CHARACTERIZATION OF EBT3 RADIOCHROMIC FILM FOR PRECISE MEASUREMENT OF OUTPUT FACTORS IN STEREOTACTIC RADIOSURGERY

By

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LIST OF ABBREVIATIONS

Gy- Gray

IMRT- Intensity Modulated Radiation Therapy

d_{max} – Maximum depth

LINAC- Linear accelerator

CO_2- Carbon Dioxide

SRS- Stereotactic Radiosurgery

OD- Optical Density

PV- Pixel Value

MU- Monitor unit

IPEM- Institute of Physics and Engineering in Medicine

OF- Output Factor

$Rmin^{-1}$ – Roentgen per minute

$Ckg^{-1}min^{-1}$ – Coulomb per kilogram per minute

EBT- External Beam Therapy

SD- Standard deviation

HUSM- Hospital Universiti Sains Malaysia

Mev- Mega electron Volts

MV- Megavoltage

ROI- Region of interest

C_{fs} – Field size correction factor

S_c- Collimator scatter factor

S_p – Phantom scatter factor

AVM- Arteriovenous malformation

CCD- Charged-coupled device

TLD- Thermoluminescent dosimeter

ABSTRACT

Objective : Radiochromic film become a demanding tool in a work of characterizing dosimetric properties in small field stereotactic radiosurgery. The aim of this project is to perform a comparative study in measuring output factor using EBT3 radiochromic film and PTW PinPoint Ion Chamber.

Materials and methods: Output factor mesurements using EBT3 films and PTW PinPoint Ion Chamber were performed using 6MV photon beam from medical linear accelerator .The measurements was done in solid water phantom and CNMC Model 74-320 water phantom. Measuments were done at d_{max} (1.5cm) depth inside water phantom and 100 cm source surface distance.

Results :Percentage difference of measured output factor with EBT3 Gafchromic film and PTW Ion PinPoint Chamber was appoximately 10-11%. Analysis on dose response for EBT3 and EBT2 gives difference approximately 4% in magnitude. The result obtained for scanning orientation study show minimal difference in output factors for different side orientation which differs by less than 2%. Variations for all doses were found to be less than 0.16 (net difference of optical density) for 4°C and 28°C but 0.026 for 37°C. Net optical density for the films stored in 37°C recorded huge difference in relative standard deviation which approximately only 4% compared to 4°C and 28°C which are 34-37% but still represents linear relationship with dose.

Conclusion : EBT3 is suitable for measurements of output factor in stereotactic radiosurgery and can be use on validation of dose when high spatial resolution is required for clinical practice.

ABSTRAK

Objektif: Filem Radiochromic menjadi alat yang mencabar dalam kerja mencirikan sifat dosimetri dalam medan kecil steroetatik radiosurgeri. Tujuan projek ini adalah untuk membuat kajian perbandingan dalam mengukur faktor output menggunakan EBT3 filem radiochromic dan kebuk pengionan.

Radas dan Kaedah: Pengukuran faktor output menggunakan filem EBT3 dan kebuk pengionan telah dilakukan dengan menggunakan 6MV foton bim dari pemecut linear klinikal . Ukuran itu dilakukan dengan fantom air pepejal dan CNMC Model 74-320 fantom air. Ukuran telah dilakukan pada d_{max} fantom air dan 100 cm jarak dari permukaan kepada sumber.

Keputusan: Perbezaan peratusan faktor output diukur dengan filem EBT3 Gafchromic dan kebuk pengionan adalah 10-11 %.Analisis respons dos untuk EBT3 dan EBT2 memberikan perbezaan kira-kira 4% dalam magnitud. Keputusan yang diperolehi bagi kajian imbasan orientasi pada orientasi berbeza menunjukkan perbezaan yang minimum untuk faktor output dengan kurang daripada 2%. Semua variasi dos didapati kurang daripada 0.16 (perbezaan bersih ketumpatan optik) untuk 4 ° C dan 28 ° C tetapi 0.026 untuk 37 ° C. Ini menunjukkan bahawa ketumpatan optik bersih bagi filem yang disimpan dalam 37 ° C mempunyai perbezaan besar dalam sisihan piawai relatif kira-kira hanya 4% berbanding dengan 4 ° C dan 28 ° C iaitu 34-37%.

Kesimpulan: EBT3 sesuai untuk pengukuran faktor output dalam stereotaktik radiosurgeri dan boleh digunakan untuk pengesahan dos apabila resolusi spatial yang tinggi diperlukan untuk amalan klinikal

CHAPTER ONE : INTRODUCTION

1.1 Radiotherapy

Radiotherapy is the abbreviation of radiation therapy which concentrates on cancer treatment. The combination of radiotherapy with surgery, brachytherapy, and chemotherapy makes the treatment much more effective. Radiotherapy comprises internal (brachytherapy) and external beam radiation therapy where both of it having similarities in using ionizing radiation.However, brachytherapy uses gamma ray emitted from radioactive source whereas external beam radiation therapy uses x-ray produced by LINAC. Basically, external beam radiation therapy also uses electron as a function of treating superficial tumors and photons for deep seated tumors.

Patient will lie down on the table couch and linac head is angled to precisely target x-ray beam to abnormal growing tissues (tumor) during the treatment. Multi-leaf collimator device is used to collimate the area of interest while sparing healthy tissues replacing its predecessor, shielding block which having various thickness and sizes. It is installed inside the LINAC treatment head and move automatically into any irreguar shape for beam modification so that much more accutare beam is delivered especially to irregular lesion. As the technology become advanced, the devices were invented to accomplish the challenges in protecting organ at risk and other surrounding normal tissues such as micro multi leaf collimator and cone collimator.

1.2 Radiosurgery

Radiosurgery also known as stereotactic radiosurgery is the treatment usually focuses the delivery of high energy photon beam in one shot without the needs of invasive surgery. Recently, small field dosimetry is commonly used for accurate delivery of beam to the target which utilizes various radiotherapy techniques such as stereotatic radiosurgery, and IMRT. Usually, the treatment is for the smallest area need to be treated which close proximity to the sensitive organ such as brain. Circular cone is mounted to the head of linear accelerator during treatment for beam shaping purposes and radiation dose is delivered to that smallest area. In order to reduce any other damage to surrounding healthy tissue, radiosurgery aims to attain high dose gradient.

Huet, C. et al. studied on small field size and concluded that suitable dosimeter required which possesses high spatial resolution , good tissue equivalence ,lack of lateral particle disequilibrium and variation of photons and secondary electrons spectra with beam sizes. Linear accelerator based SRS is one common techniques practice nowadays since it is adjustable and economical. The existing LINAC is modified by inserting tertiary collimating system known as cone collimator to shape the beam into various circular diameter and the gantry rotates around the patient to produce an arc of radiation focused on the target. Multiple non – coplanar arcs were delivered with single or multiple isocentre. (Vivian et al., 1999).

1.3 Output Factor

Output factor is the ratio of dose delivered at d_{max} in circular field to the ratio of dose delivered at d_{max} at reference field. Meanwhile, there will be an existance of scattered radiation from the equipments of linac head, patient scatter and collimator as well which contributes to the inaccurate dose delivery to the patient. Therefore, it is important to measure the total scatter factor also known as output factor in small beam.

Monitor unit calculation requires dose rate estimation whick comprises output factor for accurate delivery of high dose to the target localization.For fulfiling the aims of high precision to give the correct amount of dose to target lesion, we must take into account the ralationship of field size varies with dose. As field size becomes smaller, how much it affects the output factor of linac beam due to scattering contributions from phantom , coliimators and lack lateral electron equilibrium.

For low energy xrays and Cobalt-60 beams, the output is expressed in $Rmin^{-1}$ or $Ckg^{-1}min^{-1}$ whereas linac beam is measured in cGy/ MU. Dosimeters is placed at d_{max} in water phantom , then being irradiated with the amount of radiation in monitor unit and eventually the output is measured. Since both denominator and numerator are measured in cGy/MU, therefore it has no unit due to the cancellation.

$$\text{Output Factor} = \frac{\text{Dose delivered at } d_{max} \text{ any field}}{\text{Dose delivered at } d_{max} \text{ at reference field } (10 \times 10 \text{ cm}^2)}$$

In this study, measurement of output factor using two different dosimeters were compared in terms of percentage differences. It can be calculated using

$$\text{Percentage difference} = \frac{\text{Measured} - \text{calculated}}{(\text{Measured} + \text{calculated}/2)} \times 100\%$$

1.4 Radiochromic film

Ionizing radiation cannot be measured directly , therefore a dosimeter which acts as detector is needed to measure the amount of radition delivered. . The film undergoes chemical reaction when it is exposed to ionizing radiation or visible light. Radichromic film is a type of dosimeter which replaces its predecessor, radiographic film that can measure how much radiation is exposed upon it by the evaluation of the degree of the darkening of it so-called optical density. It is defined as

$$OD = \log PV_{unirradiated} / PV_{irradiated}$$

Additionally, radiochromic film is a detector usually used for the determination of uniform dose distribution at certain depth unlike thermoluminescence diode, ion chamber which only focuses on point dose measurement. After 24 hours of irradiation, the film can be read using film scanner which will then gives out reading in terms of pixel values.

However, films experience to be affected by surrounding conditions such as humidity, and inaccuracy of measurement occured. As the dose delivered increases, the darker it will be following an irradiation, solid-state polymerization takes place in the film and the colour changes immediately. (Huet,C et al., 2011). This eliminates the needs of chemical processing after irradiation ang less time consuming. Different EBT generation has different configuration on thickness of polymers and this differs on sensitivity to lights.

1.5 Significance of the study

The significance of this study is to characterize the EBT3 radiochromic films in measuring output factor of small beam dosimetry. The challenges faced in small beam dosimetry is achieve dose uniformity over the volume of the detector. The output factor measured using EBT3 were evaluated and compared with output factor measured using PTW Pinpoint Ion Chamber. Ion chamber is chosen as an ideal dosimeter for measurement of small filed inside CNMC Model 74-320 water phantom because it possesses adequate spatial resolution. A curve is plotted for illustration for both dosimeters response of output factor with different small beam field. From this comparison, we could conclude the suitability of precise measurement using EBT3 in characterization of dosimetric properties in stereotactic radiosurgery.

CHAPTER TWO: LITERATURE REVIEW

2.1 Literature Review

Several studies has been conducted by several authors on output factor measurements using different types of detectors such as radiochromic films, ionization chambers,diode dosimeters, and thermoluminescence dosimeterfor small field sizes of megavoltage X-ray beams. After all, they came out with issues that influence the accuracy of these measurements in terms of relative standard deviations among those different types of detectors.

In a task of determining the most suitable detector for measurements in small beam used in radiotherapy, as these small fields are characterized by high dose gradients, a lack of lateral particle equilibrium and a variation of photons and secondary electrons spectra with beam sizes; a dosimeter with a high spatial resolution and good tissue equivalence is required. Radiochromic films use a radiation- sensitive dye organized into microcrystals and embedded in a gelatin binder to measure the dose of ionizing radiation. Following an irradiation, a solid-state polymerization takes place in the film and its colour progressively changes(Huet ,C. et al., 2012).

Meanwhile, the results for output factor measurement using EBT and EBT2 radiochromic film shows that there is a slight percentage difference of approximately 1% of relative standard deviation. The relative standard deviation of the output factors for the three sets of measurements of three different batches is less than 1.5% (1 SD) (Huet,C. et al.,2012). As a comparison, for similar measurements with EBT films, Pantelis et al. (2010) obtained a relative standard deviation of around 2.5% (1 SD). In fact, the agreement in the relative output factor measured with EBT3 films and Advanced Markus Ion Chamber was found to be within 2% with a maximum difference of 3.3% observed for the smallest appicator size in kilivoltage x-ray beam study (Gill, S., & Hill, R. (2013).Also, several studies have shown that the measurements of output factor of the smallest beams with different detectors can lead to a deviation uf up to 30% (Haryanto et al.,2002; Tsai et al.,2003; Derreunmaux et al.,2010)

Moreover, a study been conducted by Butson et al. on dose response of EBT and EBT2 film found that the net optical density between two diifferent batches has different approximately 8-9% in magnitude. It appears that the older EBT film has similar sensitivity to the new EBT2 and newer EBT produced filmshows smaller sensitivity compare to EBT2 . This hightlights that the variation in sensitivity can occurs from different batches (Butson et al. , 2009)

However, there is a difference response in portrait orientation compared to the response in landscape orientation (Andres et al., 2010). According to Reinhardt et al. ,the standard deviation of pixel values of EBT3 film sheet was below 1.2 % and the standard deviation of the mean value of all film pieces was even below 0.2%. Also, the investigation been conducted for both former film types, EBT and EBT2 on sensitivity to the scanning orientation , and the deviations do not exceed 0.8% (0.9%) in terms of pixel value (dose) for all investigated dose levels of 0.5Gy, 1.0 Gy, 3.0 Gy and 5.1 Gy (Reinhardt et al.,2012).

Furthermore, investigation also been conducted on the factors which might affect the sensitometric response of radiochromic film. The result of high temperature behavior study on EBT2 show that there is no significance difference between the sensitometric responses of the films. EBT2 film will withstand exposure to temperatures up to at least 40°C with no changes in the sensitometric response, provided that the irradiation and read-out are made under normal working conditions (Andres et al., 2010).

2.2 Aim and Objectives

The purpose of this project is to characterize EBT3 radiochromic film dosimetry system for precise measurement of output factors in stereotactic radiosurgery

The objectives are:-

1. To determine the output factor using EBT3 film in stereotactic radiosurgery

2. To compare dose response between EBT3 radiochromic film with EBT2 film

3. To investigate the properties of EBT3 radiochromic film which include

- Side orientation effect
- Post irradiation effect with temperature

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CHAPTER 3 : MATERIALS AND METHODS

3.1 MATERIALS

3.1.1 Linear Accelerator

Output factor measurements of linear accelerator were carried out by Siemens Primus that available in Nuclear Medicine, Radiotherapy and Oncology department of HUSM. Tle linac used to deliver conventional external beam radiation therapy with various energy photon and electron. Usually, electon beam is delivered to treat superficial tumor whereas photon beam for the treatment of deep-seated tumor. The energy ranging for photon beam from 6 MV to 18 MV and electron beam from 6 ,9, 12, 15,and 18 MeV are available. There are total 58 “leaves” of MLC , 29 at the anterior side and remaining 29 at the posterior side. These leaves is act as the purpose of beam shaping and intensity modulation of radiation beams. This linac also equipped with cones collimator to perform SRS procedure such as AVM cases.

Figure 3.1.1: Siemens Primus Linear Accelerator

3.1.2 Circular Collimator

Circular collimator (cone) is one of stereotactic hardware used in SRS which delivers beam in various sizes as small as 5mm diameter, hence defines a circular opening for radiation beam. The cones are mounted to the secondary collimator housing with retainer cap so that it will not move and secured to the base plate at linac treatment head.

In this work, only 13 different radionics circular collimator of various diameters starting from 5 mm to 45 mm were used. The irradiation was carried out with 6 MV photon beam with fixed jaw opening of 5x5 cm^2.The photon beam was collimated to fine beam using this so-called tertiary collimation system before being focuses to target accurately.

Figure 3.1.2 : Radionic Circular Collimator

3.1.3 EBT3 and EBT2 Radiochromic Film

Radiochromic film is commonly used in radiation dosimetry due to its properties of eliminating the needs of chemical processing , can be handled in light and undergo colour changes after irradiation. EBT3 radiochromic film has the same composition of active layer which is approximately 0.028 mm as its predecessor EBT2 film. However, its features of equal thickness of matte polyester layer makes it differ from EBT2 film and thus reduce the formation of Newton ring artefacts. The active layer is sandwiched by matte polyester layer of 0.12 mm on upper side and bottom side unlike EBT2 which the polyester layer of 0.175 mm only at the bottom side.

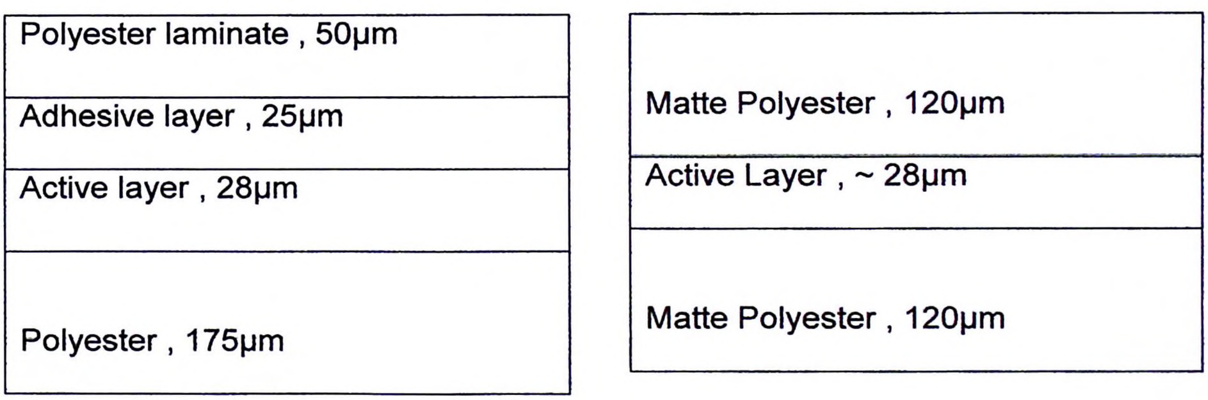

Figure 3.1.3 : Schematic diagram represents the configuration of EBT2 and EBT3 radiochromic film

3.1.4 PTW Pinpoint Chamber

PTW Pinpoint Chamber Type 31016 is a waterproof dosimeter, and very suitable to measure dosimetric properties in air, solid water phantom , and water.This Pinpoint Ion Chamber possess inner diameter of only 2.9mm and sensitive volume of 0.016 cm^3 and that is why it is the most suitable device for the this purpose of measurement. This device gives response to nominal energy range up to 60 MV photon and 6 to 50 MeV for electron . The table below explains details specification for this chamber

Table 3.1.4a : Details of PTW Pinpoint Ion Chamber

Active volume	0.016cm^3
Area Density	89mg/ cm^3
Sensitivity	0.04nC/cGy
Leakage current	$< 4 \times 10^{-15}$ A
Wall thickness	0.66mm
Wall material	Acrylic (PMMA) and graphite
Electrode material	Al 99.98 R
Electrode diameter	0.3mm
Electrode length	1.6mm


Figure 3.1.4: PTW Pinpoint Chamber Type 31016

3.1.5 PTW Unidose E Electrometer

UNIDOS E, is being used in this study , to measure the charge collected by pinpoint ion chamber. This device can also be used for measuments involve in radiation therapy and diagnostic radiology. Besides, it shows the reading in digital forms , hence it makes the measurement much more easier instead of its appearance which is compact, economical and user-friendly .

Other than that, it complies with IPEM guidelines on dosimetry transfer instrument as an electrometer, so we can make use of it according to this worldwide suitability . In fact, we can also connect solid-state detectors to this electrometer as it can do such measuremen involving integrated dose , charge , dose rate and current simutaneously.

Figure 3.1.5: PTW UNIDOS E electrometer

3.1.6 Solid water phantom and CNMC Model 74-320 water phantom

Solid Water phantom is used in this study for film calibration and output factor measurement using EBT3 film. It is designed to make the calibration much more easier without the needs of setting up, transporting and filing water tanks. It can be also used for electron calibation and dosimetric measurements including relative ionization, depth dose, and beam profile. Manufacturers design this solid water phantom in a few thickness so that users could adjust the height while performing experiments.. Futhermore, it scatters and attenuates diagnostic and radiotherapy range x-rays thus giving ionization reading as same as liquid water with approximately. 1% difference for same depth and exposure time. Table 3.1.6 a explains the features of solid water phantom

Table 3.1.6 : Features of solid water phantom

Material:	Epoxy resins and powders to control density and radiation properties
Density:	1.04 g/cm2
Flatness	0.15 mm
Length & width tolerance	±0.5 mm (0.02 in)
Thickness tolerance	0.15 mm
Batch consistency	±0.5%

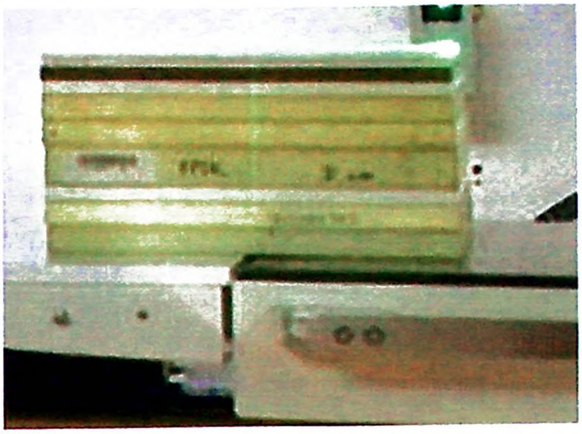

Figure 3.1.6a : Solid water phantom

CNMC Model 74-320 water phantom with dimension 30x30x 40 cm^3 is used in this study for measurements of output factor using PTW PinPoint Ion Chamber provided with side-mounted handles, a drain and a ball valve. It is constucted with 3/8 acrylic material makes it transparent to observe water levels. The ion chamber is place within the water using ion chamber holder and driven by a stainless steel lead screw so that it can be adjusted up and down manually for desired depth.

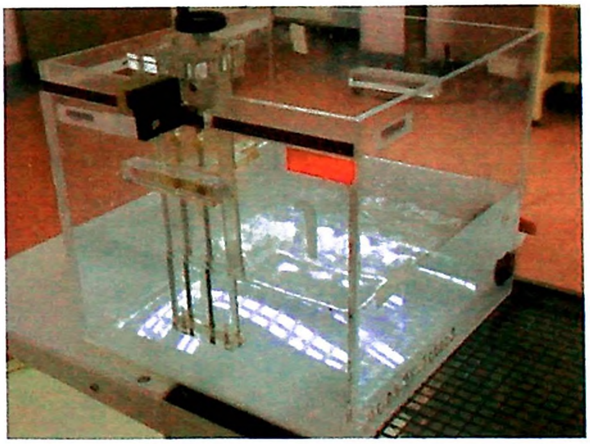

Figure 3.1.6b : CNMC Model 74-320 water phantom

3.1.7 Incubator cells and refrigerator

Incubator cells and refrigerator is used int his study to investigate post-irradiation effect on temperature. An envelope which contain films pieces is stored at the upper compartment in refrigerator to maintain temperature of 4°C. Incubator cells is ideal for storage of cell cultures at 37°C with 5% CO_2 . However, it also being used in this study to store tissue culture cell plate which contains film pieces.

Figure 3.1.7a: Refrigerator

Figure 3.1.7b: Incubator cells

3.18 EPSON Flatbed Scanner and Film dosimetry software

For film read out, EPSON Flatbed Scanner is used to evaluate how much the degree of film darkening and give readings in pixel values.The composition of this scanner are the glass pane and optical array of CCD capture device which act as image sensor. It also can be used as paper scanner since the basic of read out is the moving of a bright light under the glass pane.Verisoft software with selected ROI at the isocenter is used for optical density evaluation.

3.2 METHODS

3.2.1 EBT3 Film Calibration

Basically, before the measurement is performed using radiochromic film, the calibration curve must be obtained so that unknown doses on film could be determined. Measurement was done for 6 MV photon energy generated by linear accelerator Siemens Primus using EBT3 radiochromic film at d_{max}.

EBT3 radiochromic film is cut into pieces of 3x3 cm^2. Then, water slab of 15 cm height including d_{max} is positioned on table couch. Next, the film is being placed at the centre of solid water phantom at d_{max} and being irradiated in a given dose range by field size of 10x10 cm^2 ,100 cm source surface distance. The gantry were set up to zero degree so the beam is directed towards the isocenter of the film. As the dose delivered to film increases, the darker the film will be.

All pieces of irradiated film is scan using EPSON Flatbed Scanner 1 day after irradiation to allow complete self-development of the film. Firstly, all film pieces is positioned on the scanner bed. Secondly, the film pieces were previewed and waiting period is usually 30 seconds. Next, the film pieces were scanned and the images were saved. This process is usually takes about 10-15 minutes to complete.

Verisoft software will give out the result in terms of the pixel reading. A few pixel readings were recorded , by substracting the unirradiated and the irradiated pixel reading, it will make the determination of dose measurement much more accurate and hence net OD is calculated pixel by pixel for a given ROI. Lastly, dose calibration curve is plotted and determined.

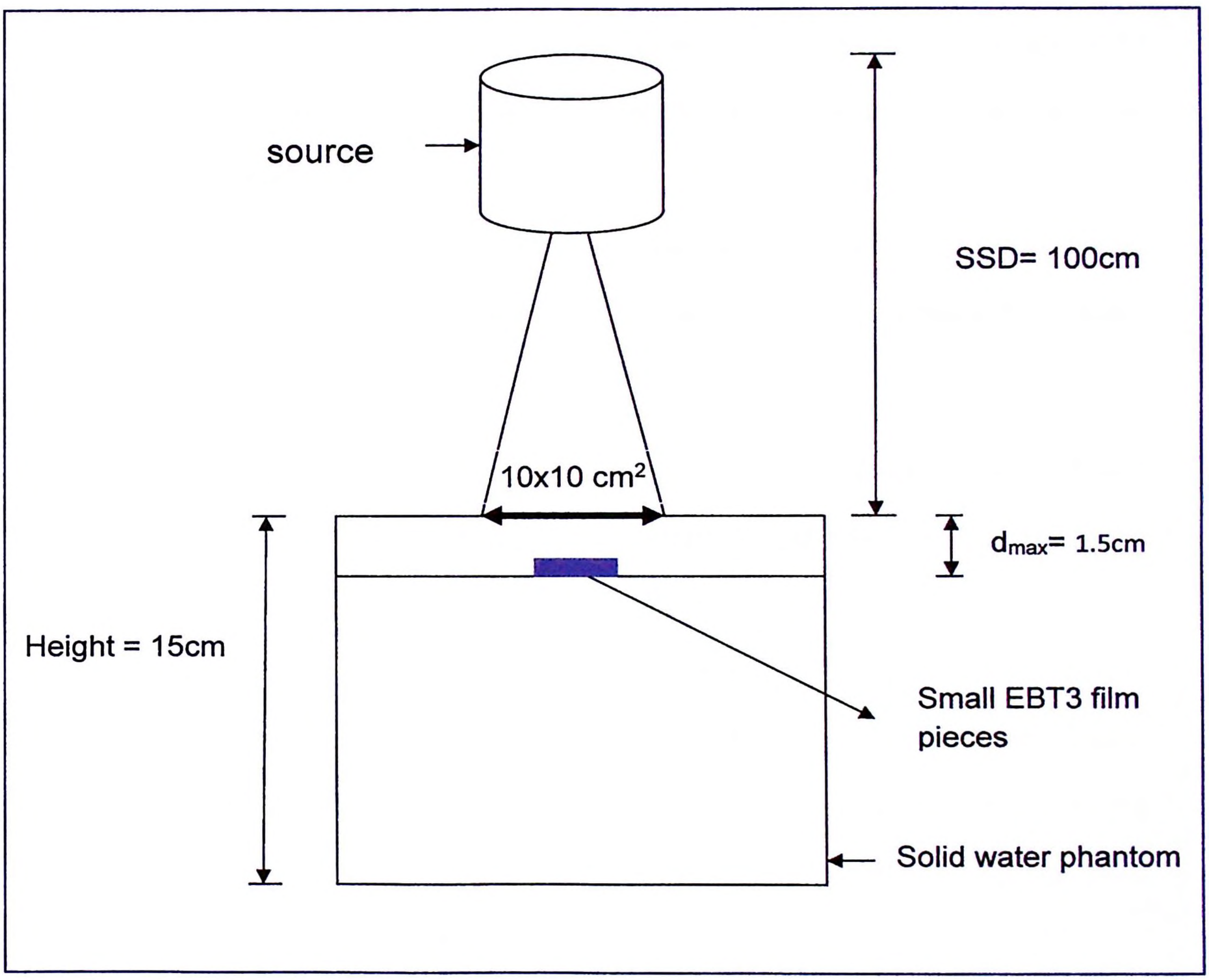

Figure 3.2.1 : Schematic diagram of experimental setup of EBT3 Film Calibration

3.2.2 Output Factor Measurement

In this study, this measurement is perfomed using two types of dosimeter which are EBT3 radiochromic film and PTW Pinpoint Ionization Chamber. Measurement was being done for 6 MV photon energy generated by linear accelerator Siemens Primus at d_{max}.

Radionic circular cone of various diameter up to 45mm was attached to the cylindrical housing which is mounted to the treatment head of liner accelerator , and it is situated below the secondary jaws of collimator. The retainer cap is screwed so that it will be locked and prevent the cone from any possible movement.Film is an indirect method while ion chamber is a direct method in measuring the dose.

The set up of output factor measurement using EBT3 radiochromic film is as same as film calibration setup but the secondary collimator was adjusted so that the field size become 5x5cm^2 .All film pieces were exposed with 300 MU for all conicular collimator sizes starting from 5 mm, 7.5, 10, 12.5, 15, 17.5, 20, 22.5, 25, 27.5, 30, 32.5 and 45 mm diameter cone collimator afterwards. Then, the films were scanned to determine the OD based on the darkening of the films. Ratio of OD of circular cone were normalized to OD of 10 x 10 cm^2 field size for output factor determination.

Besides that, the output factor measurement also performed using PTW Pinpoint Ionization Chamber by at d_{max} of 1.5cm beneath water phantom surface and connected to the PTW Unidose E Electrometer. For irradiation procedure,100 MU was exposed starting 5 mm diameter cone and the same steps were repeated using 7.5, 10, 12.5, 15, 17.5, 20, 22.5, 25, 27.5, 30, 32.5

and 45 mm diameter cone collimator afterwards. The irradiation procedure was done two times to get the average reading of charge collected by PTW Unidose E Electrometer. Output factor was determine by finding the ratio of charge of circular collimator at 1.5 cm depth to the charge of field size of 10x10 cm^2 at 1.5 cm depth.

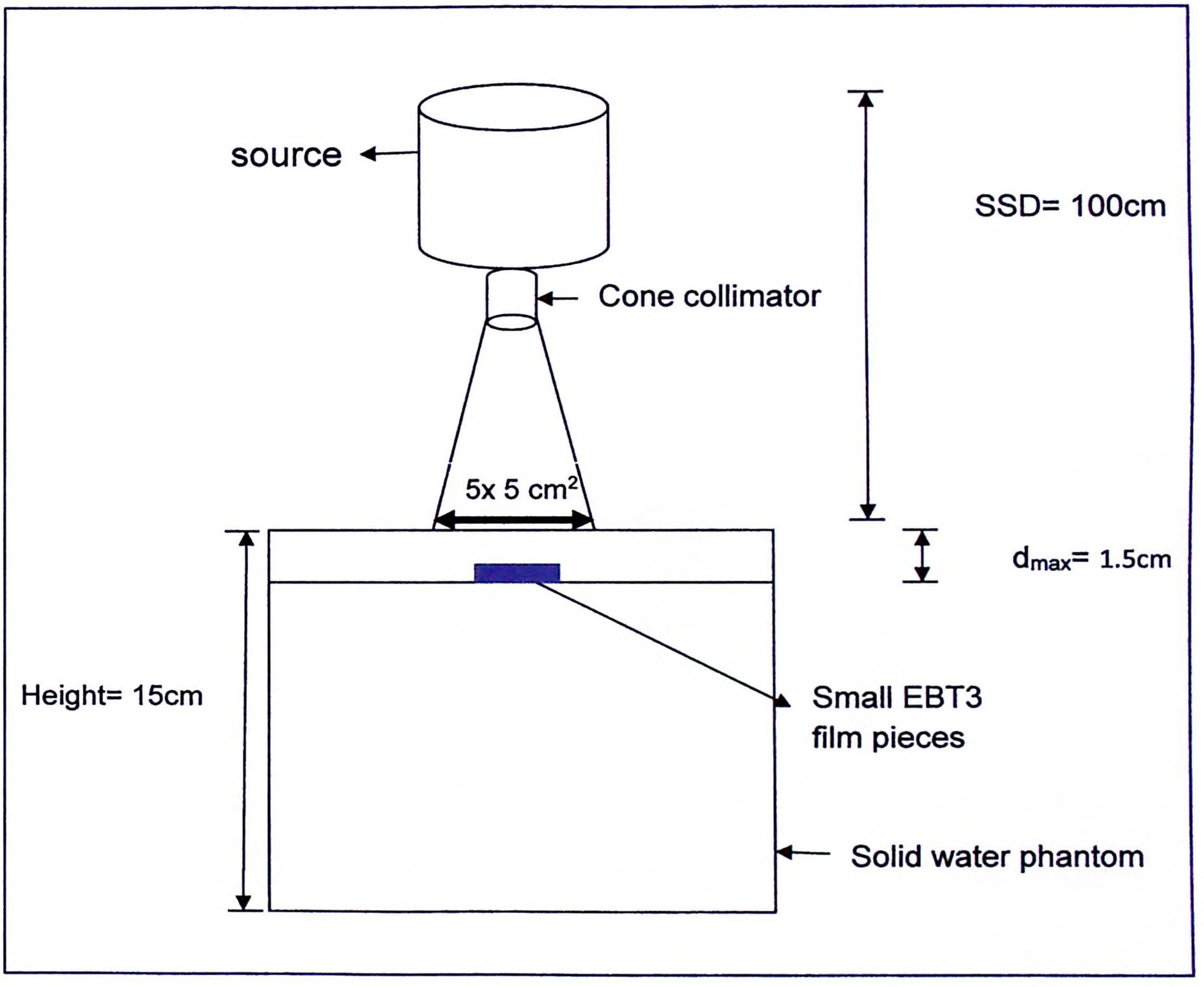

Figure 3.2.2a : Schematic diagram of experimental setup of output factor measurements using EBT3 film