# FEASIBILITY OF USING EBT2 RADIOCHROMIC FILM AND MOSFET FOR RADIOTHERAPY DOSE MEASUREMENT IN NASOPHARYNX CANCER TREATMENT

**by**

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| | |
|---|---|
| 1D | One Dimensional |
| 2D | Two Dimensional |
| 3D | Three Dimensional |
| 4D | Four Dimensional |
| AAPM | American Association of Physicist in Medicine |
| BDS | Beam Directional Shell |
| BMP | Bitmap Image File |
| CCD | Charged Coupled Detector |
| CT | Computed Tomography |
| CTV | Clinical Target Volume |
| dpi | Dots Per Inch |
| $d_{max}$ | Depth of Maximum Dose |
| $D_{max}$ | Maximum Depth Dose |
| EBT | External Beam Therapy |
| EPID | Electronic Portal Imaging |
| FET | Field-Effect Transistor |
| FSF | Field Size Factor |
| GTV | Gross Target Volume |
| Gy | Gray |
| IAEA | International Atomic Energy Agency |
| IARC | International Agency for Research on Cancer |
| IC | Ionisation Chamber |
| ICRU | International Commission on Radiation Units and Measurements |

| | |
|---|---|
| IGRT | Image Guided Radiotherapy |
| IMRT | Intensity Modulated Radiotherapy |
| ISP | International Specialty Products |
| JPEG | Joint Photographic Experts Group |
| kV | Kilovoltage |
| LINAC | Linear Accelerator |
| MLC | Multileave Collimator |
| MOH | Ministry of Health |
| MOSFET | Metal Oxide Semiconductor Field Effect Transistor |
| MPD | Mid-Plane Dose |
| MU | Monitor Units |
| MV | Megavoltage |
| NCR | National Cancer Registry |
| NPC | Nasopharynx Cancer or Carcinoma |
| O.D | Optical Density |
| OAR | Organ At Risk |
| OSLD | Optical Stimulated Luminescence Dosimeter |
| PDD | Percentage Depth Doses |
| PDF | Portable Document Format |
| POI | Point of Interest |
| ppi | Pixels Per Inch |
| PSD | Patient to Source Distance |
| PTV | Planning Target Volume |
| PV | Pixel Values |
| QA | Quality Assurance |

| | |
|---|---|
| QART | Quality Assurance in Radiotherapy |
| QC | Quality Control |
| RGB | Red, Green and Blue |
| ROI | Region of Interest |
| RPL | Radiophotoluminescene |
| SD | Standard Deviation |
| SSD | Source-Skin-Distance |
| TIFF | Tagged Image File Format |
| TLD | Thermoluminescent Detector |
| TPS | Treatment Planning System |
| TV | Tumour Volume |
| $\overline{x}$ | Mean Value |

**KEBOLEHLAKSANAAN MENGGUNAKAN FILEM RADIOKROMIK EBT2 DAN MOSFET UNTUK PENGUKURAN DOS RADIOTERAPI DALAM RAWATAN KANSER NASOFARINKS**

## ABSTRAK

Isipadu tumor Kanser Nasofarinks terletak di kepala dan leher dan berdekatan dengan pelbagai organ yang berisiko. Dengan itu, verifikasi dos radioterapi sebelum rawatan adalah langkah yang sangat penting. Ini memastikan dos yang mencukupi diberi ke isipadu tumor di samping melindungi organ yang berisiko. Pencirian respon dosimetri bagi kedua-dua *Metal Oxide Semiconductor Field Effect Transistor* (MOSFET) dan filem radiokromik EBT2 telah dijalankan sebelum mengendalikan verifikasi dos bagi rawatan radioterapi. Pencirian filem radiokromik EBT2 telah dijalani melalui beberapa ujian dan menyumbang 5.05% *combined standard uncertainty*. Ujian-ujian tersebut adalah kebolehulangan filem (0.25%), kesan kegelapan filem (0.25%), pergantungan saiz medan (4.98%), dan pergantungan sudut (2.01%). Tujuh eksperimen telah dijalani dan menyumbang 3.48% *combined standard uncertainty* bagi MOSFET. Eksperimen-eksperimen tersebut adalah kebolehulangan MOSFET (1.36%), kesan kepudaran filem (2.00%), *perturbation* (2.58%), lineariti (2.88%), pergantungan saiz medan (2.90%), pergantungan sudut (3.36%), pergantungan SSD (2.59%). Selepas ujian pencirian filem radiokromik EBT2 dan MOSFET, verifikasi dos bagi pelan radioterapi telah dijalankan secara *in vitro*. Ini menunjukkan bahawa dos yang diukur adalah lebih tinggi daripada dos yang dikira melalui *Treatment Planning System* (TPS). Dos TPS menunjukkan bahawa kedua-dua dosimeter berada dalam variasi 10%. Dengan ini, filem radiokromik EBT2 dan MOSFET adalah bersesuaian digunakan sebagai dosimeter dalam bidang radioterapi.

**FEASIBILITY OF USING EBT2 RADIOCHROMIC FILM AND MOSFET FOR RADIOTHERAPY DOSE MEASUREMENT IN NASOPHARYNX CANCER TREATMENT**

## ABSTRACT

Nasopharynx cancer (NPC)'s tumour volume located at the head and neck which nearby with bundles of organ at risk (OAR). Therefore, it is important to have radiotherapy dose verification prior to the treatment. This is to make sure adequate dose delivered to tumour volume whereas protect well to organ at risk. Dosimetry response of both Metal Oxide Semiconductor Field Effect Transistor (MOSFET) and Radiochromic EBT2 film were characterised before the dose verification of radiotherapy treatment was conducted. The characterisation of Radiochromic EBT2 film was ruled out from the tests which contributed combined standard uncertainty 5.05%. Tests are film reproducibility (0.25%), film darkening effect (0.25%), field size dependence (4.98%), and angular dependence (2.01%). Seven experiments were undergone to contribute 3.48% combined standard uncertainty for MOSFET. The experiments are MOSFET reproducibility (1.36%), fading effect (2.00%), perturbation (2.58%), linearity (2.88%), field size dependence (2.90%), angular dependence (3.36%), SSD dependence (2.59%). After the characterisation of Radiochromic EBT2 film and MOSFET, treatment plan dose verification was conducted *in vitro*. It showed a trend that measured doses higher than calculated doses by Treatment Planning System (TPS). TPS doses verified both dosimeters doses within 10% variation. Thus, both Radiochromic EBT2 film and MOSFET were suitable to be used as radiotherapy

# CHAPTER 1 INTRODUCTION

## 1.1 Overview

Cancer is one of the top ten causes of hospitalization in both Ministry of Health (MOH) and private hospitals in Malaysia. Even more noteworthy is cancer incident in Malaysia increased from 32000 new cases in 2008 to about 37000 in 2012 (*International Agency for Research on Cancer (IARC), 2013)*. It is particularly worth mentioning that cancer has overtaken heart disease as the number one killer in the year 2014 based on the latest Health Facts 2014 which was released by MOH.

For year 2007, National Cancer Registry (NCR) reported the five most common cancers among Malaysians were breast cancer (18.1%), head and neck cancer (13.2%), colorectal cancer (12.3%), respiratory system cancer (10.2%) and followed by cervix uteri cancer (4.6%). Head and neck cancer included nasopharynx, larynx, tongue, mouth, nose and sinuses, salivary gland, hypopharynx, other oropharynx, tonsil, pharynx unspecified and lip. It was then followed by other cancers (41.6%) like lymphoma, leukemia, stomach, liver, prostate, bladder, nervous systems and others.

Nasopharynx cancer (NPC) is the most common head and neck cancer among Malaysians. NCR 2007 reported that Chinese had the highest percentage (68.36%) of NPC incident, followed by Malay (29.64%) and Indian (2.00%) (Figure 1.1). NCR also reported NPC had higher incident rate in male rather than in female (Figure 1.2). Surgery, radiotherapy and chemotherapy are used either alone or in combination for NPC treatment in Malaysian's cancer management. Radiotherapy is the modality which treat the cancerous cell by external beams or internal beams (brachytherapy) using ionising radiation. It involved the use of photon in kilovoltage (kV) to megavoltage (MV) range.

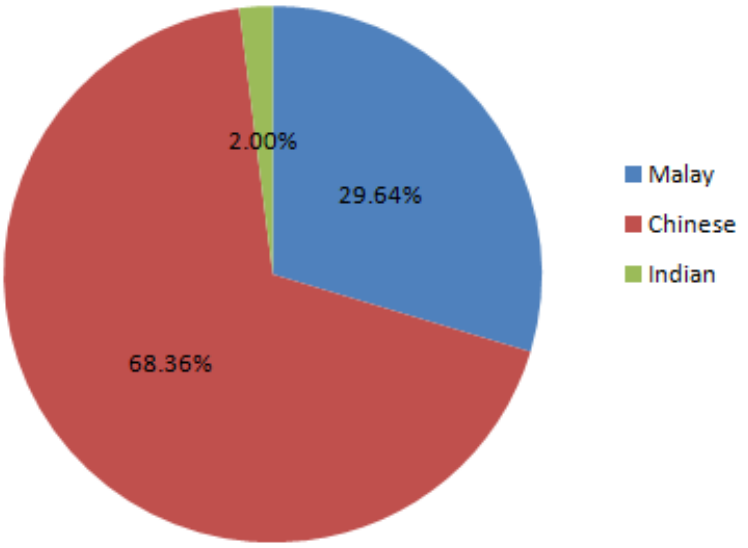



Figure 1.1 Nasopharynx cancer by major ethnicity, Malaysia 2007 (NCR, 2007).

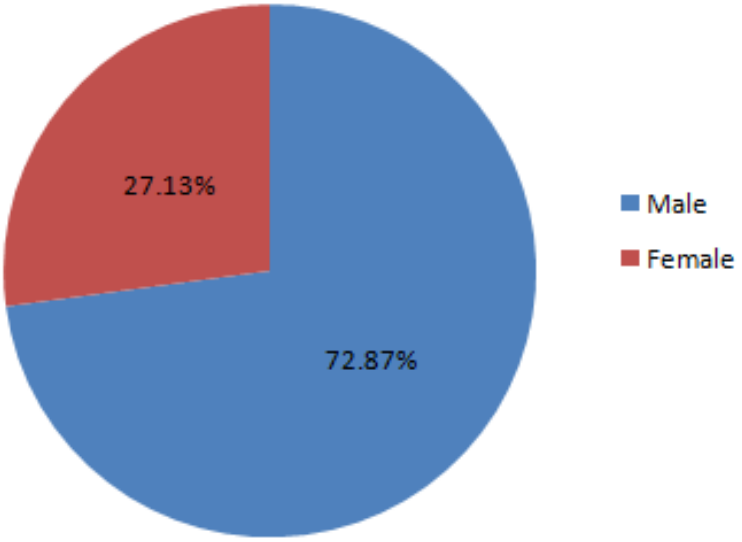



Figure 1.2 Nasopharynx cancer by sex, Malaysia 2007 (NCR, 2007)

The goal of radiotherapy is to eradicate tumour cell while sparing the organs at risk (OAR) and nearby healthy tissues (Travis, 1989). Intensity Modulated Radiotherapy (IMRT) is an advanced treatment technique which can deliver significant high doses to tumour volume (TV) while sparing the surrounding normal tissue (Lee, Chuang *et al*., 2002)

Before started a radiotherapy treatment, a series of comprehensive Quality Assurance in Radiotherapy (QART) procedures was carried out for machine installation and calibration, source delivery and safety, operational procedures, clinical dosimetry and the whole treatment planning process is designed and implemented (IAEA TRS115, 1994). Quality control (QC) procedures should be followed before and during treatment. It is important to verify calculated doses and measured doses tally, especially for IMRT which is a highly complex technique. It is also crucial to confirm the accuracy and reproducibility of treatment delivery.

Ionisation chamber (IC), semiconductor detector, thermoluminescent detector (TLD), radiochromic film and metal oxide semiconductor field effect transistor (MOSFET) were the devices which had been developed to improve the efficacy of radiotherapy verification test. Radiochromic film and MOSFET are two dimensional (2D) detectors and provides high spatial resolution of measured dose distribution which is crucial for head and neck radiotherapy dosimetry.

QC of IMRT plan includes verification of absolute dose distribution at one or more points of interest (POI) as well as of 2D dose distributions in different plane in a water equivalent phantom. QC of IMRT is highly concerned on the dosimetry of TV and OAR.

Radiotherapy treatment for NPC involves OARs, such as brainstem, bilateral eyes, bilateral parotids and oral cavity. Therefore, QC to verify TV and OARs doses are crucial before pressing the start button onto the linear accelerator (LINAC) control panel for treatment.

## 1.2 Problem Statements

Conventional dosimeters such as IC, semiconductor detector and TLD often fail to meet the requirement to provide high spatial resolution of 2D dose distributions and absolute dose determination at POI.

IC has difficulty to measure large dose gradient due to the size of chamber. TLD require time consuming calibration and post processing procedure (Chung, Lee *et al*., 2009).

Although radiochromic film required careful calibration and post processing procedures (Chung, Lee *et al*., 2009), it provides high spatial resolution of 2D dose distribution which is necessary for IMRT QC. Whereas, MOSFET is easy to use, small size, light weight, instant readout and reducing time for processing. In this study, MOSFET and Radiochromic EBT2 film were used as clinical dosimeters.

## 1.3 Objectives

1. To verify the exposed radiation dose of TV and OARs in conventional mid-plane dose (MPD) plan and IMRT plan in NPC radiotherapy.
2. To characterise both dosimeters, Radiochromic EBT2 film and MOSFET:
    a) Radiochromic EBT2 film characterisation included film orientation, film sensitivity to room light, film darkening effect, film water immersion effect, film reproducibility, dose dependence, field size dependence, angular dependence and percentage depth dose (PDD) calibration.
    b) Characterisation of MOSFET include MOSFET fading effect, reproducibility, dose perturbation, dose dependence and linearity, field size dependence, angular dependence, SSD dependence and PDD calibration.

## 1.4 Organization of Research

To achieve the objectives, this research study was divided into five chapters.

Chapter one describes the introduction of this research study. It consists of four parts, overview, problem statements, objectives and organization of research.

Chapter two elaborates literature review on five major areas. It includes review of common dosimeters used in radiotherapy; historical review of radiochromic EBT2 film, MOSFET, and others dosimeter like IC and TLD; *in vivo* dosimetry; and radiotherapy technique.

Chapter three describes instrumentations and methodology used in this research. Instrumentations are Radiochromic EBT2 film, MOSFET, flatbed scanner, ImageJ software program, Mobile MOSFET dose verification system, phantoms (solid water phantom, customised acrylic head and neck phantom and hemi-cylindrical acrylic phantom), LINAC, Computed Tomography (CT) scanner, and CMS XiO treatment planning system, IC, electrometer, MOSFET build-up cap and beam directional shell (BDS). Whereas methodology included characterisation of scanner, radiochromic EBT2 Film and MOSFET, general characteristic as a dosimeter for Radiochromic film and MOSFET, calibration of MOSFET system and *in vitro* dose verification on a customised phantom.

Chapter four describes the results and discussion of this research.

Chapter five describes the conclusion of this research. Nevertheless, recommendations for future research are provided.

# CHAPTER 2 LITERATURE REVIEW

## 2.1 Common Dosimeters Used in Radiotherapy

For the past few years, extensive research has been carried out to develop detectors for radiotherapy treatment verification, QC and QART check. Dosimeter is a detector that is able to measure absolute dose or unit to derive equivalent dose (Podgorsak, 2003). Absolute dose is usually measured in Gray (Gy) which is equivalent to energy in joule that is being absorbed in human tissue per kilogram (Shapiro, 1990).

Radiotherapy dosimetry can be measured in one dimension (1D), two dimensions (2D) and three dimensions (3D). 1D dosimetry is for a point dose measurement; 2D gives a dose distribution map; 3D is for target volume dose measurement. IC, semiconductor dosimeter, TLD, optical stimulated luminescence dosimeter (OSLD) and radiophotoluminescene (RPL) are the common 1D dosimeters used in radiotherapy field. Radiochromic film and MapCheck is the popular dosimeter used in 2D radiotherapy dosimetry. Cylindrical PRESAGE dosimeter, polymer gel and Frickle gel are the common 3D dose verification dosimeter (Guo, Adamovics et al. 2006).

## 2.2 Radiochromic EBT2 Film in Medical Physics

Before Radiochromic films were introduced, radiographic films were used widely in diagnostic radiology. The latter films were designed primarily for detecting low energy (kilovoltage) radiation based on silver halide film technology of photographic industry. Radiochromic films were developed after this for quantitative dose measurements in megavoltage beams (radiotherapy in megavoltage (MV) energy). When the films are exposed to ionising radiation, the films change colour without dark room facility or film developer. In clinical and research for MV energy beams,

radiochromic films MD-55 with 50-100 Gy doses range were initially introduced, followed by models HD-810 and HS which were provided by International Specialty Products (ISP). However, low sensitivity prevented their routine use in 2D dose distribution measurements in clinical environment. Radiochromic film EBT (External Beam Therapy) followed by a newer version called EBT 2 was then introduced. IMRT verification becomes feasible with Radiochromic EBT 2 films in clinical application.

## 2.3 MOSFET in Medical Physics

The basic principle of transistor was first patterned by Julius Edgar Lilienfield in 1925. After this, Dawon Kahng and Martin M. (J) Atalla invented the MOSFET as an offshoot to the patented field-effect transistor (FET) design in 1959.

MOSFET was initially designed for monitoring radiation dose in the space. In the recent years, MOSFET is widely used for dose verification in medical radiation such as in therapeutic and diagnostic applications. Nowadays, MOSFET is frequently used in dose verification in radiotherapy for IMRT and beam Quality Assurance (QA) purpose.

## 2.4 Other Dosimeters in Medical Physics

Other than Radiochromic EBT2 film and MOSFET, IC and TLD are popular detectors among the choices of radiotherapy dosimetry.

Development of radiation dosimetry is closely tied with IC. In 1908, Paul Villard proposed the use of IC connected to an electrometer (Frame 2005). In 1940, Frisch invented the gridded IC and hence gas-filled detector in late 1940 (Flakus F.N., 1981). Nowadays, IC is the gold standard for absolute radiotherapy dosimetry. It is

recommended by International Atomic Energy Agency (IAEA) to use IC for determination in reference irradiation conditions which is named beam calibration. Due to different specific requirement during measurement, ICs are designed in various shapes and sizes. Cylindrical (thimble type) and parallel plate (plane-parallel) are the common IC used in radiotherapy dosimetry (Izewska J and Rajan G, 2010). IC is reusable and self reading for immediate determination of exposure.

TLD has been used as 1D dosimeter in radiotherapy to measure the point dose over 30 years. It is a popular dosimeter due to its small size, reusable, and can use in measurement for a wide range of radiotherapy energy. Due to lengthy annealing process of TLD, it cannot provide immediate readout. Thus TLD is time consuming and is not popular in recent decades (AAPM report No.87, 2005).

## 2.5 *In Vivo* Dosimetry and *In Vitro* Dosimetry

In Latin, *in vivo* is meant for "within living" and *in vitro* is meant for "in glass". *In vivo* dosimetry measures the dose received by patients during the radiotherapy treatment; whereas *in vitro* dosimetry measure the dose received by the phantom which represent patients before or after the radiotherapy treatment (Mijnheer, 2008). Both *in vivo* and *in vitro* dosimetry play important role in radiotherapy QA especially during advanced radiotherapy techniques. It can prevent the potential errors in dose calculation, data transfer, dose delivery, patient setup, and others.

*In vivo* and *in vitro* dosimetry can be done in two ways: the dosimeter invasively inserted into the patient or phantom at the POI, or the dosimeter non-invasively placed on the patient or phantom or at some distance with appropriate build up. American Association of Physicist in Medicine (AAPM) Report 87 has summarized a guideline for *in vivo* dosimetry in clinical routine.

## 2.6 Radiotherapy Techniques

Radiotherapy is rapidly growing in this few eras since it is one of the beneficial option for malignant and benign diseases treatment (Slater, 2012). In 1954, the first treatment on human being, followed by first hospital-based proton facilities in mid 1980s. A series of research is always ongoing to develop new techniques to destroy cancer cells yet minimizing dose to healthy tissue.

LINAC was introduced in the 1960s. It produces high energy and deep penetration MV treatment. At the very first beginning, the simulation was done on-site marking followed by x-ray simulation and currently CT simulation by the rapidly advent of imaging technologies since 1970s. Nevertheless, computerized treatment planning technology was developed in the last quarter of $20^{th}$ century too (DeVita Jr and Rosenberg, 2012). It contributed to 3D conformal, IMRT and Image Guided Radiotherapy (IGRT) which can precisely match the tumour shapes by several directions using multiple shaped beams (Evolution of cancer treatments: Radiation, American cancer Society, 2014) (DeSantis, Lin et al., 2014)(Figure 2.1). With IMRT, each beam has modulated intensity of the radiation to deliver varying amounts of dose. These hundreds of “beamlets” are made possible by computer-controlled multileave collimator (MLC) which are mounted inside the linear accelerator. These move continuously during the treatment to deliver varying doses of radiation within the field (Figure 2.2). An extensive planning process needs to be carried out in IMRT treatment.

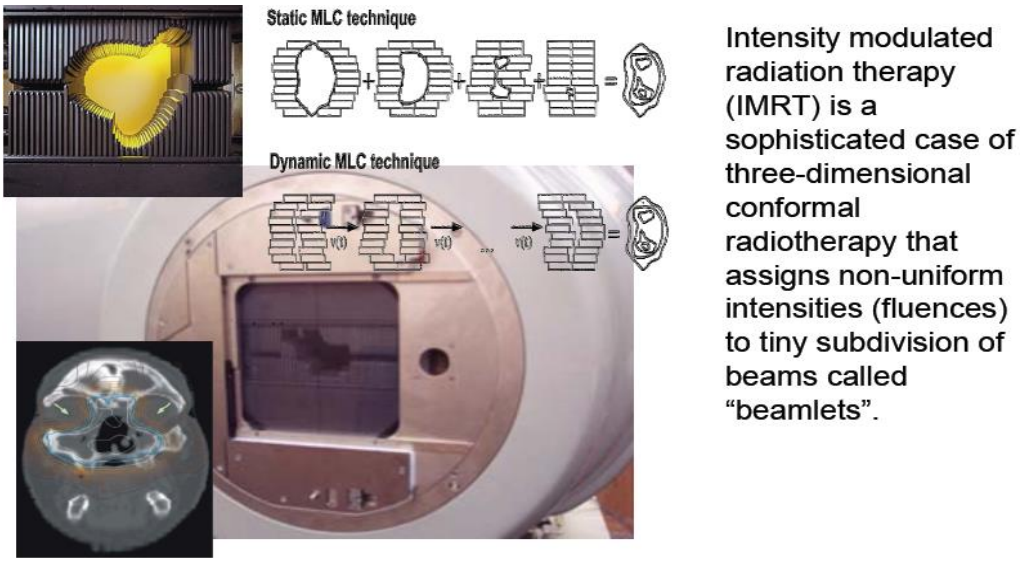



Figure 2.1: Computer controlled multileaves collimators in IMRT
(Source: Hand notes of IAEA Post Graduate Education Course in Radiation Protection and Safe Use of Radiation Sources).

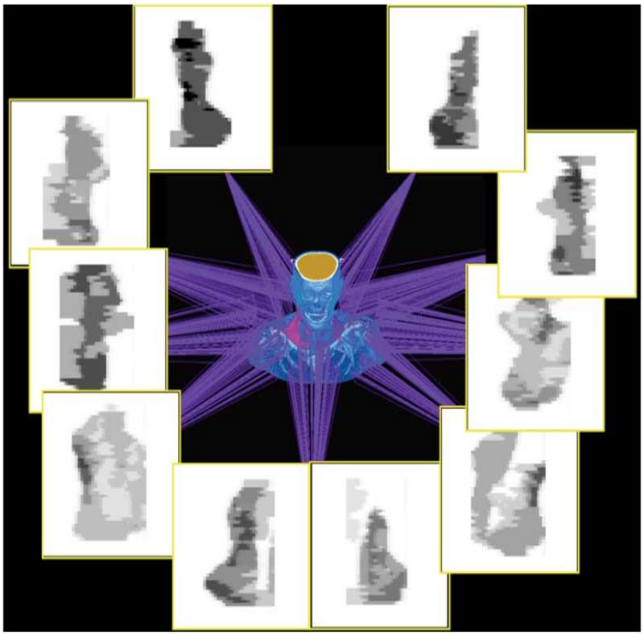
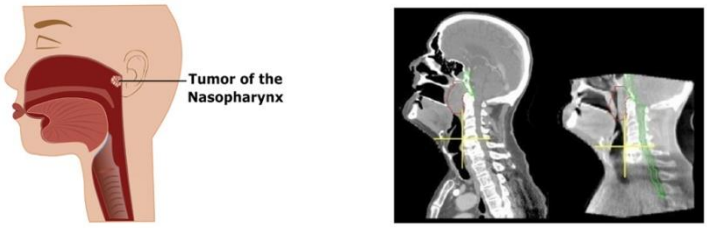


Figure 2.2: Modulated dose intensity by several beamlets in different beams' position.
(Source: Hand notes of IAEA Post Graduate Education Course in Radiation Protection and Safe Use of Radiation Sources).

## 2.7 *In vitro* Dose Verification on a Customised Acrylic (PERSPEX) Head and Neck Phantom

### 2.7.1 Introduction

The purpose of this research is to verify the measured delivered dose in radiotherapy to the treatment planned dose. This dose verification procedure was done on a customised acrylic (Perspex) head and neck phantom using two different measurement tools; Radiochromic EBT2 film and MOSFET. NPC (Figure 2.3) is the highest ranking among the head and neck cancer in Malaysian population especially Chinese population (The National Cancer Registry (NCR), 2011). Thus NPC cases were chosen in this study. Radiotherapy has four major procedures, which are simulation, radiotherapy planning, dose verification and radiotherapy delivery (Figure 2.4).




(a) (b)

Figure 2.3: Nasopharynx Cancer (NPC). (a) Illustration of NPC in human head anatomy (Source: NCR, 2011). (b) Red contour showed NPC target volume in sagittal plane of CT images (Source: CMS XiO TPS).

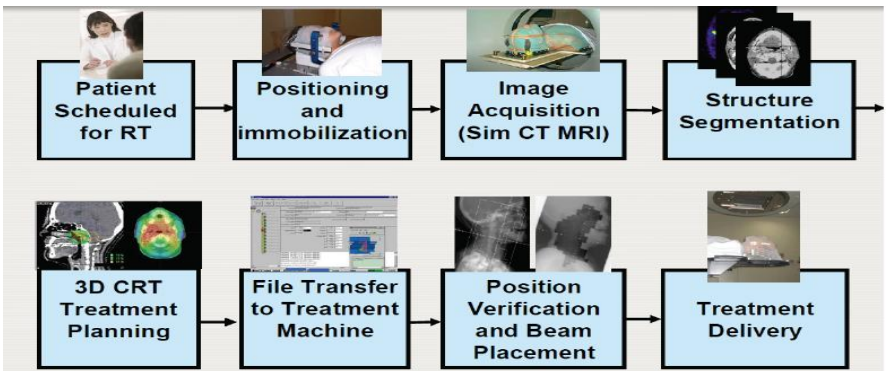



Figure 2.4: The radiotherapy standard procedures (Source: CMS XiO brochure).

### 2.7.2 Simulation

In the very beginning for NPC radiotherapy, the oncologist will mark the desired treatment area on the patient's skin by estimation from anatomical structure. With improvement in technology, NPC radiotherapy went from conventional simulation using a simulator named 2D treatment planning to CT simulation. The latter was named 3D treatment planning (Figure 2.5) and now even four-dimension (4D) treatment planning is a possibility (Barrett, Dobbs et al. 2009). In radiotherapy planning, it is crucial to have a comfortable positioning for patient for high reproducibility. An immobilization tool, for example a BDS, is commonly used in NPC radiotherapy to ensure high reproducibility of treatment (Figure 2.6).

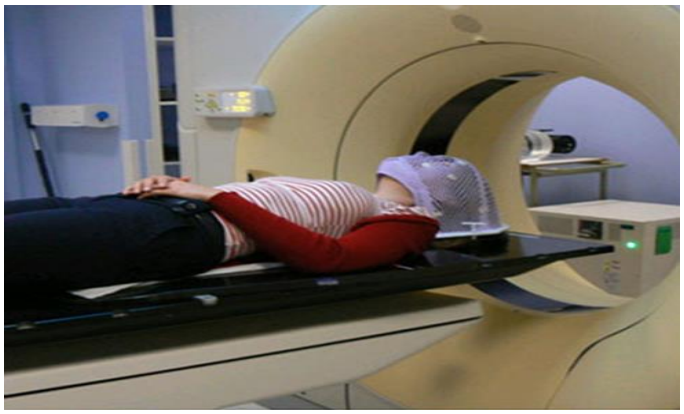


Figure 2.5: A brain cancer patient having a 3D simulation planning using CT scanner, with a head BDS (Source: Cancer Research UK).

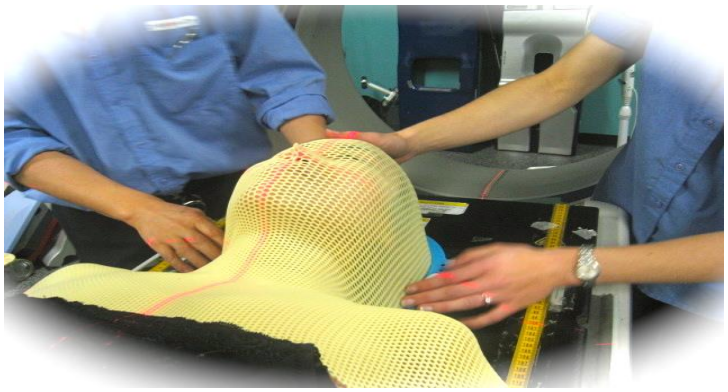


Figure 2.6: A customised head and neck BDS is molding onto a particular head and neck cancer patient (Picture taken at simulation room Pantai Hospital Penang).

### 2.7.3 Radiotherapy Planning

Radiotherapy planning is the process of determining the best method of treating a tumour volume using high energy radiation (Stanton *et al.*, 1996). At Pantai Hospital Penang, the radiotherapy plans were done by computerized XiO Treatment Planning System (TPS). The main purpose of radiotherapy planning is to ensure tumour volume receives a uniform and adequate radiation dose whilst the healthy tissues and organs at risk are protected (Stanton *et al.*, 1996). According to the International Commission on Radiation Units and Measurements 50 (ICRU 50, 1993) tumour volume can be categorized as gross target volume (GTV), clinical target volume (CTV) and planning target volume (PTV) (Figure 2.7). Oncologist will contour the target volume according to the above mentioned protocol and decide on the desired treatment dose.

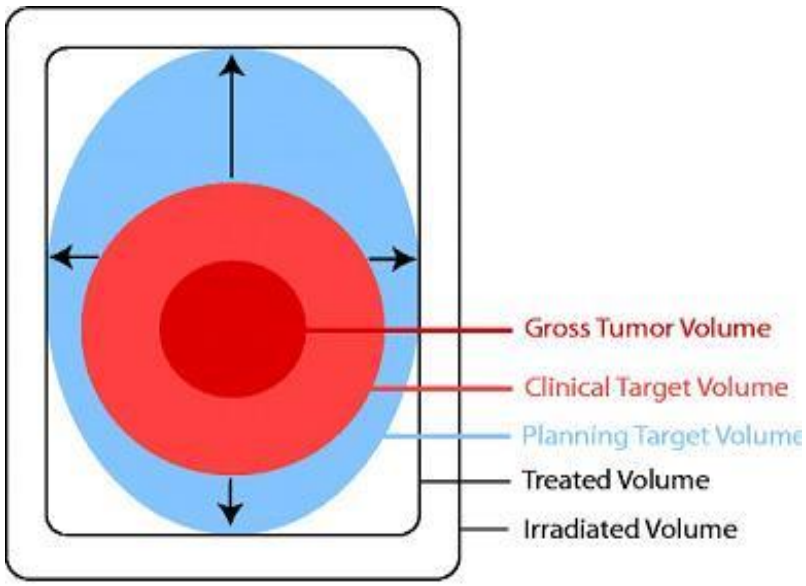



Figure 2.7: The illustration of ICRU 50 target volume definition.
(Source: ICRU 50, 1993).

The medical physicist will design a customised radiotherapy planning with appropriate radiation field arrangements. Lead block or MLC will enhance the

radiotherapy plan by shielding the organs at risk and healthy tissues from irradiation. Manual calculation of dosage or complex computerized planning will be the next step of radiotherapy planning. The types of radiotherapy plan can be categorized as single field, MPD, wedge-paired, multi-fields conformal and IMRT (Figure 2.8).

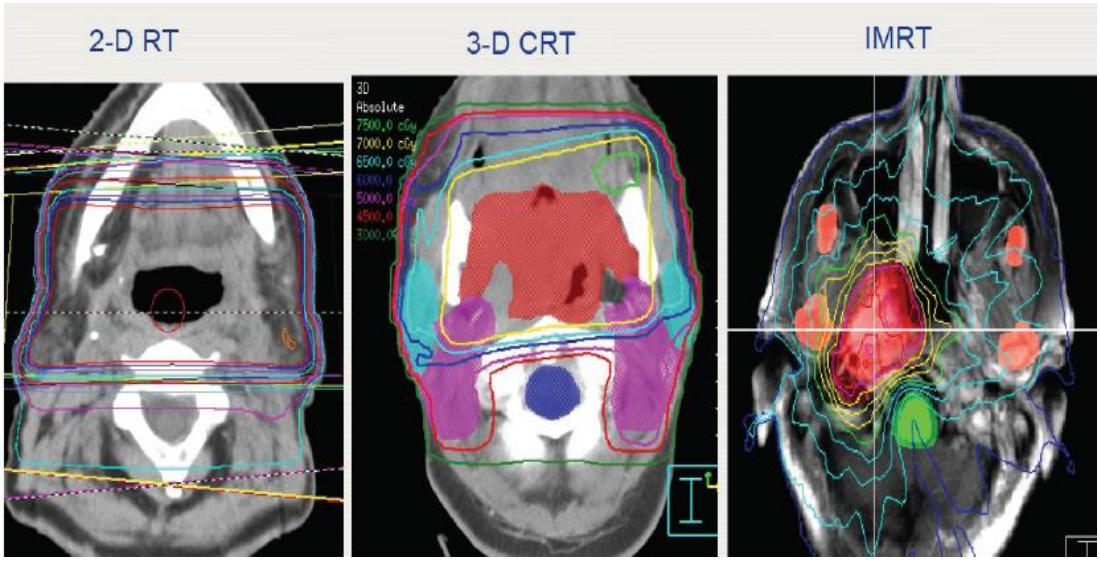



Figure 2.8: Isodose lines for different types of radiotherapy plan; 2D radiotherapy plan, 3D radiotherapy plan and IMRT plan (Source: Lei Xing 2011).

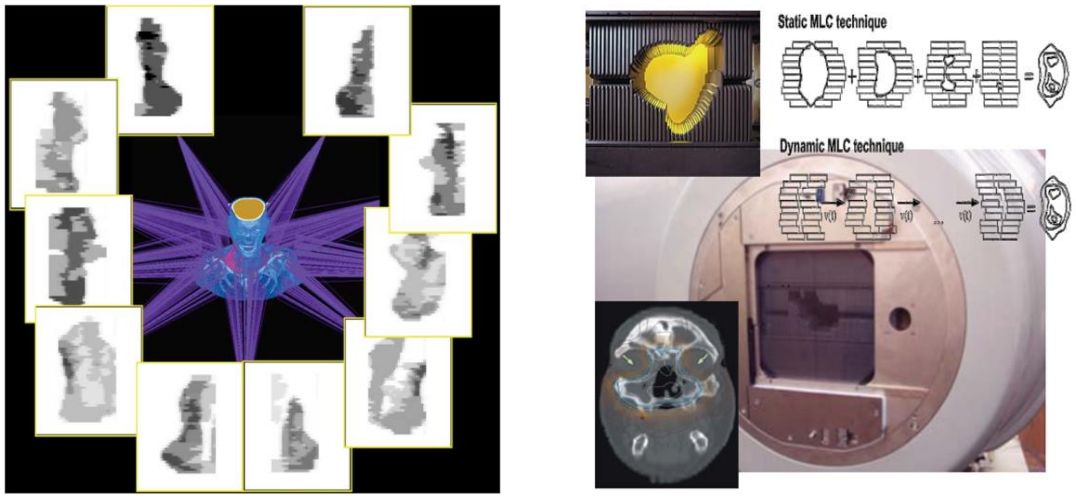
In this research, the dose verification of three radiotherapy plans planned by XiO TPS; MPD plan and two different seven fields IMRT plans were done on a customised acrylic head and neck phantom.

### 2.7.3(a) Mid-Plane Dose (MPD) Plan

MPD plan is a parallel opposed field beam configuration (Stanton *et al.*, 1996). This field arrangement is suited for treatment of midline structures. Since the human head is symmetrical and nasopharynx tumour is assumed to be located along the midline of the clivus bone, NPC can be treated with lateral MPD plan. This is done in some cancer centers.

### 2.7.3(b) Intensity Modulated Radiotherapy (IMRT) Plan

IMRT is an advanced conformal radiotherapy that utilizes computer optimized inverse treatment planning and computer controlled treatment delivery (Chuang *et al.*, 2002). It is currently the most favoured choice for head and neck cancer radiotherapy, including NPC. This radiotherapy involves multiples beam angles and segments which have varied or modulated dose intensity (Figure 2.9). It is able to produce a customised radiation dose intensity to maximize the tumour dose while minimizing the dose to adjacent OAR and healthy tissues.




(a) (b)

Figure 2.9: Illustration of an IMRT plan. (a) IMRT plan with multiple beam angles and modulated dose intensity. (b) MLC leaves formed non-uniform intensities to the beams. (Source: Lei Xing 2011).

### 2.7.4 Dose Verification

After treatment planning, the next procedure is dose verification prior to radiotherapy delivery. Since IMRT has high complexity dose patterns and techniques, QC should be done for both equipment operation and delivery of treatment to individual patients (Williams 2014). In Pantai Hospital Penang, for equipment operation wise, QC was done using MapCheck2 to check the dose map whereas for patient, portal film or electronic portal imaging (EPID) was taken before the start button was pressed.

Measurements on phantom where the human anatomy is reproduced are often recommended in addition to *in vivo* measurements (Cho *et al.,* 2007). Therefore, a series of testing using *in vitro* measurement tools like Radiochromic EBT2 Film and MOSFET were performed on the phantom in this study.

### 2.7.5 Radiotherapy Delivery

In Pantai Hospital Penang, radiotherapy is delivered once the verification in dose and patient positioning passed the requirement. In normal cases, NPC radiotherapy is delivered over a total of 33 to 37 fractions with five fractions per week.

# CHAPTER 3 INSTRUMENTATION AND METHODOLOGY

## 3.1 Instrumentations

### 3.1.1 Radiochromic EBT2 Film

#### 3.1.1(a) Physical Properties of Radiochromic EBT2 Film

Radiochromic EBT2 film is available in 8 x 10 inch and 14 x 17 inch sheets. The effective atomic number, $Z_{eff}$, is calculated as 6.84. Radiochromic EBT2 Film is formed by polyester overlaminate (50 microns), pressure sensitive adhesive layer (25 microns), active layer (28 microns) and polyester substrate (175 microns) (ISP, 2009). Compared with Radiochromic EBT Film, the active part of the film has been reduced to a single layer. The structure is shown in Figure 3.1.

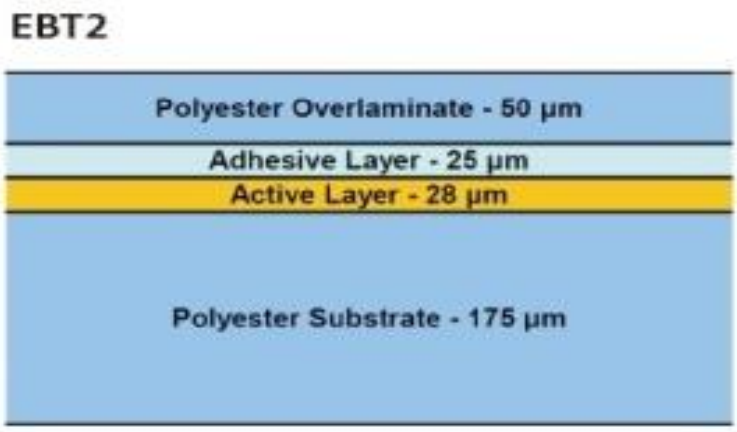



Figure 3.1: Configuration of Radiochromic EBT2 film (Source: ISP, 2009).

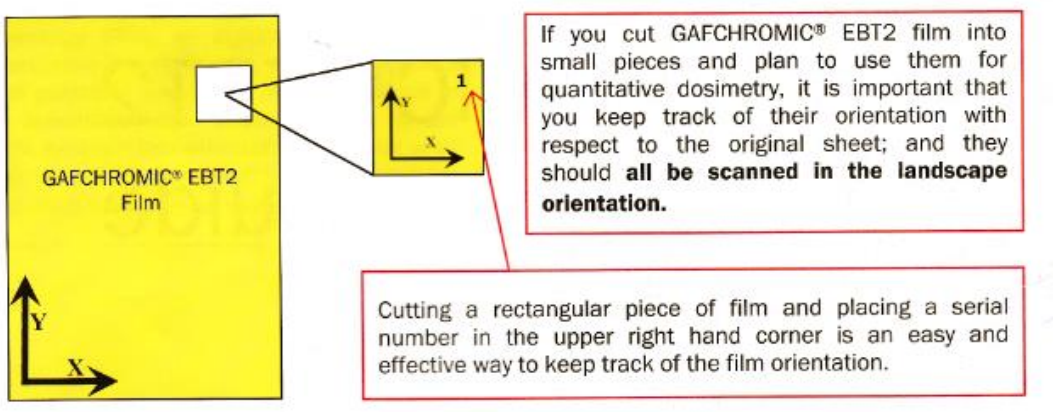



Figure 3.2: Method used to keep track of the film orientation (ISP, 2009).

This film incorporates a yellow marker dye which protects the active layer from exposure to ultraviolet and visible light. Besides, this yellow dye can be used as the baseline for the response. Later, a synthetic polymer replaced gelatin to make this film more tightly controlled from lot to lot for uniform response to radiation.

Radiochromic EBT2 film is marked with a small slit to distinguish the sides. To let the 50 microns polyester laminate side face us, the slit must at the right side top edge and the film held in landscape orientation as shown in Figure 3.2.

### 3.1.1(b) Dosimetric Response of Radiochromic EBT2 Film

Radiochromic EBT2 film uses the exactly same active component as the original version Radiochromic EBT but incorporates a yellow dye. Since this film is asymmetrical in its cross section with two different thicknesses of outer polyester layers, therefore, the side of film facing the scanner bed is important. The film has to be placed on the same side facing the scanner bed to get a consistent response especially when scanning in portrait orientation.

Radiochromic EBT2 film gives a different response in different channels of the scanner. In the dose range from 1 cGy to 10 Gy (as done in this research), the red colour channel is the most suitable channel response. The green colour channel is suitable for measurements up to 40 Gy whereas the blue colour channel is used to adjust small response differences over the area of a film (ISP, 2009).

### 3.1.1(c) Advantages and Disadvantages of Radiochromic EBT2 Film

Radiochromic EBT2 film can be easily cut to desired shape and size. It can be also immersed in water for hours and cleaned with water or alcohol; this makes it viable for use in a water phantom. This film has low sensitivity to light; therefore it is

convenient to handle in room light. It can develop in real time and also the density changes stabilize rapidly after exposure.

One of the disadvantages of Radiochromic EBT2 film is that it is no longer possible to measure using blue channel response as the dye is yellow colour; it produces a strong signal in the blue channel. Therefore for doses more than 50 Gy it is not recommended to use the Radiochromic EBT2 film. However Radiochromic HD810 film can be used for dose more than 50 Gy. Besides, Radiochromic EBT2 Film is slightly thicker compared with the original Radiochromic EBT film.

### 3.1.2 Metal Oxide Semiconductor Field-Effect Transistor (MOSFET)

#### 3.1.2(a) Physical Properties of MOSFET

The physical size of standard MOSFET is 2.5 mm (width of flex) x 200 mm (length of flex) x 0.3 mm (thickness of flex). The MOSFET detector is coated by a thin 0.6 mm layer black epoxy mounted on to the end of laminated polyamide cable, sized 2.5 mm (width) x 3.5 mm (length) x 1 mm (thickness). Consequently, the mounted bubble side is referred as epoxy side and the opposite side is referred as flat side. The structure is shown in the Figure 3.3.


Figure 3.3: Standard MOSFET system by BEST Medical Canada.

### 3.1.2(b) Dosimetric Response of MOSFET

The sensitive volume of MOSFET dosimeter is 0.2 mm x 0.2 mm cross sectional and 0.5 µm thick (Ramaseshan, Kohli *et al*., 2004).

MOSFET consists of a p-type silicon semiconductor substrate, a layer of insulating oxide and a metal gate (Kohno *et al.,* 2008). A positive bias is applied between the gate and source terminals (+ 15 V and + 1 V) before irradiation (Ramasesham *et al.,* 2004) (Rosenfeld 2006). When irradiated, the ionising radiation generates electron hole pairs in the insulating layer and some holes drift toward the substrate under the appropriate bias voltage and then get trapped. A negative voltage is then applied between the gate and the source terminals after irradiation in the read state.

### 3.1.2(c) Advantages and Disadvantages of MOSFET

The instantaneous reading and immediate reuse are the main advantages of the MOSFET. Using MOSFET to get the real time measurement can help to detect and correct the delivered dose before the radiation therapy is ended. Besides, its portability, small size, and no need cables to measure the signal by the detector make MOSFET a better choice. The negligible attenuation of radiation and low power requirement make MOSFET a good alternative in *in-vivo* dosimetry. Characteristics of MOSFET such as lightweight, flexible, ability to conduct multiple pinpoint dose measurement without patient shielding, and little sensitivity variation with temperature and dose readout (both direct dose and accumulated dose) are its other advantages.

However, MOSFET's limitation is that it has to be replaced when saturated. MOSFET is well-functioned when the accumulated dose less than 10000 mV; low dose performance degrades once accumulation dose equivalent achieved 17000 mV

(The Best Medical Canada Operator's manual, 2010). If used, there is high noise drift at low dose; therefore, replacement is advised at the accumulated dose of more than 17000 mV. Besides, MOSFET shows slight field size dependence for 18 MV X-ray (Ramaseshan *et al.* 2004). However this does not affect our research since only 6 MV X-ray is used in this study. The manual recommends that the MOSFET reader should be on for 30 minutes prior to measurement for stable and reliable results (The Best Medical Canada Operator's manual, 2010).

### 3.1.3 Epson Expression 10000XL Scanner Film Dosimetry

Epson Expression 10000XL scanner (Figure 3.4) is a professional colour flatbed scanner with A3 size scan bed. It is convenient for large-format scanning since it is possible to accommodate reflective media up to 12.2" x 17.2" or transparencies up to 12.2" x 16.5". It has Micro Step Drive™ technology which gives brilliant clarity with detail. It has extraordinary image quality (2400 x 4800 dots per inch (dpi) resolution) and smooth gradations with 48-bit colour which captures over 4 trillion colours and 4,096 shades of gray. The light source of this scanner is Xenon gas cold cathode fluorescent lamp. This Xenon lamp is an instant start lamp which makes it to be always in the ready status. The scanner is equipped with a linear CCD array detector and features a dual lens system. The system can be used in transmission or reflective mode, however, transmission mode is preferred for film dosimetry. The scanned images output formats are Joint Photographic Experts Group (JPEG), Bitmap image file(BMP), Tagged Image File Format (TIFF) and Portable Document Format (PDF).

Figure 3.4: Epson Expression 10000XL scanner with transparent unit.

### 3.1.4 ImageJ software program and film analysis

ImageJ is a free public domain software program used in image processing and analysis. It can display, edit and analyse various format images, including TIFF, GIF, JPEG, BMP, and DICOM. In this research, ImageJ was used to analyse the scanned Radiochromic EBT2 film. It allows extraction of 16 bits per channel (red, green and blue) from the 48 bits colour mode. This is the advantage of ImageJ which allows film pixel value reading by different colour channels, for example, red channel reading was used in Radiochromic EBT2 film analysis. For Radiochromic EBT2 film characterisation and analysis, scanned images in TIFF format were analysed using rectangular selection tools for area and pixel value calculation. Scale was set to analyse at the same region of interest (ROI) (1 cm x 1 cm) for the three repeated scans of each image. Therefore, 1 cm x 1 cm ROI was evenly cropped for pixel value calculation in RGB colour mode. The tool bar for ImageJ software program was shown in Figure 3.5.

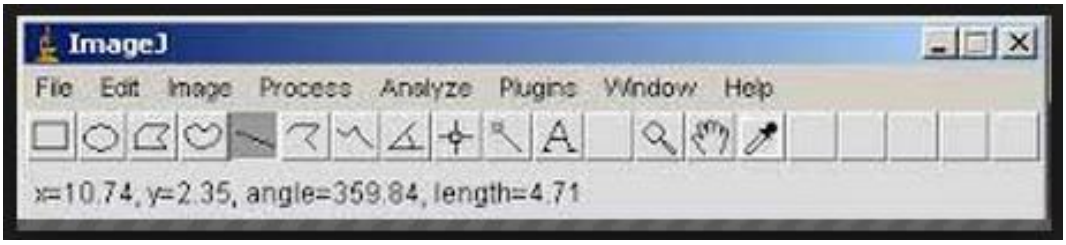



Figure 3.5: ImageJ tool bar.

### 3.1.5 MobileMOSFET Dose Verification Systems

MobileMOSFET Dose Verification System consist of Remote Monitoring Dose Verification Software which is installed in the computer, wall mounted Bluetooth™ Wireless Transceiver and an easy carry mobileMOSFET reader which act as a channel between MOSFET and the software. The MOSFETs are connected to mobileMOSFET Reader TN-RD-16 (SN: 00526 BEST Medical Canada). To obtain

measured dose in real time, mobileMOSFET reader will then interact with mobileMOSFET Dose Verification Software at the computer through the Bluetooth™ Wireless Transceiver. This is user friendly and the seamless integrated system simplifies dosimetry. It also minimizes the QA time. Up to 40 MOSFETs can be read on-line with additional systems and transceivers.

### 3.1.6 Phantom

#### 3.1.6(a) Solid Water Phantom (White Polystyrene)

White polystyrene solid water phantom (Figure 3.6) helps to eliminate the inconvenience of setting up and filling water tanks. The materials, epoxy resins and powders, are used to control the density and radiation properties. The main concern is the general density must be equivalent to the water density. Density of solid phantom used in this research is 1.04 g/cm$^3$, which is considered water equivalent. Both PTW and RW3 solid phantoms had similar transmission values as compared to water to within ± 1.5% using gamma ray (140.5 keV) transmission measurement (R.F.Hill, 2007). Thickness of the solid water phantoms used in this research vary from 0.1 cm, 0.2 cm, 0.5 cm, 1 cm, 2 cm, 3 cm, 5 cm and 6 cm. These make it adequate to form various thicknesses in the calibration process.

Figure 3.6: Solid water phantom made by white polystyrene in various thicknesses.

### 3.1.6(b) Customised Acrylic (Perspex) Head and Neck Phantom

A customised head and neck phantom was made using clear acrylic (Perspex). Clear acrylic is relatively cost effective compared to anthropomorphic human phantom. It has excellent durability for the phantom. The mass density of acrylic is relatively close to water density (1.0 $gcm^{-3}$); that is 1.18 $g/cm^3$. On the other hand, effective atomic number for acrylic is 6.48 whereas it is 7.42 for water. This phantom has similar density as human soft tissue in CT images. The difference of transmission value for acrylic is ± 4% compared to density of water (R.F.Hill, 2007).

The head and neck phantom (Figure 3.7) was made using 1.0 cm thickness acrylic slab. A human's head and neck CT slices were printed out in 1.0 cm slice thickness and then traced on the acrylic slab. Acrylic slabs were cut using electric hand cutter and polished to make the shape smooth. The cut acrylic slices were then stacked together using Germany adhesive double sided tape to ensure no air gaps remained in between the slabs.

Figure 3.7: Customised Head and Neck Phantom using 1 cm slice of acrylic (Perspex). Both the front and side views are shown.