizes in the TPS of 1 and 2.5 mm were also compared.

Figure 5.9 and 5.10 shows the comparison of the percentage difference of EBT2 film measurement and both of TPS (PFD and EDGE^{TM}) calculations in direct angle of field size 10 × 10 cm^2 and field size 15 × 15 cm^2, respectively.

It was found that at the surface dose, it shows the largest difference between measurement and calculation from both TPS (PFD and EDGE^{TM}) and the calculated dose shows higher value than the measured one. This result shows the same one when compared between field sizes of 10x10 and 15x15 cm^2 and for grid sizes between 1 and 2.5 mm. At the buildup dose (2 and 5 mm depths), the TPS modelled from data of EDGE™ detector give more superior agreement with EBT2 film than the TPS modelled from data of PFD. The percentage difference between EBT2 film and both TPS at both depths (2 and 5mm) and both field sizes range 1.4%-5.5% compared with the TPS modelled from EDGE™ detector (both grid sizes) and 3.2%-17% compared for the TPS modelled from PFD (both grid sizes). At other depths, the results of both TPS (PFD and EDGE™) and both grid sizes (1 and 2.5 mm) fairly agree with those of EBT2 film measurement.

In this study, both TPS modelled from the EDGE ™ detector and PFD are higher than the EBT2 film measurement at the surface dose. It might because the AAA cannot predict accurately the calculation dose at the surface region. This result agreed with that from Chow et al [8] who reported that at the gantry angle of 0° , the AAA calculation overestimated the surface dose when compared to the Monte Carlo simulation for 6 MV photon beams in the solid water phantom.

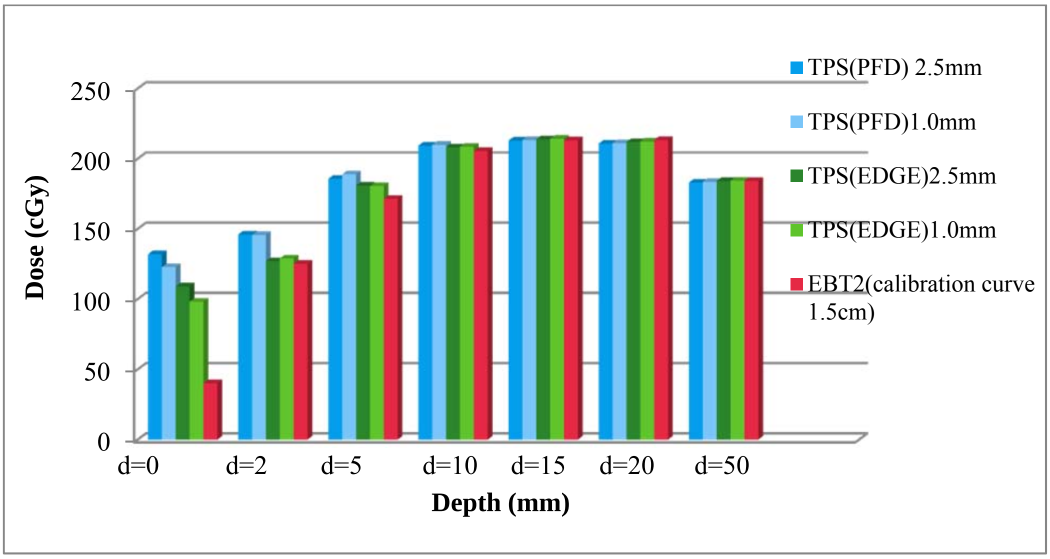


Figure 5.7. The absolute point dose at the central axis of beam of both TPS (PFD,EDGE™) calculation using grid size 2.5 and 1mm compared the EBT2 film measurement for field size of 10×10 cm^2 .

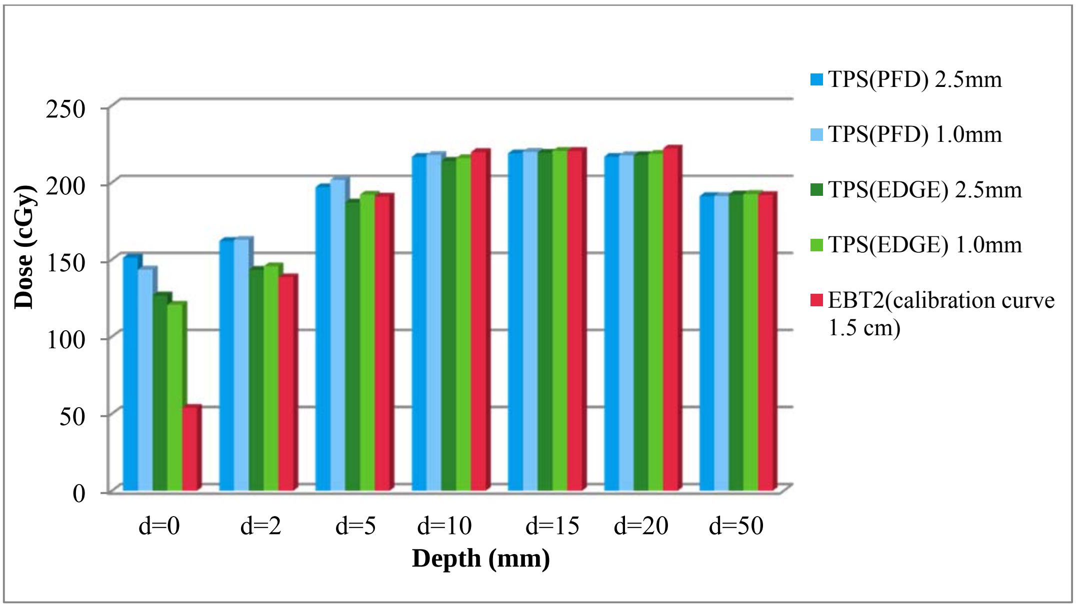


Figure 5.8. The absolute point dose at the central axis of beam of both TPS (PFD,EDGE^{TM}) calculation using grid size 2.5 and 1mm compare the EBT2 film measurement for field size of 15×15 cm^2.

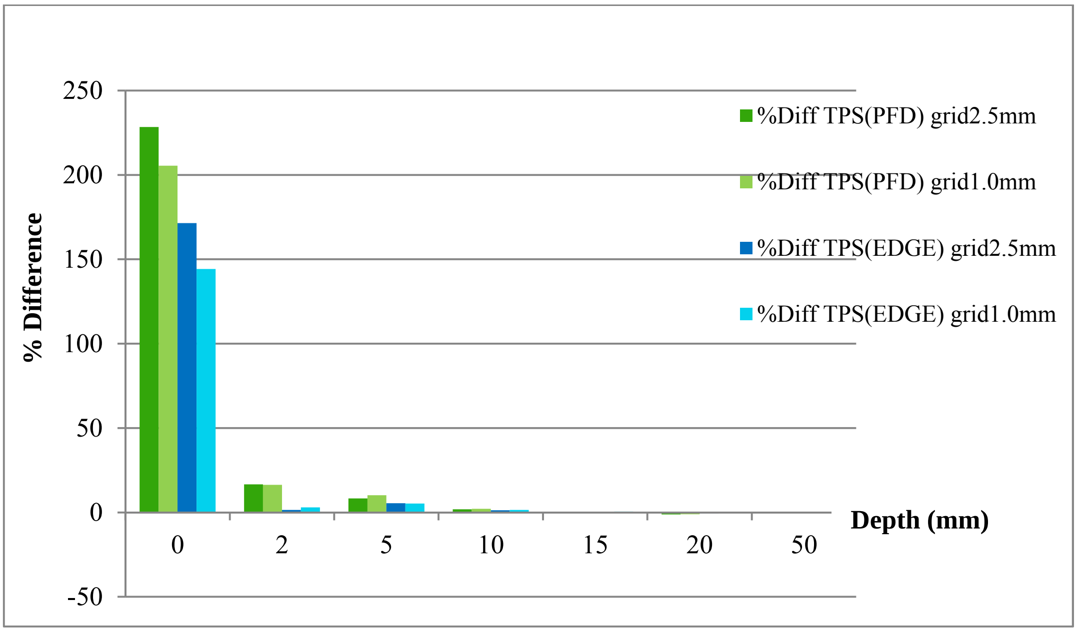


Figure 5.9. The comparison of the percentage difference of EBT 2 film measurement and both of TPS (PFD and EDGE) calculations in direct angle technique for field size of 10 × 10 cm^2.

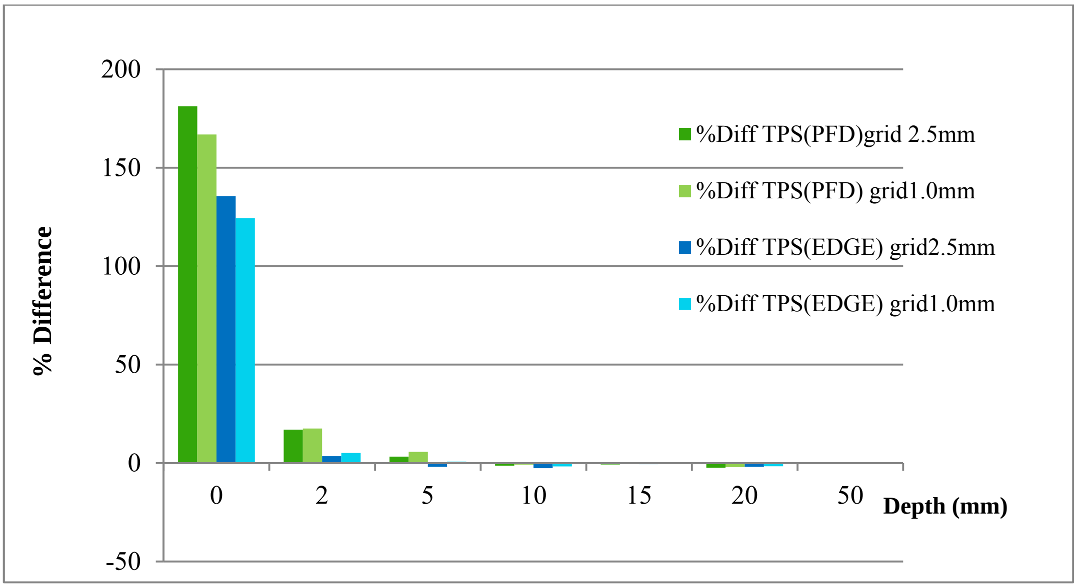


Figure 5.10. The comparison of the percentage difference of EBT 2 film measurement and both of TPS (PFD, EDGE^{TM}) calculations in the conventional technique for field size of 15 × 15 cm^2.

5.3.4. Comparing the tangential technique of EBT2 measurement and TPS calculation

The tangential wedge field isodose distribution was created in the TPS as shown in Figure 5.11 in which the beam data was configured from 2 sets of beam modeling. The first one was measured by using EDGE detector and the other one was measured by PFD detector in which the latter has currently been using in the clinic at Ramathibodi hospital.

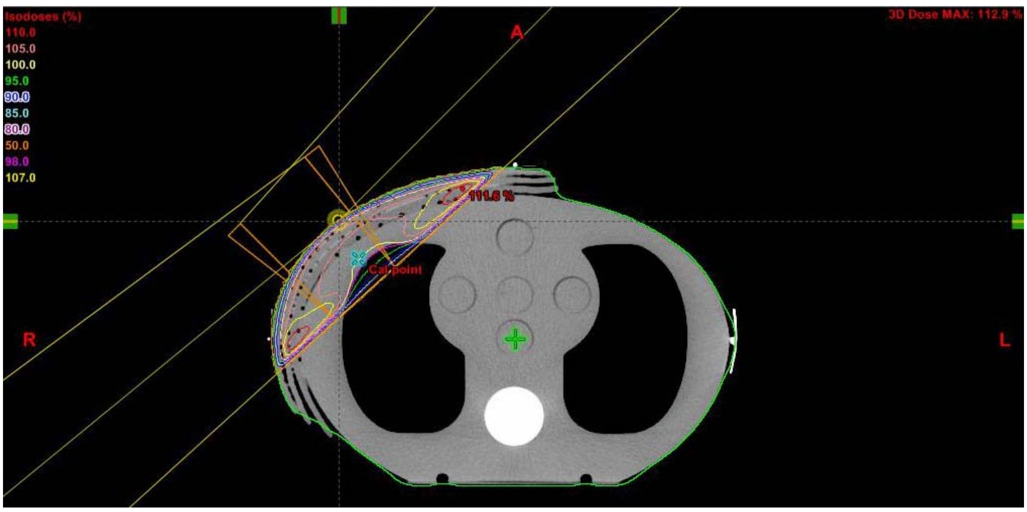


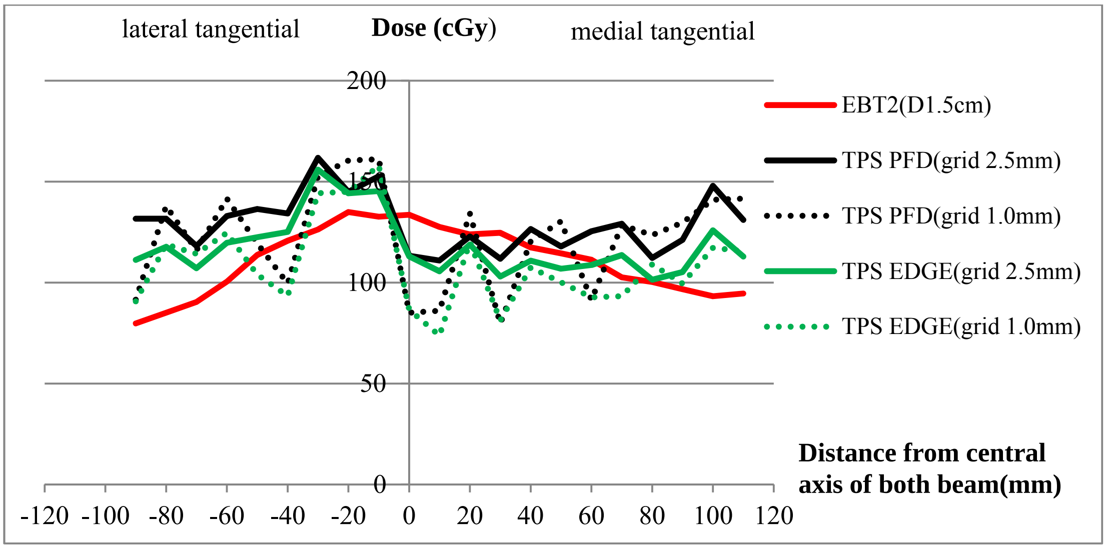
Figure 5.11. The isodose distribution of tangential wedge field in CIRS phantom.

Figure 5.12 (a,b,c,d) show comparing the dose profiles for the tangential wedge field between the EBT2 film measurement at a surface, 3, 6, and 11 mm depths, respectively. When considering both of grid sizes (1 and 2.5 mm), at the surface, the dose profile is lower than the dose at other depths. Also the percentage dose difference between EBT2 and the TPS by PFD reaches a maximum of 65.1% and between EBT2 and the TPS by EDGE^{TM} is a maximum of 42.2%. At 3 mm depth, dose from TPS by PFD is less than the measured dose by maximum of 11.8 % and dose from TPS by EDGE^{TM} is less than the measured dose by maximum of 7.3%. For other depths (6 and11 mm), the percentage difference of TPS by PFD and TPS by EDGE^{TM} are lower than the measured dose by maximum of 9.2% and 7.4%, respectively.

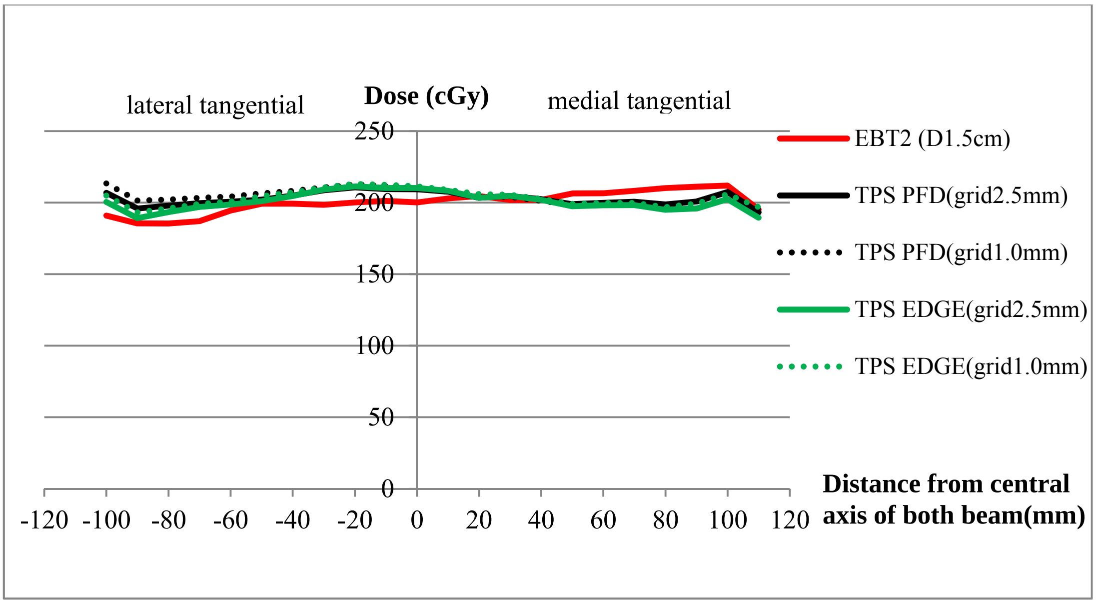
However, considering dose along the off axis distance within ±50 mm across the fields, it was noticed from Figure 5.13 that for all depths, except the surface dose, the calculated dose profile for both across wide field of medial and lateral tangential fields agree well within ±5% from the EBT2 measurement. In contrast, for the region of beam edge especially at the surface, the percentage difference is very high. It might due to the inaccuracy of the TPS to calculate dose at the air-phantom interface. And also it might because of the air gap appeared between the Superflab, film and suface of the CIRS lung phantom.

Chow *et al* [8] found that the mean dose different of AAA in oblique beam showing higher depth dose differences in large field size compared to the Monte Carlo simulation due to the effect of the overestimation of electron backscatter from higher density medium in the convolution/superposition algorithm for dose calculation.

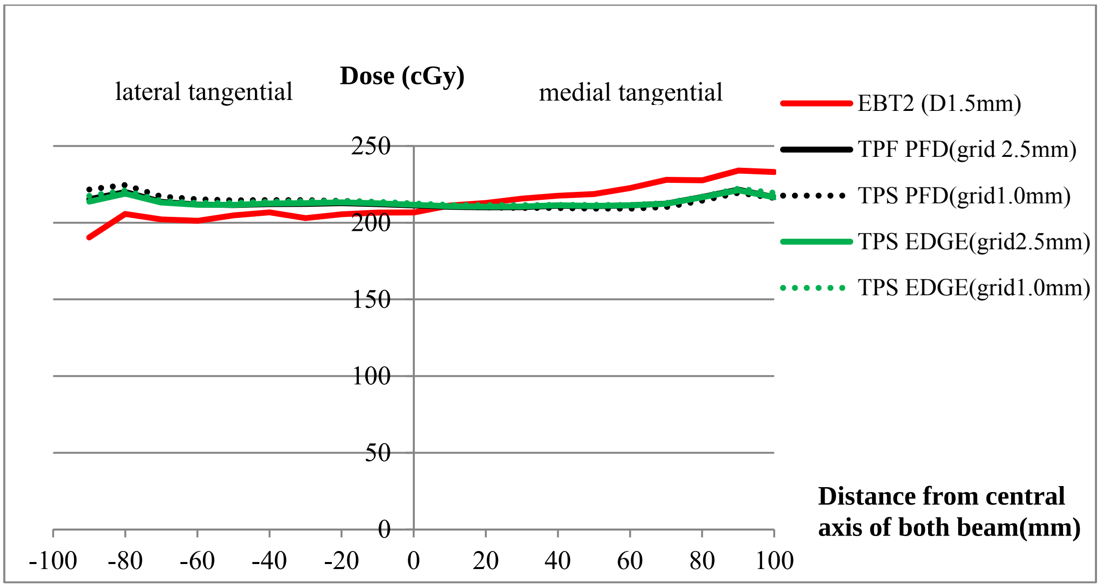
In this study, the dose calculation of TPS modeling from using the EDGE^{TM} detector does not differ from that of the TPS using the PFD in the tangential wedge field. The smaller volume of the detector to measure the beam data for beam configuration has almost no different dose calculation at the surface and buildup region in the tangential wedge field.The findings agree to the study by Panettieri *et al* [6] who found that the changing in the measurement beam reference data has minor differences in the calculated absorbed dose of the buildup region because the AAA beam modeling is primarily based on precalculated data acquired by MC simulations used in the calculation.



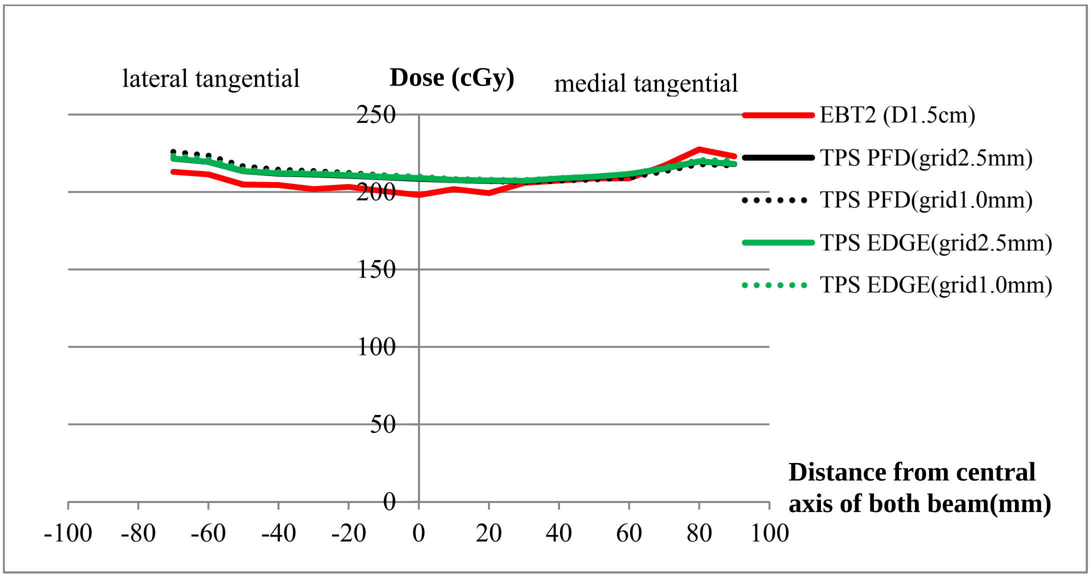
(a) At the surface



(b)At depth 3 mm

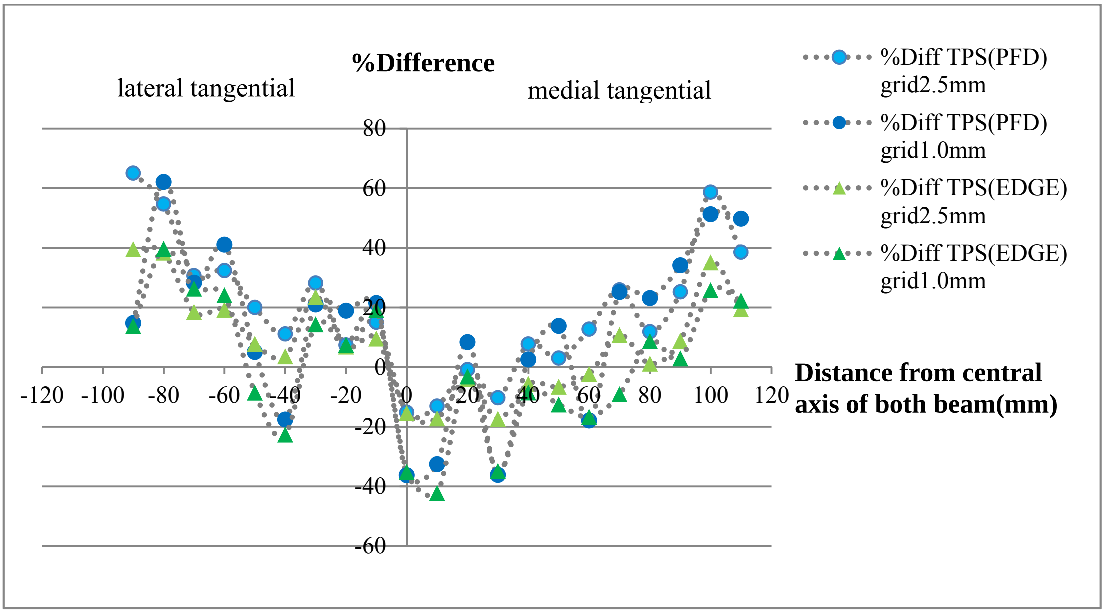


(c) At depth 6 mm

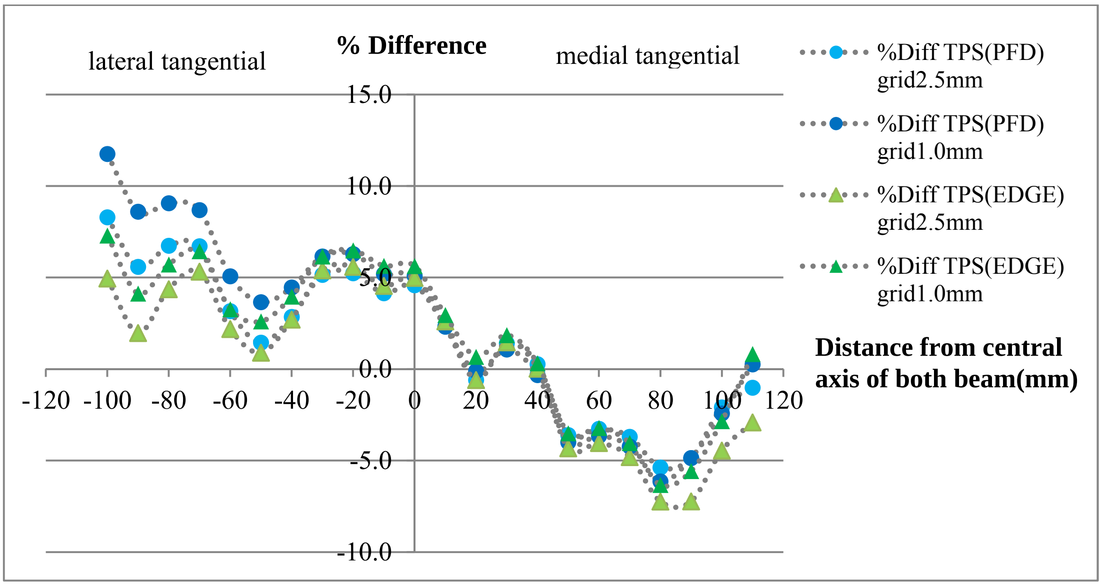


(d) At depth 11 mm

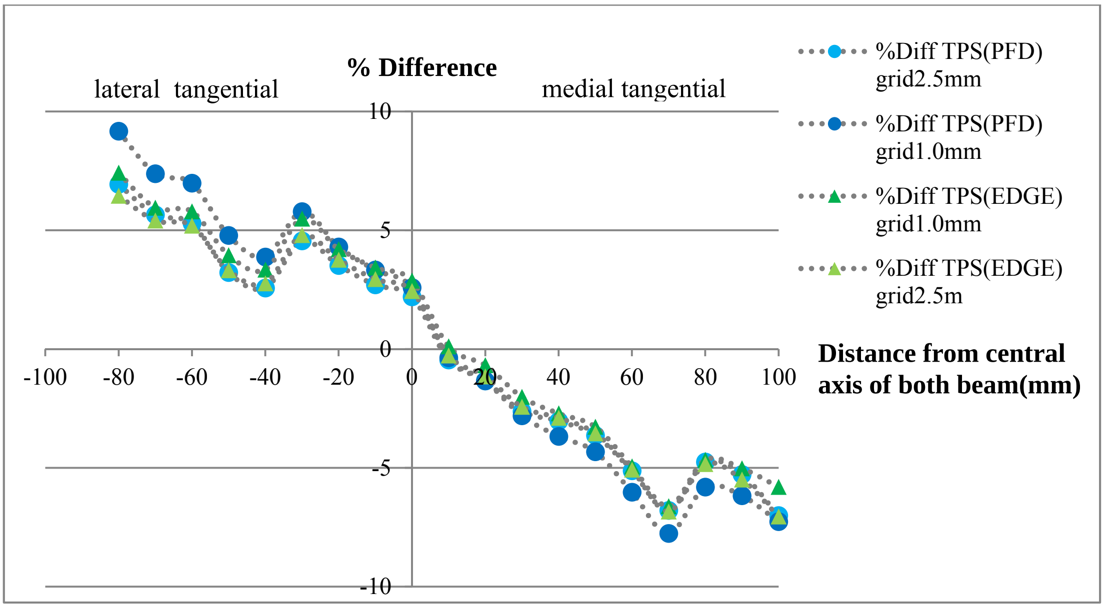
Figure 5.12. Comparing dose profile between the EBT2 (calibration curve at depth 1.5cm) and both of TPS (PFD and EDGE^{TM}) different grid size of 2.5 and 1.0mm.: a) at the surface, b) at 3 mm depth, c) at 6 mm depth, d) at 11 mm depth.



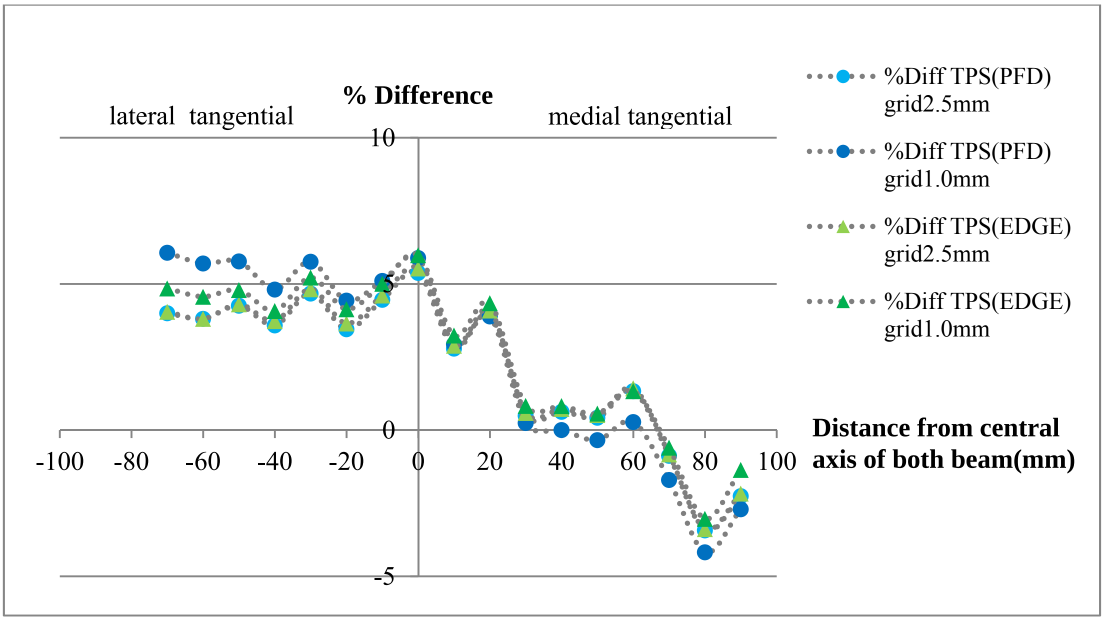
(a) At the surface



(b) At depth 3 mm



(c) At depth 6 mm

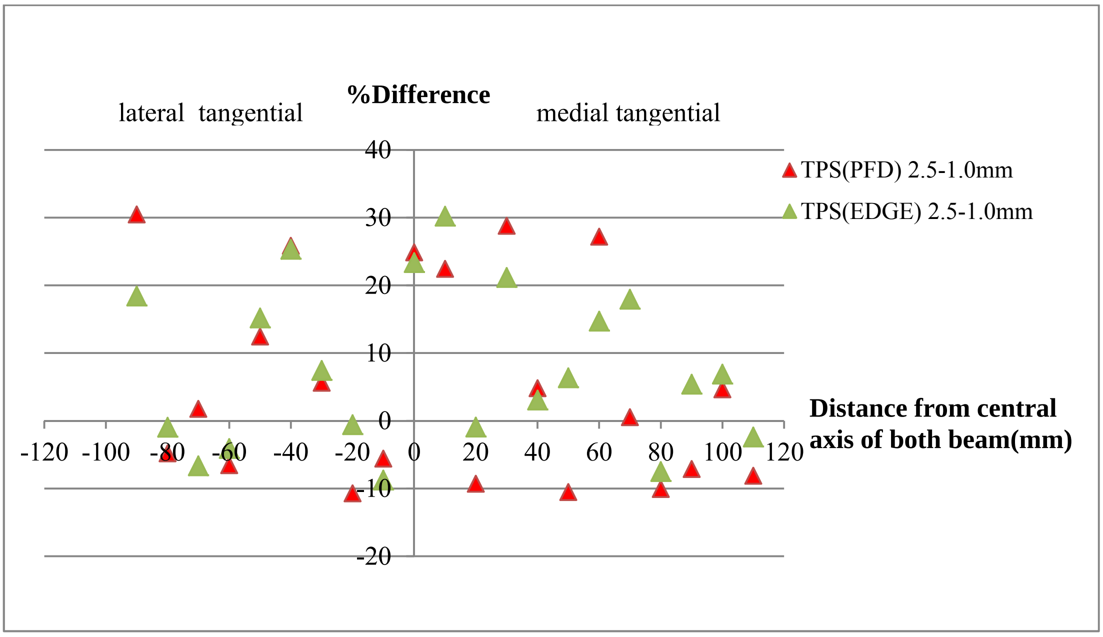


(d) At depth 11 mm

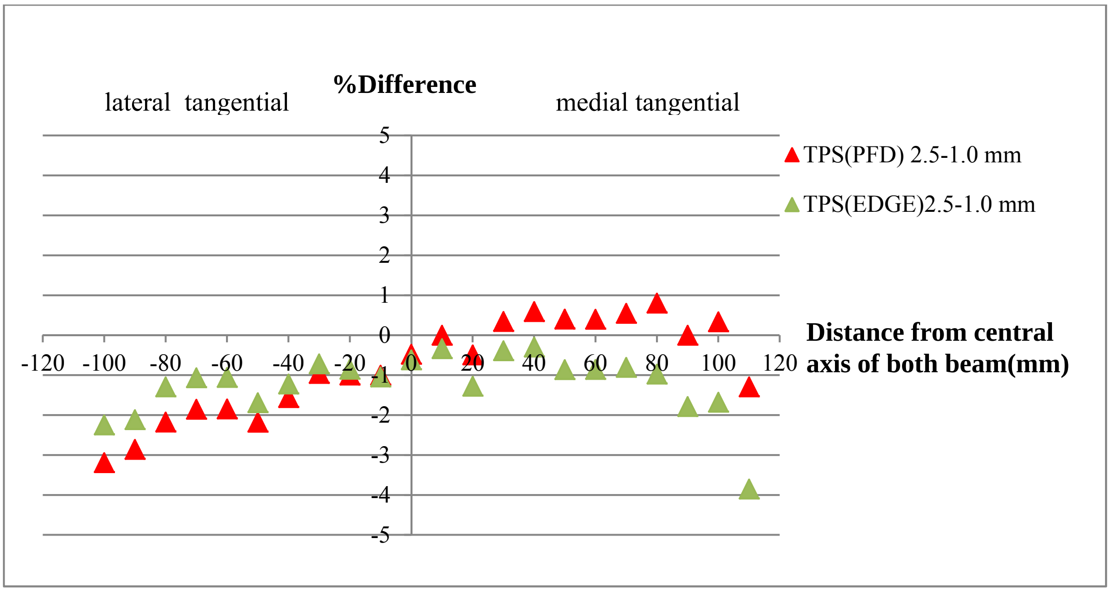
Figure 5.13 Comparison between the percentage difference dose profile EBT2 measurement (calibration curve at 1.5cm depth) and TPS calculation for (a) at the surface, (b) at depth 3 mm, (c) at depth 6 mm, and (d) at depth 11 mm.

Figure 5.14 shows the percentage dose difference of TPS between grid size of 2.5 and 1 mm a) at the surface, b) at 3 mm depth, c) at 6 mm depth, and d) at 11 mm depth. It was observed that at the surface, both of AAA algorithm which measuring beam data by the EDGE™ detector and PFD have the percentage difference between using different grid sizes approximately 30%. However, for the other depth, the % dose difference between grid size 2.5 mm and 1.0 mm are less than 4% for both of TPS. It was noticed that the percentage dose difference between both grid sizes from TPS (EDGE™) is less than that from TPS (PFD). It means that the effect of grid sizes is more sensitive to the beam data measured by the smaller volume of the detectors. Nevertheless, the study of Panettieri *et al* [6] found that a change in grid size (2-5 mm) did not affect the calculation of absorbed dose in build up region especially after the first 2 mm of tissue and only small variation at the surface dose.

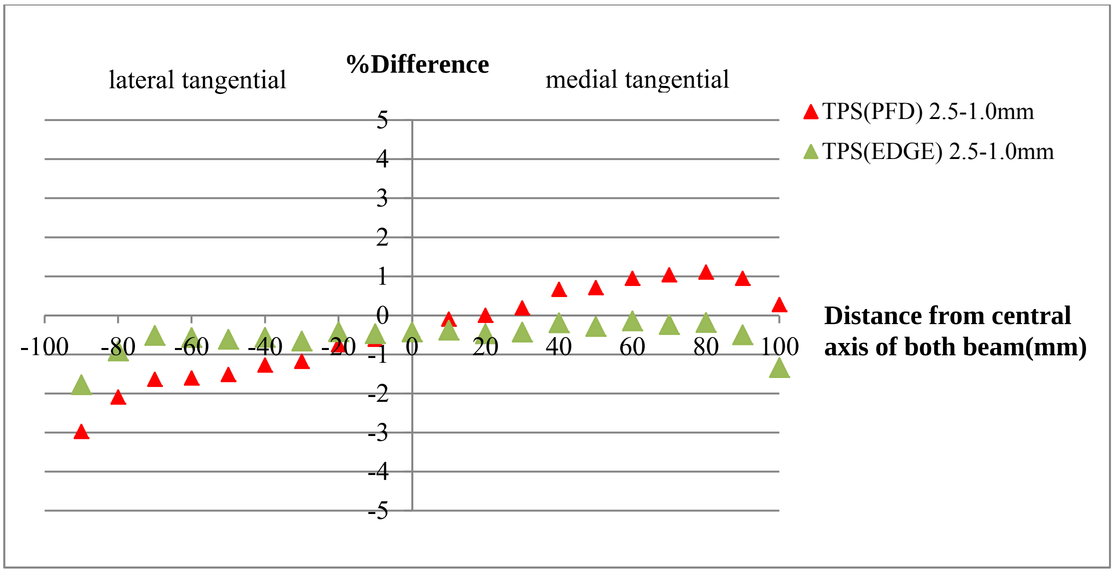
Akino *et al* [3] found that at 3 mm depth with the 2.5 mm grid size, the TPS underestimated dose by 14.7% compared to the measurement. But when the dose calculated with the 1 mm grid size, it showed slightly small difference between calculation and measurement.



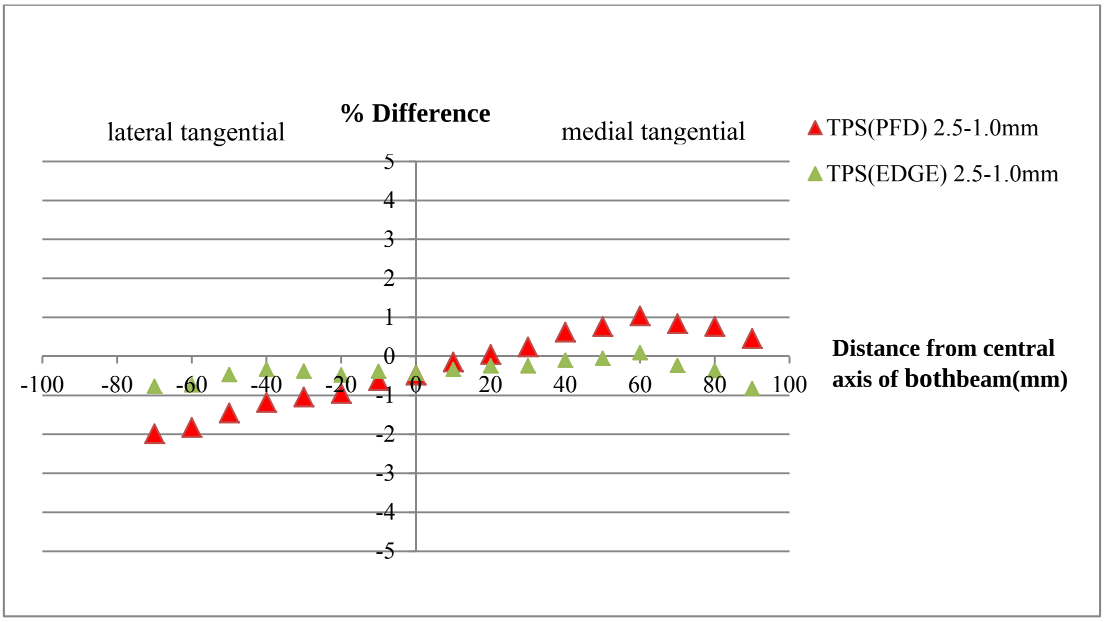
(a)At the surface



(b)At depth 3 mm



(c)At depth 6 mm



(d)At depth 11 mm

Figure 5.14 The percentage dose difference of TPS between using a grid size of 2.5 mm and 1.0 mm in the tangential technique (a) at the surface, (b) at depth of 3 mm, (c) at depth of 6 mm, and (d) at depth of 11 mm.

CHAPTER VI
CONCLUSIONS

The EDGE^{TM} detector measured percentage depth dose (PDD) for the TPS beam commissioning data and the results show that the surface dose is lower than that using the PFD by maximum value up to 10.3 % for open field and 10.7% for wedge field. The AAA 8.9 algorithm was performed in the beam configuration task by using PDD data from EDGE^{TM} to compare the calculation of current TPS modeled by using PFD. The results of surface dose from both of TPS (PFD and EDGE^{TM}) are much larger than that measured by EBT2 film in both conventional and tangential techniques. Nevertheless, at the build up region for conventional technique, dose from TPS by PFD is less than the measured dose by maximum value of 20% and dose from TPS by EDGE is less than the measured dose by maximum about 8%. In addition, at the buildup region for tangential field technique, the percentage difference of TPS by PFD and TPS by EDGE are lower than the measured dose by maximum value of 12% and 8%, respectively. It was noticed that the results of tangential technique at the off axis distance were found that the calculation of both TPS (PFD and EDGE^{TM}) shows dose profiles which are different from that by EBT2 film with a maximum value of 19.4% at 3 mm depth at the beam edge. However considering dose across the fields within ±50 mm, in the buildup region, the calculated dose profile from both TPS agree well within ±5% from the EBT2 measurement.

According to the ICRP Publication No.59 [22], the skin depth recommended for practical dose assessments is at 0.07 mm that depth is the interface between the epidermis and dermis layers of the skin. In this study, the surface dose was measured at the interface between the air and the skin of the phantom. So, this result can not actually predicted the surface dose according to those reports.

It can be concluded from this study that the dose calculation of TPS modelled from using the EDGE^{TM} detector does a bit differ from that of the TPS using the PFD in the tangential technique. The smaller volume of detector to measure the beam data for beam configuration shows less difference in dose calculation at the buildup region. The influence of grid sizes show a bit larger difference in dose calculated by TPS (PFD) than that by TPS (EDGE^{TM}). It is suggested in these finding that surface dose from both measurement and calculation is challenging to perform accurately. The accuracy of dose at build up region remains dependent on the volume of the detector and also the calculated dose grid size. PFD and EDGE^{TM} show comparable results. However, selecting appropriate detectors for the TPS beam commissioning is still important to improve the accuracy of TPS for dose calculation.

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APPENDIX

1.Direct angle technique

The absolute dose (cGy) of the direct angle technique of EBT2 film measurement (calibration curve at depth 1.5 and 5 cm) compared with TPS calculation (PFD and EDGE™) using grid size of 2.5 mm as shown in Table 1 and grid size of 1.0 mm as shown in Table 2.

Table 1 The absolute point dose (cGy) at the central axis of beam for both TPS (PFD and EDGE™) calculation using grid size of 2.5 mm compared with the EBT2 film measurement for field sizes of 10×10 and 15×15 cm^2 in the direct angle technique.

Field sizes (cm^2)	Depth (mm)	EBT2 (calibration curve) (cGy)		TPS modeling (2.5mm) (cGy)	
		D=1.5cm	D=5cm	EDGE™	PFD
10×10	0	40.2	37.83	109.10	
	2	125.2	122.46	127.00	146.00
	5	171.42	168.02	180.80	185.70
	10	205.5	203.63	208.13	209.33
	15	213.1	212.03	213.80	212.93
	20	213.35	212.38	211.87	210.77
	50	184.1	182.76	184.10	183.00
15×15	0	53.76	50.14	126.67	151.20
	2	138.52	135.11	143.30	162.00
	5	190.8	182.4	187.03	196.97
	10	219.7	218.62	214.00	216.60
	15	220.5	219.18	219.27	218.90
	20	222.1	220.92	217.73	216.73
	50	191.8	190.25	192.30	191.10

Table 2 The absolute point dose (cGy) at the central axis of beam for both TPS (PFD and EDGE™) calculation using grid size of 1.0 mm compared with the EBT2 film measurement for field sizes of 10×10 and 15×15 cm^2 in the direct angle technique.

Field sizes (cm^2)	Depth (mm)	EBT2 (calibration curve) (cGy)		TPS modeling (1.0mm) (cGy)	
		D=1.5cm	D=5cm	EDGE™	PFD
10×10	0	40.2	37.83	98.20	122.8
	2	125.2	122.46	128.93	145.67
	5	171.42	168.02	180.53	188.90
	10	205.5	203.63	208.0	209.93
	15	213.1	212.03	214.23	213.33
	20	213.35	212.38	212.2	211.00
	50	184.1	182.76	184.3	183.50
15×15	0	53.76	50.14	120.63	143.47
	2	138.52	135.11	145.63	162.83
	5	190.8	182.4	192.10	201.63
	10	219.7	218.62	215.87	217.87
	15	220.5	219.18	220.47	219.90
	20	222.1	220.92	218.53	217.63
	50	191.8	190.25	192.50	191.20

2.Tangential technique

The transverse dose (cGy) in the X direction across the field in tangential technique using EBT2 film measurement (calibration curve at depth 1.5 cm) compared with the TPS calculation (PFD and EDGE™ detectors) with grid sizes of 2.5 and 1.0 mm at the surface (Table3), at depth 3 mm (Table 4), at depth 6 mm (Table 5), and at depth 11 mm (Table 6).

Table 3 The transverse dose (cGy) in the X direction across the field in tangential technique at the surface.

	Distance from central axis of tangential field (mm)																				
	-90	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	90	100	110
EBT2	79.7	85.1	90.4	100.4	113.7	120.8	126.2	134.9	132.7	133.6	127.6	123.8	124.7	117.4	114.5	111.3	102.6	100.3	96.7	93.2	94.6
TPS (PFD) *(grid size 2.5 mm)*	131.6	131.6	118.1	132.9	136.4	134.2	161.8	144.9	152.6	113.3	110.9	122.8	111.8	126.5	117.9	125.4	129.1	112.2	121.1	147.9	131
TPS (PFD) *(grid size 1.0 mm)*	91.5	137.9	116	141.6	119.4	99.5	152.7	160.4	161.1	85.1	86	134.2	79.6	120.4	130.3	91.3	128.4	123.5	129.7	141	141.6
TPS (EDGE^{TM}) *(grid size 2.5 mm)*	111.2	117.7	107.1	119.7	122.5	125.1	155.9	144.2	145.3	113	105.6	118.8	103	110.8	106.9	108.7	113.6	101.4	105.2	125.9	112.9
TPS (EDGE^{TM}) *(grid size 1.0 mm)*	90.7	118.8	114.2	124.6	103.9	93.4	144.3	145	158	86.6	73.7	119.9	81.2	107.4	100.1	92.7	93.2	109	99.5	117.2	115.6

Table 4 The transverse dose (cGy) in the X direction across the field in tangential technique at 3 mm depth.

	Distance from central axis of tangential field (mm)																					
	-100	-90	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	90	100	110
EBT2	191.0	185.4	185.3	187.0	194.3	199.2	199.2	198.4	200.1	201.1	200.1	202.9	204.5	201.8	201.9	206.3	206.4	208.2	210.1	211.1	211.8	195.2
TPS (PFD) *(grid size 2.5 mm)*	206.8	195.8	197.8	199.6	200.5	202.1	204.9	208.6	210.6	209.4	209.3	207.6	203.3	204.6	202.4	198.9	199.7	200.5	198.8	200.8	207.4	193.2
TPS (PFD) *(grid size 1.0 mm)*	213.4	201.4	202.1	203.3	204.2	206.5	208.1	210.6	212.7	211.5	210.3	207.6	204.3	203.9	201.2	198.1	198.9	199.4	197.2	200.8	206.7	195.7
TPS (EDGE^{TM}) *(grid size 2.5 mm)*	200.4	189.1	193.4	197	198.6	201	204.6	209.1	211.3	210.2	210.1	208.2	203.3	204.7	201.9	197.4	198.1	198.2	194.9	195.8	202.4	189.5
TPS (EDGE^{TM}) *(grid size 1.0 mm)*	204.9	193.1	195.9	199.1	200.7	204.4	207.1	210.6	213.1	212.4	211.4	208.9	205.9	205.5	202.5	199.1	199.8	199.8	196.8	199.3	205.8	196.8

Table 5 The transverse dose (cGy) in the X direction across the field in tangential technique at 6 mm depth.

	Distance from central axis of tangential field (mm)																			
	-90	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	90	100
EBT2	190.4	205.7	202.2	201.2	204.8	206.8	203.0	205.5	206.5	206.7	211.3	212.9	215.8	217.6	218.7	222.6	227.9	227.6	234.0	233.0
TPS (PFD) *(grid size 2.5 mm)*	215.3	220	213.6	211.9	211.4	212.1	212.2	212.7	212.1	211.2	210.3	210	210.1	211	210.7	211.2	212.4	216.8	221.6	216.7
TPS (PFD) *(grid size 1.0 mm)*	221.7	224.6	217.1	215.3	214.6	214.8	214.7	214.3	213.4	212	210.5	210	209.7	209.6	209.2	209.2	210.2	214.4	219.5	216.1
TPS (EDGE™) *(grid size 2.5 mm)*	213.7	219	213.1	211.7	211.6	212.5	212.7	213.2	212.6	211.7	210.7	210.4	210.5	211.3	210.9	211.3	212.3	216.6	221.1	216.6
TPS (EDGE™) *(grid size 1.0 mm)*	217.5	221	214.2	212.9	212.9	213.7	214.1	214.1	213.6	212.6	211.5	211.4	211.4	211.7	211.5	211.6	212.8	217	222.2	219.5

Table 6 The transverse dose (cGy) in the X direction across the field in tangential technique at 11 mm depth.

	Distance from central axis of tangential field (mm)																
	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	90
EBT2	213.0	211.4	204.7	204.5	201.9	203.3	200.5	198.0	201.9	199.2	205.9	207.3	208.7	208.7	217.0	227.5	223.0
TPS (PFD) *(grid size 2.5 mm)*	221.5	219.4	213.4	211.8	211.3	210.3	209.4	208.7	207.5	207.1	206.9	208.6	209.6	211.5	215.1	219.7	218
TPS (PFD) *(grid size 1.0 mm)*	225.9	223.4	216.5	214.3	213.5	212.3	210.7	209.7	207.8	207	206.4	207.3	208	209.3	213.3	218	217
TPS (EDGE™) *(grid size 2.5 mm)*	221.6	219.4	213.5	212.1	211.6	210.7	209.7	209	207.7	207.4	207.1	208.8	209.8	211.7	215.2	219.8	218.2
TPS (EDGE™) *(grid size 1.0 mm)*	223.3	221	214.5	212.8	212.4	211.7	210.5	209.9	208.4	207.9	207.6	209	209.9	211.5	215.7	220.6	220

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