

**DOSIMETRIC CHARACTERISTIC OF AN AMORPHOUS  
SILICON ELECTRONIC PORTAL IMAGING DEVICE FOR  
DYNAMIC INTENSITY MODULATED RADIATION THERAPY**

The seal of Mahidol University is a circular emblem. It features a central blue circle containing a golden Thai stupa (chedi) with intricate carvings. This central circle is surrounded by a wider yellow ring. Inside the yellow ring, the university's name is written in Thai script: 'มหาวิทยาลัยมหิดล' (Mahavithayalai Mahidol) at the top and 'วิทยาเขตศาลายา' (Witayalai Sallaya) at the bottom. There are also small golden floral motifs on the left and right sides of the yellow ring.

**KHUMMOOK KRONGYUTH**

**A THESIS SUBMITTED IN PARTIAL FULFILLMENT  
OF THE REQUIREMENTS FOR  
THE DEGREE OF MASTER OF SCIENCE  
(MEDICAL PHYSICS)  
FACULTY OF GRADUATE STUDIES  
MAHIDOL UNIVERSITY**

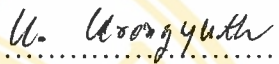
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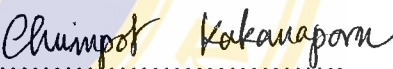
Thesis  
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SILICON ELECTRONIC PORTAL IMAGING DEVICE FOR  
DYNAMIC INTENSITY MODULATED RADIATION THERAPY**

  
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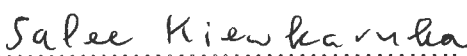
  
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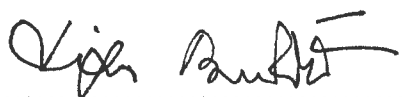
  
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SILICON ELECTRONIC PORTAL IMAGING DEVICE FOR  
DYNAMIC INTENSITY MODULATED RADIATION THERAPY**

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Khummook Krongyuth

**DOSIMETRIC CHARACTERISTIC OF AN AMORPHOUS SILICON ELECTRONIC PORTAL IMAGING DEVICE FOR DYNAMIC INTENSITY MODULATED RADIATION THERAPY.**

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**ABSTRACT**

In external beam radiotherapy, electronic portal imaging devices (EPIDs) are used for real-time digital acquisition of images prior to and during radiation treatment in order to assist in verifying patient setup. Recently, the EPID has been used for dosimetric application especially for pre-treatment verification of intensity modulated radiation therapy (IMRT). In this study, the dosimetric characteristic of an amorphous silicon EPID for dosimetric verification of IMRT delivered by dynamic multileaf collimator (dMLC) from 6 and 10 MeV photon beams were investigated, and then compared with CadPlan fluence utilized by RTPs and film measurements. The dosimetric characteristics studied were dose response, field size response, effect of dead time in frame acquisition, response with leaf speed, response of dose-rate fluctuation, memory effect and long term detector reproducibility. Relative dosimetric measurements using EPID such as open and wedged static fields, IMRT test pattern field and actual fluence from clinical IMRT fields were included. The results showed that the dosimetric characteristics from EPID were linear with dose and dose rate, and response to MLC leaf speed up to 3.0 cm/s for both photon energies. The reading from EPID and ionization chamber measurements at the field size response were up to 4% and 5% different for 6 and 10 MeV respectively. The dead time in frame acquisition was found to be a source of error of up to 20 % in the EPID measured signals for both x-ray beams. Response with dose-rate fluctuation was within 3.5% for two energies. Memory effect was not significant. The long term detector reproducibility was found to be within 2% for dynamic field delivery from both energies. The result of relative dosimetry of EPID for IMRT fields was similar to the film measurements; however they were different when compared to CadPlan fluence measurements. In conclusion, EPID has potential for use as a dosimetric instrument for IMRT verification.

**KEY WORDS : ELECTRONIC PORTAL IMAGING DEVICE / INTENSITY MODULATED RADIATION THERAPY / VERIFICATION**

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การศึกษาคูณสมบัติเฉพาะของอุปกรณ์ Electronic Portal Imaging Device ชนิด Amorphous Silicon เพื่อนำมาใช้ในการตรวจสอบความถูกต้องในเทคนิคการฉายรังสีสามมิติแปรความเข้ม (DOSIMETRIC CHARACTERISTIC OF AN AMORPHOUS SILICON ELECTRONIC PORTAL IMAGING DEVICE FOR DYNAMIC INTENSITY MODULATED RADIATION THERAPY)

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บทคัดย่อ

การนำอุปกรณ์ Electronic Portal Imaging Device หรือ EPID มาใช้ในทางรังสีรักษานั้นส่วนใหญ่จะใช้สำหรับการตรวจสอบความถูกต้องของตำแหน่งการรักษาผู้ป่วยในการฉายรังสี ในปัจจุบันมีการนำอุปกรณ์ชนิดนี้มาประยุกต์ใช้เกี่ยวกับทางด้าน dosimetry มากขึ้น โดยเฉพาะนำมาใช้ในการตรวจสอบความถูกต้องของปริมาณรังสีในเทคนิคการฉายรังสีแปรความเข้ม (Intensity Modulated Radiation Therapy, IMRT) วัตถุประสงค์ในการศึกษาครั้งนี้คือการตรวจสอบคุณสมบัติทาง dosimetry ของ EPID ชนิด amorphous silicon ที่ใช้ในการตรวจสอบความถูกต้องของปริมาณรังสีในเทคนิคการฉายรังสีแปรความเข้มซึ่งใช้ dynamic multileaf collimator (DMLC) สำหรับลำรังสีโฟตอนพลังงาน 6 และ 10 เมกะโวลต์ และเพื่อเปรียบเทียบผลของ relative dosimetry ระหว่างการวัดด้วย EPID และการวัดด้วย และฟิล์ม คุณสมบัติทาง dosimetry ของ EPID ที่ศึกษาประกอบด้วย dose response, field size response, effect of dead time in frame acquisition, response with leaf speed, response of dose-rate fluctuation, memory effect และ long term detector reproducibility ส่วน Relative dosimetry ประกอบด้วยการวัดใน open field, wedged field, IMRT test pattern field และ CadPlan fluence IMRT fields ของผู้ป่วย ผลการศึกษาพบว่า การทดสอบ dose response และ response with leaf speed ของทั้งสองพลังงานมีความสัมพันธ์ระหว่างค่า reading ของ EPID กับ relative dose เป็นเส้นตรง ค่าความแตกต่างของ EPID กับ ionization chamber ใน field size response คือ 4% และ 5% สำหรับพลังงาน 6 และ 10 เมกะโวลต์ ตามลำดับ ผลของ dead time จะทำให้เกิดความคลาดเคลื่อนของสัญญาณถึง 20% สำหรับโฟตอนทั้งสองพลังงาน ผลของ response with dose-rate fluctuation ของทั้งสองพลังงานอยู่ในช่วง 3.5% สำหรับผลของ memory effect พบว่ามีผลน้อยมาก และ reproducibility ของ detector ทั้งสองพลังงานอยู่ใน 2% สำหรับผลของ relative dosimetry พบว่า การวัดด้วย EPID มีผลใกล้เคียงกับการวัดด้วยฟิล์ม แต่มีผลแตกต่างค่อนข้างมากเมื่อเปรียบเทียบกับ actual fluence จากการศึกษา EPID สามารถนำไปใช้งานทาง dosimetry ได้ และสามารถที่จะพัฒนาเพื่อนำมาใช้งานในการตรวจสอบความถูกต้องของปริมาณรังสีในเทคนิคการฉายรังสีแปรความเข้มได้

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## LIST OF ABBREVIATIONS

| Abbreviation     | Term                                              |
|------------------|---------------------------------------------------|
| AAPM             | The American Association of Physicist in Medicine |
| aSi              | Amorphous silicon                                 |
| BEV              | Beam eye's view                                   |
| CCD              | Charged-coupled device                            |
| cGy              | Centi-gray                                        |
| cm               | Centimeter                                        |
| cm <sup>2</sup>  | Square centimeter                                 |
| cm <sup>3</sup>  | Cubic centimeter                                  |
| CT               | Computed tomography                               |
| d <sub>max</sub> | Depth of maximum dose                             |
| dMLC             | Dynamic multileaf collimator                      |
| DTA              | Distance-to-agreement                             |
| DQE              | The detective quantum efficiencies                |
| % Diff           | The percent difference                            |
| 3D-CRT           | Three dimensional conformal radiation therapy     |
| 3D-RTP           | Three dimensional radiation therapy planning      |
| EDR2             | Extended dose range                               |
| EPID             | Electronic portal imaging device                  |
| H&D              | Hurter and Driffield                              |
| IAS2             | An image acquisition systems                      |
| IDU              | An image detection unit                           |
| IMRT             | Intensity modulated radiation therapy             |
| LMC              | Leaf motion calculator                            |
| MeV              | Megaelectron Volt                                 |
| MLC              | Multileaf collimator                              |
| mm               | Millimeter                                        |

## LIST OF ABBREVIATIONS (Continued)

| Abbreviation     | Term                                    |
|------------------|-----------------------------------------|
| mm <sup>2</sup>  | Square millimeter                       |
| mR               | Milli-Roentgen                          |
| MU               | Monitor unit                            |
| MV               | Megavolt                                |
| nC               | Nano-Coulomb                            |
| PD               | Portal dose                             |
| QA               | Quality Assurance                       |
| R                | Roentgen                                |
| RTPS             | The radiation treatment planning system |
| S                | Second                                  |
| SDD              | Source to detector Distance             |
| SNR              | Signal to noise ratio                   |
| SSD              | Source to Surface Distance              |
| TFT              | Thin film transistor                    |
| Z <sub>eff</sub> | The effective atomic number             |

## CHAPTER I

### INTRODUCTION

Radiation therapy has been used for many years to eliminate and diminish localized cancers. Traditionally, radiation therapy has been delivered through a small number of two-dimensional external radiation beams that treat the cancer target, but also irradiate areas of normal tissue. In decade, radiation therapy treatment planning and delivery are in the process of changing dramatically. This change is being driven in large part by continuing advances in computer technology that has led to the development of sophisticated three-dimensional radiation therapy planning (3D-RTP) systems and the computer-controlled radiation therapy treatment delivery systems. Such planning and delivery systems have made practical the implementation of three-dimensional conformal radiation therapy (3D-CRT). The goal of 3D-CRT is to conform the spatial distribution of the prescribed dose to the 3D target volume, while minimizing the dose to the surrounding normal structures. Typically, the delivery of 3D-CRT is accomplished with a set of fixed radiation beam, which are shaped using the beam eye's view (BEV) projection of the target volume. The radiation beam normally have a uniform intensity across the field, or, where appropriate have this intensity modified by simple beam fluence modifying devices like wedges or compensating filters. Now, even before this form of radiation therapy has been implemented throughout the radiation oncology community, a newer type of an advanced form of 3D-CRT called intensity modulated radiation therapy (IMRT) is rapidly evolved. IMRT treatment plans are often generated using 3D-RTP systems, which use inverse planning to determine the distribution of optimized non-uniform radiation beam intensities across the target volume. Note that the modern IMRT techniques are significantly more complex than traditional radiation treatment, including conventional 3D-CRT. The radiation is delivered using a linear accelerator with a multileaf collimator (MLC) that shapes the beams to conform to the

three-dimensional tumor shape. The computer-generated treatment plan is designed to tightly conform to the target shape and protect surrounding normal tissue. The advantage of IMRT which is over than 3D-CRT is more tumor coverage and spare critical organ by reducing the toxicity to surrounding areas. In addition, it can be escalated dose to improve tumor control. IMRT is usually delivered by complicated motions of MLC that generates patient-specific non-uniform intensity distribution. The delivery of MLC-based IMRT can be accomplished by several techniques. In static MLC-IMRT (SMLC-IMRT) technique, dose is delivered as a series of static, irregular positioned between fields. In dynamic MLC-IMRT (DMLC-IMRT) technique, the leaves continuously change position while the beam remains on. The patient specificity and highly sophisticated nature of the beam profile lead to a requirement for pre-treatment verification of IMRT field. There are two reasons why verification is of particular interest in IMRT. First, verify that the planned fluence distributions have been successfully delivered. A particular concern is that these new procedures may not be adequately covered by standard verification protocol. Point dose measurements frequently used as part of standard verification procedures may be difficult to apply in some IMRT cases, where the measurement point falls on a steep dose gradient. Commissioning and quality assurance (QA) of new types of planning and delivery techniques requires careful attention, including checking of small-field output factors in dose calculations and effects of MLC leaf position error on dose delivery. Because of the dynamic delivery, the leaves move across the field. Thus, positional inaccuracy of the leaves may affect the dose distribution everywhere within the field. Moreover, the acceleration and deceleration of the leaves when they move from one segment to the next may also cause undesirable artifact in the delivered intensity profile. Second, patient positioning verify, where high dose gradients are used to spare organ at risk close to a target volume, special attention should be given to ensuring that the patient is correctly positioned. This may include organ motion both between intrafraction and interfraction (1).

## **1.1 Dosimetric verification of IMRT**

The use of IMRT in clinical routine is spreading rapidly and its advantages in better target coverage in combination with sparing of normal tissue and organ at risk. However, a practical drawback on the implementation of IMRT into the clinical routine remains the time consuming patient specific QA that precedes the actual treatment. The most widely used form of pre-treatment verification for IMRT generally consists of absolute dose measurement combined with relative dose distribution measurement in a phantom. Both measurements of IMRT verification can be described.

### **1.1.1 Absolute dose measurement**

The measurement of absolute point doses frequently used as part of standard verification procedures. An approach for this IMRT verification measurement is to substitute the patient with a geometric phantom and measure the resultant dose using ionization chamber. The measure dose is then compared to the dose calculated by the radiation treatment planning systems (RTPS). If the measure dose agreement, implies that the beam delivery is accurate.

### **1.1.2 Relative dose distribution measurement**

An approach to this IMRT verification is to transfer the IMRT fluence for each field to a test phantom and calculate the cumulative dose distribution with RTPS. These fields can then be delivered to the test phantom setup on the linear accelerator, the dose distribution measured generally with film, and the result compared to the RTPS dose calculation. Furthermore, the single fluence map is also measured by film and then compared the fluence map with RTPS, time-consuming involving recalculation of the IMRT plan, set-up time on the linear accelerator, film processing and digitization, and comparison to the plan. Frequent film calibration and processor QA is also necessary (2).

### 1.1.2.1 Film dosimetry

A convenient tool is provided to determine relative dose distribution. Due to its dose integration capability and good spatial resolution, film dosimetry has become an important method of verifying IMRT plans. Kodak's XV2, Agfa' structurix and Kodak extended dose range (EDR2) films are most widely used for relative dose distribution measurement. The film response to radiation shows a significant dependence on the depth, energy and field size that may compromise the accuracy of the measurements. The dose-response range of films is quite limited. The linear region of the dose response curve (Hurter and Driffield, or H&D) for Kodak's XV2 film and Agfa' structurix film, for example, does not exceed 80 cGy (3). Thus, these films are used for single fluence map verification of IMRT but not used for cumulative dose distribution. Due to the use of conventional films may result in errors in measured dose distributions caused by underdosing of the film by some segments because monitor unit (MU) for some segments may be reduced to  $\leq 1$ . The recently introduced Kodak extended range EDR2 film has a linear dose response region extended to 500 cGy. The increased dose range makes EDR2 film particularly useful in verification of IMRT dose distribution (4). However, film procedure is time-consuming involving recalculation of the IMRT plan, set-up time on the linear accelerator, film processing and digitization, and comparison to the plan. Frequent film calibration and processor QA is also necessary.

### 1.1.2.2 Portal imaging dosimetry

Portal imaging is the acquisition of images with radiotherapy beam. The imaging media generally consists of radiographic film and electronic portal imaging device (EPID). The current main use of portal images has been the study of set-up errors in patient treatment. This has resulted in improving treatment accuracy and accounting for the uncertainties in treatment delivery. Now, the developing area of research with portal imaging device is their use for determining patient dose information. This means that portal imaging is becoming able to give both geometrical and dosimetric information and thus to provide powerful verification tools for advanced technique such as conformal therapy and IMRT (5). There are two main approaches to dosimetric verification. The first approach is to calibrate the

imager in terms of patient exit dose and to compare this with the exit dose map from the treatment planning system. The second approach is to use a model to calculate the portal dose image and to compare that with the measured portal dose image.

### 1.2 Electronic portal imaging device (EPID)

Electronic portal imaging devices (EPIDs) as shown in figure 1 have many potential advantages over film for portal imaging. The obtained image is immediately available and so can be used interactively to adjust patient of field position during radiotherapy. The image is digital, which aid image processing, contrast enhancement and image matching. Moreover, digital archiving saves space and allows for rapid retrieving of image over a network. Various types of EPIDs were developed, however, only the camera based, liquid ionization chamber and amorphous silicon type EPIDs have evolved into commercially available systems. Each type of EPID can be described (6).

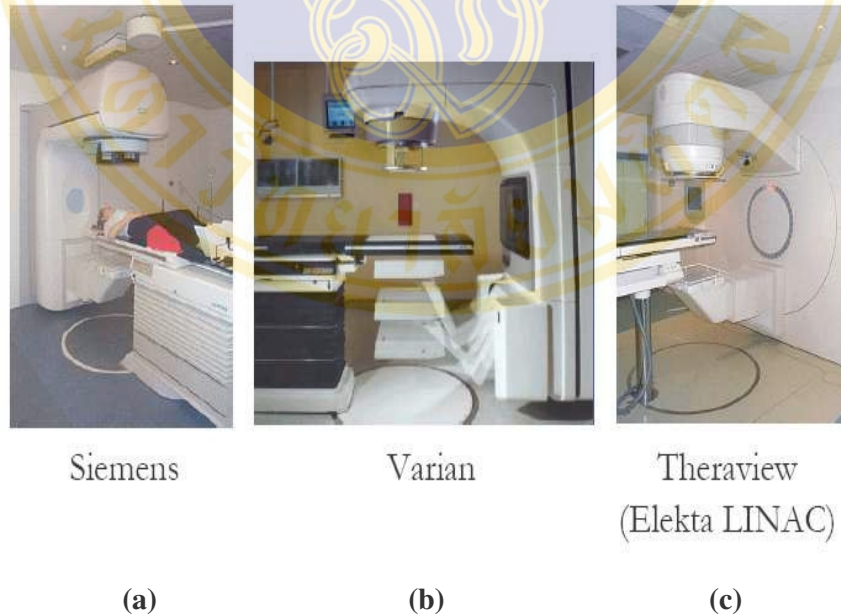


**Figure 1.** Examples of commercially available electronic portal imaging device: (a) Siemens BeamView system; (b) Varian PortalVision system; and (c) Elekta TheraView system (5).

### 1.2.1 Camera-based EPID (7)

Camera-based systems consist of a metal plate and a phosphor [Gadolinium oxysulfide ( $\text{Gd}_2\text{O}_2\text{S}$ )] screen viewed by a camera using a  $45^\circ$  mirror (Figure2). When irradiated, high energy electrons generated in the metal plate and the phosphor screen are converted into light in the phosphor screen and this light creates the video signal generated by the camera. The video signal from the camera can be digitized and the digitized image can be viewed on a monitor located in the control area of the accelerator.

Video EPIDs suffer from the major limitation of light collection efficiency of the optical chain. Since the light is highly scattered within the phosphor screen, the light is emitted from the rear of the screen in all direction with equal probability. Only those light photons that are emitted within a small cone subtended by the lens of the camera can generate a signal in the camera; typically only 0.1%-0.01% of the light emitted by the phosphor screen reaches the camera. This poor light collection efficiency reduces the image quality. As a result, the development of commercial camera-based EPID has focused on increasing light collection of the optical chain by increasing the thickness of the phosphor screen to increase the light output and to a smaller extent increase the x-ray quantum efficiency (8,9), and using a large aperture lens that collect more of the light (8). However, the result of using large aperture lenses decrease spatial resolution and generate distortion.

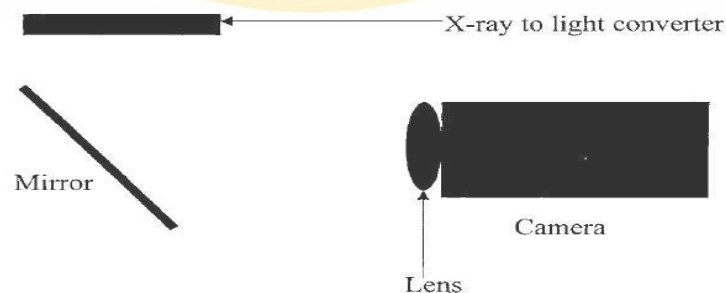


**Figure 2** Cross-sectional representation of a camera-based electronic portal imaging device(8).

### 1.2.2 Liquid ionization chamber EPID (7)

Liquid ionization chamber device (Figure3) consists of two sets of electrodes that are oriented perpendicularly to each other separated by a 0.8 mm gap, which is filled with a fluid (2,2,4-trimethylpentane) that is ionized when the device is irradiated. Each set of electrodes consists of 256 wires spaced 1.27 mm apart to provide an active area of 32.5 cm on a side. One set of electrodes are connected to 256 electrometers and the other set of electrodes is connected to a high voltage supply that can apply a 300 V potential to each electrode individually. The liquid ionization chamber array is read out by applying a high voltage to each of the high-voltage electrodes in succession and measuring the signal generated in each of the 256 signal electrodes.

The advantage of the liquid ionization chamber EPID is its compact size, which makes the device a convenient replacement for film cassettes and the lack of geometric distortion in the image. The major limitation of a scanning radiation detector is quantum utilization, since only one high voltage electrode is active at any one time. However, the physics of signal generation in the 2,2,4-trimethylpentane improves the quantum utilization of the liquid ionization chamber considerably. The signal measured by the liquid ionization chamber depends on the rate of formation and the rate of recombination of the ion pairs that are generated in the ionizing fluid. When no high voltage is applied to the electrodes, the rate of recombination of the ion pairs is relatively slow. Therefore, the concentration of ion pairs can increase over a period of time until an equilibrium is reached between ion pair formation, and is a function of the dose rate at the liquid ionization chamber and ion-pair recombination, the latter is proportional to the square of the ion-pair concentration. The signal measured by any electrode does not depend on the dose rate during the 5-20 ms period when the high voltage is applied but on the previous irradiation history of the electrode. However, the effective period of the charge integration (0.5s) is still short compared with the total image acquisition time. Therefore, a large fraction of the radiation that interacts with the liquid ionization chamber does not generate any measurable signal. For this reason, the liquid ionization chamber requires higher doses to generate images than other portal imaging devices.

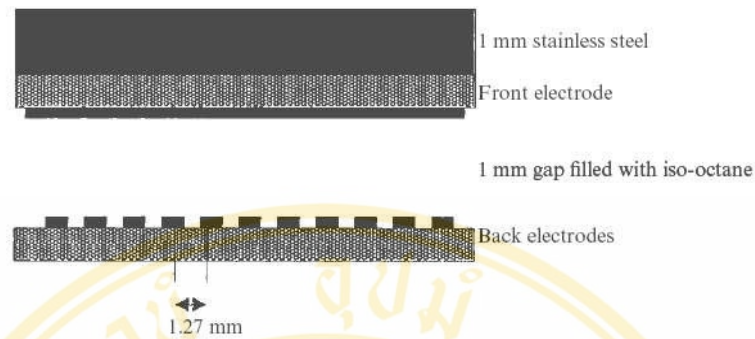


**Figure 3** Cross-sectional representation of a liquid ionization chamber array(5).

### 1.2.3 An amorphous silicon EPID (7)

Active matrix panel imagers (AMFPIs) (Figure4) based on hydrogenated amorphous silicon (a-si:H) photodiodes and thin film transistors (TFTs) are a major area of current research. The detector essentially has four major parts. (a) A 1-mm copper buildup plate absorbs the x-ray photons and emits recoil electrons. It also serves to partially shield the downstream scintillation screen from any scattered radiation and thus enhances the efficiency of detection of primary incident x-ray. (b) A scintillating phosphor screen ( $\text{Gd}_2\text{O}_2\text{S: Tb}$ ) absorbs the recoil electrons and transform them to visible light. (c) A pixel matrix deposited on a glass substrate constitutes the sensitive image-forming layer. Each pixel consists of an a-Si n-i-p photodiode to integrate the incoming light in charge captures, and a thin film transistor (TFT) that acts as a 3-terminal switch for readout. (d) The associated electronics drives the TFT switches and reads out the charge capture. The gate driver powers the gate lines while the data lines feed the accumulated charge to the read-out electronics. When a voltage is applied to a gate line, all the TFTs in that row become transparent and the charge is transferred to the data lines. The row is read out successively, with the TFTs in the next row becoming transparent as soon as the current one is read

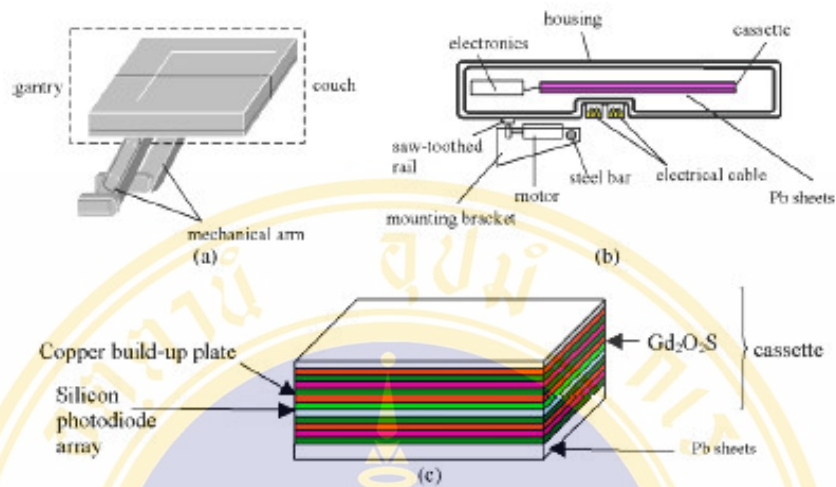


**Figure 4** Amorphous Silicon Portal Imager: (a) imager and support structure, (b) component within imager housing and, (c) layers contained within the imaging cassette(10).

The most advantage of an amorphous silicon EPID is its has good image quality (high contrast, spatial resolution and large signal to noise ration (SNR)), higher speed (7 frame/sec), no geometrical distortion, higher detective quantum efficiencies (DQEs), requiring less excess dose to be delivered to the patient and their improved especially well for IMRT verification.

## **CHAPTER II**

### **OBJECTIVE**

The objectives of this study are:

1. To investigate the dosimetric characteristics of an amorphous silicon EPIDs for dosimetric verification of intensity modulated radiation therapy, delivered with dMLC for 6 MV and 10 MV photon beams.
2. To compare the dosimetric verification of IMRT fields using EPIDs with ionization chamber and film measurements.

### CHAPTER III

## LITERATURE REVIEW

The use of intensity modulated radiation therapy (IMRT) demand on a stringent verification procedure due to its very complexity. Because the high dose gradient in IMRT field make single point-dose measurement inadequate in verifying the significantly non-uniform dose distribution. The error of individual IMRT beam dose distribution from treatment planning calculation is occurred because the lack of lateral charge particle equilibrium in the small subfields. The systematic errors in the transfer of MLC leaf sequence file from the treatment planning computer to the record and verify system, and in the mechanical accuracy of the MLC leaf movement during beam delivery further necessitates the use of accurate IMRT verification.

Most often IMRT verification is performed by the use of radiographic film. However, film has several disadvantages due to the dose response can be strongly affected by processing condition and varies from one film batch to another, which can make film dosimetry unreliable. Its use is labor-intensive, requiring processing and scanning of each film. The storage and archiving of film is also uncomfortable (11).

The above procedure is effective but time-consuming. Therefore, EPID has evolved because of its provided real-time, fast image archiving, retrieval and automated image analysis. The camera-based and liquid-filled ionization chamber EPIDs have been extensively studied of dosimetric characteristic, but an amorphous silicon EPID has only been few report in the literature. Pasma et al (12) reported on the use of charged-coupled device (CCD) camera based EPID for pre-treatment dosimetric verification of intensity modulated beams produced with dynamic MLC. EPID images were acquired for all beams and these images were then converted into two-dimentional dose distribution and compared with the calculated dose distribution using a commercial treatment planning systems. The dose profile measured with EPID was also compared with ionization chamber measurements. The agreement between calculation, EPID and ionization chamber was within 2%. Chang et al (13)

studied the application of EPID for IMRT verification. With the use of liquid-filled ionization chamber EPID for profile verification and isocenter dose measurement for intensity-modulated fields, the accuracy of 3% in central axis dose can be achieved, better than the 5% requirement recommended by the Task Group 40 (14) report of the American Association of Physicist in Medicine (AAPM) for independent verification of the dose at the isocenter or at a point. Although this is sufficiently accurate for clinical QA, the slow response, detector memory effect, and beam hold-off problem make it impractical for routine IMRT verification using liquid-filled ionization chamber EPID. The camera-based EPID suffer from low light collection efficiency, optical glaring error also complicater the use of these device for dosimetry verification(15, 17). Both EPIDs type generally produced image of inferior contrast and spatial resolution to those obtained using film. Recent development in amorphous silicon EPID is rapidly replacing these EPIDs due to their superior image quality for treatment setup verification. Their improved spatial resolution makes amorphous silicon EPID especially well suited for IMRT application (11).

Munro and Bouius (16, 17) investigated the dosimetric characteristics of a small (96x96 mm<sup>2</sup>) aSi flat panel detector. They measured the linearity, spatial resolution, glare, noise and signal to noise characteristics of an indirect aSi EPID construction, containing a metal plate/phosphor screen generating opticals photon that are detected by the photodiodes. The results shown that the response of the sensor was very linear and does not suffer from the glare phenomenon associated with TV camera-based EPIDs. It can be concluded that the amorphous silicon EPID will suited to transit dosimetry. El-Mohri et al. (18) studied linearity of response and dose rate dependence, sensitivity and long and short term reproducibility of aSi flat panel. The investigation using two detection configurations of the array: indirect configuration in which an overlying phosphor screen is used to convert incident radiation to visible light photon which is detected by the photodiodes. The other type is a configuration without the screen where radiation is directly sensed by the photodiodes. They measured the individual pixel response for fluoroscopic and radiographic array operation. The result is the degree of linear response with dose was found to be better than 99%. The independence of signal on dose rate was demonstrated by means of stability of pixel response over the range of dose rates allowed by the radiation source

(80-400 MU/min) and the good long term stability in pixel response extending over a 2 month period. McCurdy et al (19) investigated some basic properties of the amorphous silicon detector for state dosimetry, such as linearity with dose rate ( $\pm 0.5\%$ ), reproducibility ( $\pm 2\%$ ) and response with variations in gantry rotation and source to detector distance. They also have applied their two step algorithm to improve performance of dosimetric treatment verification application. Greer and Popescu (20) investigated the dosimetric properties of an aSi EPID using a continuous frame-averaging acquisition mode for a 6 MV radiation beam. The properties included effect to build up, dose response, field size response, response to rapid MLC leaf speed, beam dose rate fluctuation, memory effect and reproducibility. The dependence of response on EPID calibration and a dead time in image frame acquisition occur every 64 frames were measured. EPID measurements were compared to ion chamber and film for open and wedge static fields and IMRT fields. The result of measurement was the linear with dose and dose rate and response to MLC leaf speed is up to  $2.5 \text{ cm s}^{-1}$  was found to be linear. A field size response of up to 5% relative to  $d_{\text{max}}$  ion-chamber measurement was found. The memory effect was very small less than 0.2%. Reproducibility was within 0.8% for an IMRT delivery recorded at intervals over a period of one month. The dead time in frame acquisition resulted in errors in the EPID that increased with leaf speed and were over 20% for a 1 cm leaf gap moving at  $1.0 \text{ cm s}^{-1}$ . Van Esch A et al. (21) performed detector saturation, linearity, calibration and reproducibility, ghosting, field size dependence and portal depth dose. They using an acquisition mode especially developed for portal dose (PD) integration during delivery of a static or dynamic-radiation field. This experiment result is the detector saturation ranging from 0.35 to 1.4%. The linearity of the detector response with 5% rounding error and the linearity of dose rate agree within 2% with the ionization chamber measurement and within 1% with the inverse square law behavior. Short term and long term detector reproducibility was found to be within 2% for static as well as dynamic field delivery. Ghosting is below  $\sim 1\%$  for 6 MV and 18 MV. For 6 MV, the field size dependence between aS500 EPID and ionization chamber measurements in water were similar. On the other hand, the discrepancies are up to 9% for 18 MV. The dose maximum plateau region is wider in

the aSi measurement series: widths of  $\sim 1.5$  and  $\sim 3$  cm were observed for 6 and 18 MV, respectively.

The aim of the pre-treatment verification of the dynamic IMRT field by means of a portal imager is to assess the accuracy of the intended fluence as used in the treatment planning system for dose calculation and the actually delivered fluence through the dynamic leaf motion (21). The application of aSi EPID for IMRT verification has been studied by some author. Greer and Popesu (20) performed the relative dosimetry of an aSi EPID. They measured the accuracy of the EPID in recording open and wedge static field. In open field the image were acquired with field size from  $5 \times 5$  up to  $20 \times 20$  cm<sup>2</sup>, acquired with ten frames following dose-rate stabilization, and source-to-detector-distance (SDD) of 105 cm. Similarly images were acquired with  $45^\circ$  and  $60^\circ$  steel wedges for field sizes of  $20 \times 20$  and  $15 \times 15$  cm<sup>2</sup>, respectively. EPID profile through the central axis for the open field and in the wedged direction for the wedge field were compared to ion-chamber measurement recorded at 1.5 cm depth in a water phantom at 100.0 cm SSD. Scaled the EPID result to 101.5 cm to enable comparison. IMRT test patterns were recorded with the EPID using continuous frame-averaging mode and compared to film measurement. They used a bar-pattern which consisted of the different spatial frequencies, with the highest frequency having 1 cm bars spaced at 2 cm intervals. This was input to the RTPS as an optimal fluence map and the RTPS then calculated leaf trajectories and a deliverable or actual fluence map. These were recorded on the 6 MV linear accelerator with Kodak XV film at 1.5 cm depth in a solid water phantom. They investigate the potential of the EPID for pre-treatment verification of the IMRT fluence delivery. An image was acquired of a clinical IMRT field and compared to the fluence map utilized by the RTPS for the dose distribution. The field was from a clinical six field parotid plan and the profile of leaf motion direction was compared at the control axis and at off-axis planes. The measurement resulted is the agreement between the EPID profile and ion-chamber measurement was within 3% for the open and wedge field inside the penumbra region. The agreement between EPID and film for the highest frequency IMRT bar pattern is within 5% with the main discrepancies occurring in the through region of the pattern and the agreement of EPID profile for the clinical IMRT field compare with the actual fluence file utilized by the RTPS is

reasonable considering. Van Esch A et al. (21) evaluated the portal dose image prediction using an algorithm for the aSi measurement. This algorithm is based upon the single pencil beam dose calculation algorithm as adapted into the CadPlan TPS dose calculation. The experiment was tested for 6 and 18 MV at 105 and 145 cm SDD on a series of clinical dynamic IMRT treatment field. Field sizes were used ranging from 4x4 to 12x39 cm<sup>2</sup>. Measured and predicted PD images were compared by means of line profile and via the gamma evaluation algorithm. The gamma matrix was calculated with the algorithm requesting a distance-to-agreement (DTA) of 3 mm and a maximum dose difference of 3% of the local dose. The result of experiment is gamma evaluation of the predicted versus measured PD distribution were within the pre-defined acceptance criteria for all clinical IMRT field, allowing a dose difference of 3% of the local field dose in combination with a distance to agreement of 3 mm. Chang and Ling (22) evaluated the use of aS500 EPID for the verification of IMRT beam delivery, using the synchronous, frame-averaging acquisition. The experiment was conducted at a SDD of 150 cm and using a 15 MV beam at a dose rate of 300 MU per minute. They using 25 prostate IMRT fields from five treatment plans evaluated the EPID's capability for verifying the IM profiles, acquired the frame-averaged images of these IMRT field, and converted them to dose profile using the calibration curve. Consequence, the measured relative profile and central axis dose of 25 prostate fields compared with the planned was very good agreement with a mean  $\sigma$  of 1.9% and a standard deviation of 0.5%, for central-axis dose the agreement was better than 2.0%.

The use of any EPID for dosimetric IMRT verification requires implementation of a suitable procedure to establish a relationship between pixel intensity and either fluence or dose distribution. Calibration of the EPID is very importance. Dosimetric characterization of EPID should be investigated. In our country, the studied of the application of EPID for IMRT verification have not been reported. Since the linear accelerator equipped with an amorphous silicon EPID has been installed at Siriraj Hospital. Therefore, the studies of the dosimetric characteristics of an amorphous silicon EPID for IMRT verification were investigated. These characteristics included dose response, field size response, effect of dead time in frame acquisition, response to rapid MLC leaf speeds, beam dose-rate

fluctuations, memory effect, the reproducibility for absolute dosimetry and the relative dosimetry accuracy response. The EPID was also compared to ionization chamber and film measurements for IMRT test pattern.



## CHAPTER IV

### MATERIALS AND METHODS

#### 4.1 MATERIALS

##### 4.1.1 The linear accelerator

The Clinac 23EX linear accelerator used in the experiment is manufactured by Varian Oncology System, Palo Alto, CA, with dual photon beam energies of 6 MV and 10 MV, and six electron beam energies of 6, 9, 12, 15, 18, and 22 MeV. Photon field sizes are range from  $0.3 \times 0.3 \text{ cm}^2$  to  $40 \times 40 \text{ cm}^2$  at isocenter. The distance from the target to isocenter is 100 cm. These are five stationary therapy dose rate ranges from 100-600 monitor unit per minute. The distance from the target to the block tray is 65.4 cm and the distance from the target to the bottom of the leaves is 53.8 cm. The MLC has the maximum number of 120 tungsten MLC leaves which mounted below the conventional collimator in the same direction of X-jaws.

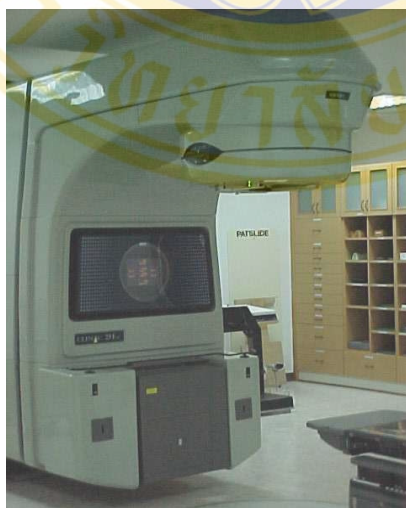


**Figure 5.** The Clinac 23EX linear accelerator (Varian Oncology System, Palo Alto, CA, with dual photon beam energies of 6 MV and 10 MV, and six electron beam energies of 6, 9, 12, 15, 18, and 22 MeV.

#### 4.1.2 The amorphous silicon electronic portal imaging device (aSi EPID)

The EPID used in this study is commercially available aSi imaging device (aS500, Varian Medical Systems), mounted on a Clinac 23 EX with dynamic MLC (120 leaves). The EPID system includes (i) an image detection unit (IDU), featuring the detector and accessory electronics, (ii) an image acquisition unit (IAS2), containing drive and acquisition electronics and interfacing hardware, and (iii) a dedicated workstation (Portal Vision PC) located outside the treatment room. The IDU is essentially a matrix of 512x384 pixels with a resolution of 0.784x0.784 mm<sup>2</sup> and a total sensitive area of 40x30 cm<sup>2</sup>. Each pixel consists of a light sensitive photodiode and a thin film transistor to enable readout. The electric charge generated by the incident photons is accumulated in the photodiode until the signal is read out and digitized through an analogue to digital (A/D) converter. Overlying the array is a scintillating layer (gadolinium oxysulphide) and a copper metal plate (of ~1 mm thickness), making the portal imager and indirect detection system. The phosphor scintillator converts incident radiation into optical photon, enhancing the sensitivity of the detector more than tenfold when compared to direct detection system. The total water-equivalent thickness of the construction materials in front of the photodiodes is 8 mm, as specifies by the manufacturer. The IAS2 control and reads the IDU. Its local hard disk contains the correction images (i.e. the dark and flood field acquisition) and the various acquisition parameter set. To record an IMRT delivery with this EPID system, there are two possible modes of operation, multiple image acquisition and continuous frame averaging. In the first mode, multiple images are acquired during radiation delivery, with each image being the average of a fixed number of frames. However, there is a delay time between each acquired image. This delay is not fixed and can be more than 2s. This mode is unlikely to be used to verify dynamic IMRT where leaf speed of up to 3 cms<sup>-1</sup> are possible (13). In the continuous frame-averaging mode, a single image consisting of the average of many image frames is acquired during radiation delivery. This acquisition mode is suited for verify dynamic IMRT.

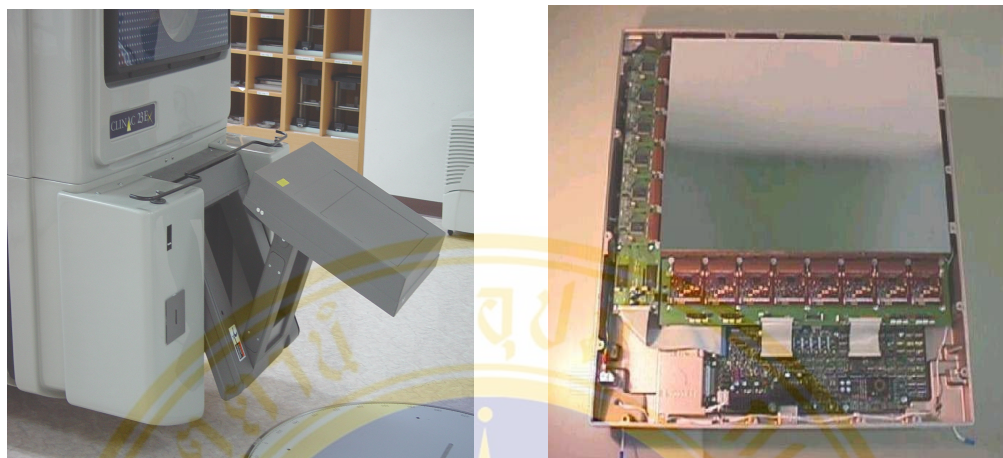


**Figure 6.** An amorphous silicon electronic portal imaging device (aS500, Varian Medical Systems).

#### **4.1.3 Computerized radiation treatment planning system (CadPlan version 6.4.7)**

CadPlan version 6.4.7 (figure 7), (Varian Oncology Systems, Palo Alto CA), is a RTP for both external beam radiation therapy and brachytherapy of Siriraj Hospital which is based on modern RISC UNIX multi-user and multi-tasking workstation technology. The hardware contains the electronics, central processing unit, graphic display systems, and the others devices. Furthermore, it is combined with a Varian MLC system which has the maximum number of 120 MLC leaves. The software component has single pencil beam algorithms using to calculate the radiation dose in volume of interest. The 3D dose matrix for one plan is calculated as a set 2D dose distribution matrix. These 2D matrixes are calculated from transversal CT image using 160x112 pixel matrix. In addition, CadPlan has an inverse treatment planning option, “Helios”, and a program, “LMC” (Leaf motion calculator), to calculate the leaf trajectories to deliver the optimized fluence pattern for IMRT treatment planning.



**Figure 7.** The Computerized Radiation Treatment Planning systems (CadPlan).

#### **4.1.4 Water phantom**

The Blue phantom (Scanditronix Wellhofer Dosimetric, Schwarzenbruck, Germany) is made from acrylic plastic (Perspex), having the scanning volume of  $48 \times 48 \times 41 \text{ cm}^3$ . It is prepared for external control from the OmniPro-Accept 6.1 Software and OmniPro IMRT software (IBA Advanced Radiotherapy, Scanditronix Wellhofer, Uppsala, Sweden). This phantom can be used for percent depth dose, beam profile and penumbra measurements with  $0.13 \text{ cm}^3$  ionization chamber.



**Figure 8.** The Blue phantom (Scanditronix Wellhofer Dosimetric, Schwarzenbruck, Germany) with the OmniPro-Accept 6.1 Software and OmniPro IMRT software (IBA Advanced Radiotherapy, Scanditronix Wellhofer, Uppsala, Sweden).

#### 4.1.5 Solid water phantom

Figure 9 shows the solid water phantom (RMI), is made in square slab of  $30 \times 30 \text{ cm}^2$  with the thickness of 0.5, 1.0, 2.0 and 5.0 cm.



**Figure 9.** The solid water phantom (RMI) is made in square slab of  $30 \times 30 \text{ cm}^2$  with the thickness of 0.5, 1.0, 2.0 and 5.0 cm.

#### 4.1.6 Ionization chamber

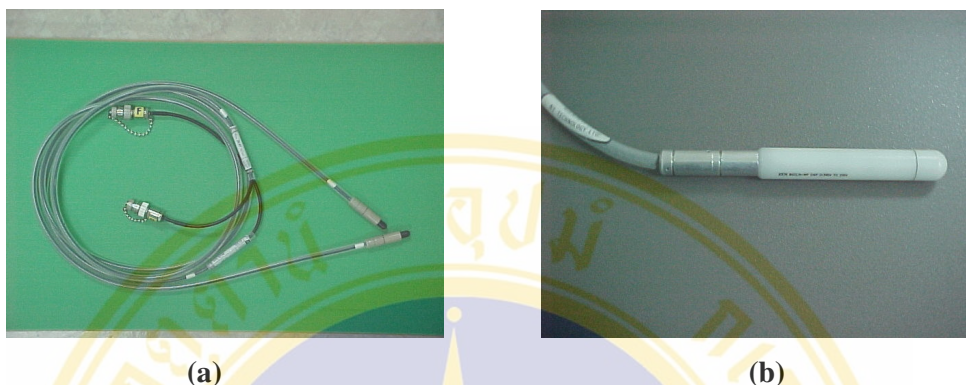


**Figure 10.** (a) 0.13 cm<sup>3</sup> ionization chamber. (b) 0.6 cm<sup>3</sup> ionization chamber.

##### 4.1.6.1 CC13 (0.13 cm<sup>3</sup>) ionization chamber

The 0.13 cm<sup>3</sup> compact cylindrical ionization chamber of Scanditronix Wellhofer as shows in figure 10 (a). There are two detector, a field and reference detectors. These are used with the Blue phantom in the continuous mode measurement. The outer and inner electrodes are made of Shonka C55 (1.76g/ cm<sup>3</sup>). The chamber has a sensitive volume 0.13 cm<sup>3</sup>, total active length 5.8 mm, cylinder length 2.8 mm, inner diameter of cylinder 6.0 mm, radius of cylinder 3.4 mm, wall thickness 0.4 mm, diameter of inner electrode 1.0 mm, length of electrode 3.3 mm, and reference point in water 3.5 mm from the distal end of the chamber. It operates with polarizing voltage  $\pm 300$  Volts.

##### 4.1.6.2 Farmer (0.6 cm<sup>3</sup>) ionization chamber

In figure 10 (b), show the 0.6 cm<sup>3</sup> Farmer ionization chamber of Nuclear Enterprise limited (NE) type 2571 consisting of a thin walled high purify graphite thimble and a pure aluminium electrode, supported a thin wall aluminium stem. The chamber has a sensitive volume 0.69 cm<sup>3</sup>, length of volume 24.1 mm, with thickness 0.36 mm, thimble outside diameter  $6.99 \pm 0.04$  mm and stem outside diameter  $8.62 \pm 0.04$  mm.

### 4.1.7 Electrometer



**Figure 11.** (a) CU500E electrometer and, (b) NE 2570/1 electrometer.

#### 4.1.7.1 CU500E electrometer

The CU500E control unit has a built-in dual channel electrometer with reversible polarity and auto ranging for set-up that is controlled by Omnipro-Accept 6.1 and software. This electrometer can be used with  $0.13 \text{ cm}^3$  ionization chamber for both fields and reference detectors. The main supply is 115 Volt or 230 Volt ( $\pm 15\%$ ) at frequency range of 47 to 63 Hertz.

#### 4.1.7.2 NE 2570/1 electrometer

The Farmer dosimeter type NE 2570/1, is used with  $0.6 \text{ cm}^3$  Farmer ionization chamber. It can be operated by two readily available 1.5 volt dry cells with full polarizing voltage  $250 \pm 20$  volt. The voltage ratio consists of V, V/2, V/4 and V/8 with polarity negative or positive and preset dose in mR, R and nC.

### 4.1.8 Film digitizer with OmniPro I'mRT software

Figure 12 shows the Vidar VXR-16 Dosimetry PRO<sup>TM</sup> film digitizer (Vidar systems Corporation, Herndon, VA, USA) having 65,536 shades of gray with an optical density range from 0 to 3.69



**Figure 12.** Vidar VXR-16 Dosimetry PRO™ film digitizer (Vidar Corporation, Herndon, VA, USA).

#### 4.1.9 Film dosimeter

The Kodak X-Omat V, Ready-pack film (Eastman Kodak Company, Rochester, NY) shown in figure 13, is a low-speed film. This film responsive exposure range of 5 to 100 cGy and the saturation exposure is about 200 cGy. The size of film is 10x12 inches (25x30.5 cm<sup>2</sup>).



**Figure 13.** The Kodak X-Omat V, Ready-pack film (Eastman Kodak Company, Rochester, NY).

#### **4.1.10 The automatic film processor (Kodak RP x-OMAT, Model M6B)**

#### **4.1.11 Thermometer and barometer**

#### **4.1.12 Spirit level**

### **4.2 METHODS**

#### **4.2.1 EPID calibration**

EPID calibration is designed to remove background noise and provide a spatially uniform response for clinical image. The response of the EPID is dependent on the photon energy and the repetition rate of the radiation beam. Calibration involves acquiring a dark-field image and flood-field image.

A dark-field image provides information about background noise and is obtained by taking a base reading for each pixel in the absence of radiation. The resultant image displays narrowly spaced bright and dark vertical bands arising from photodiode leakage currents and varying electrometer offsets (figure 14 a). A flood field image is obtained by irradiating the entire sensitive area of the detector with an open field and is used to correct for variations in individual pixel sensitivities (figure 14 b). We obtained dark and flood image at the SDD of 140 cm with the gantry positioned at an angle of  $0^\circ$  and the collimator set at  $28.6 \times 21.4 \text{ cm}^2$

Dark- and flood-field images for each acquisition mode are stored in the EPID image acquisition system database and used to correct stationary nonuniformities in detector response and dark current in clinical object images. Test images can be taken during calibration to assess the quality of the correction as shown in figure 14 c.

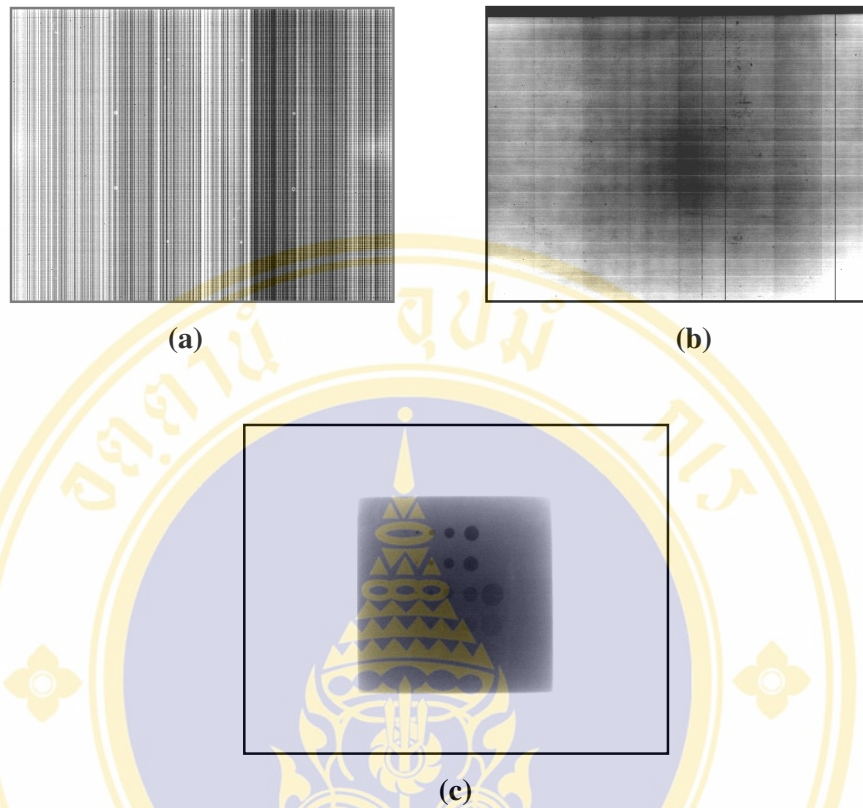


**Figure 14.** (a) A dark field image, (b) a flood field image and (c) a test image can be take during calibration.

## 4.2.2 Determination of dosimetric characterization of an amorphous silicon EPID

### 4.2.2.1 Dose response

As the EPID image is the average of acquired frames, two images acquired with different dose or monitor unit settings should result in the same pixel values provided the dose rate and hence dose per frame is the same. The pixel values will, however, be sensitive to dose rate as this will change the dose per frame.

#### 4.2.2.1.1 Linearity with respect to dose rate

The linearity of the EPID detector response with dose rate was performed using 6 and 10 MV x-ray with the linac dose rate set at 300 MU/min, this being the dose rate used in clinical routine. To modify the dose rate the source to detector distance (SDD) was varied by varying the distances of 105, 106, 108, 110, 112, 114, 116, 118, 120, 122, 124, 126, 130, 135 and 140 cm. No extra buildup was utilized on the EPID. At each distance, one image of a 5x5 cm<sup>2</sup> field was acquired with 20 MU and the means pixel values in a 10x10 pixel region at the center of each field were recorded as shown in figure 15. Each image consisted of ten averaged frames. To determine the relative dose rate with distance, the 0.6 cc ionization chamber was placed in a solid water phantom at a 3 cm depth with 16 cm thickness of backscatter phantom at each SDD.

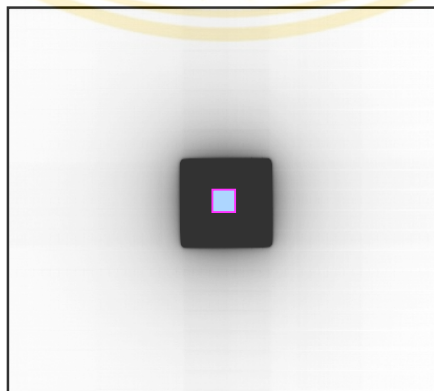


**Figure 15.** The exposed EPID of a 5x5 cm<sup>2</sup> field and the recording of the means pixel values in a 10x10 pixel region.

#### 4.2.2.1.2 Linearity with respect to dose

To verify linearity response with dose, image of a  $10 \times 10 \text{ cm}^2$  open field were acquired. The measurement was performed at 6 and 10 MV. The EPID was positioned at a fixed detector distance of 105.0 cm, and varying dose was delivered with MU setting of 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 130, 150, 170, and 200. For each MU setting, frame was continuously averaged during the irradiation. The pixel values at the center of the field in a  $10 \times 10$  pixel region were obtained as described earlier and were then multiplied by the number of frames acquired for each image. The linearity of delivered dose with MU setting was verified by ionization chamber measurements in the solid water phantom at a 3 cm depth at each MU setting. The image was shown in figure 16.

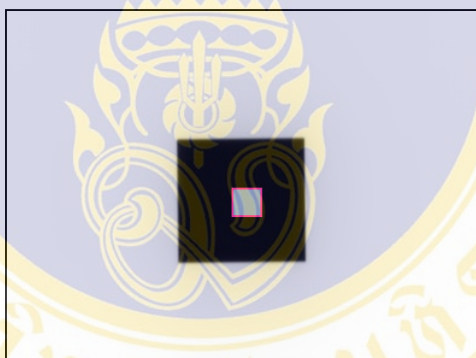


**Figure 16.** The exposed EPID of a  $10 \times 10 \text{ cm}^2$  field and the recording of the means pixel values in a  $10 \times 10$  pixel region at the center of the field.

#### 4.2.2.2 Field size response

The field response of the EPID was assessed at SDD 105 cm with 6 MV and field sizes defined by the MLC were ranging of  $3 \times 3$ ,  $4 \times 4$ ,  $5 \times 5$ ,  $6 \times 6$ ,  $8 \times 8$ ,  $10 \times 10$ ,  $12 \times 12$ ,  $15 \times 15$ ,  $18 \times 18$ ,  $20 \times 20$ ,  $22 \times 22$  and  $24 \times 24 \text{ cm}^2$ . One image was acquired for each setting with no added buildup on the EPID. The image was acquired with ten frames and pixel values recorded as described earlier. To compare the experiment, the measurement of ionization chamber of each field size was performed at a depth of 1.5 cm, in a solid water phantom with 16 cm of backscatter, and 105.0 cm to the chamber.

Both sets of the measurements were normalized to the  $10 \times 10 \text{ cm}^2$  values. The test was repeated for 10 MV.

#### 4.2.2.3 Effect of dead time in frame acquisition

The EPID system has a dead time in frame acquisition occurring every 64 frames. The ACPU is capable of adding up to 64 frames the content of the frame-buffer is moved to the 32-bit-wide DRAM of the CPU. This transfer take  $\sim 0.16 \text{ s}$ . A reset frame (non-image frame) is then acquired. This represents a dead time in image acquisition of  $\sim 0.28 \text{ s}$  every 64 frames, approximately equivalent to a loss of two image frame As radiation is continuously delivered during this dead time, the effect of the dead time on recording dynamic IMRT was investigated.

The effect of dead time in frame acquisition was assessed by used sliding window deliveries that performed with a uniform 1 cm leaf gap between the two banks of MLC leaves and a  $10 \times 10 \text{ cm}^2$  field. The measurement was performed at 6 and 10 MV. Three leaf speed of 0.25, 0.5 and  $1 \text{ cm s}^{-1}$  were created by modifying the MU setting. An image of each leaf speed was acquired by multiple image acquisition mode as shown in figure 17. Profiles were obtained along the direction of leaf motion directly under the center of MLC leaf adjacent to the central axis. Reduction in signal from a uniform profile occurring due to the dead time in frame acquisition was quantified for each leaf speed.

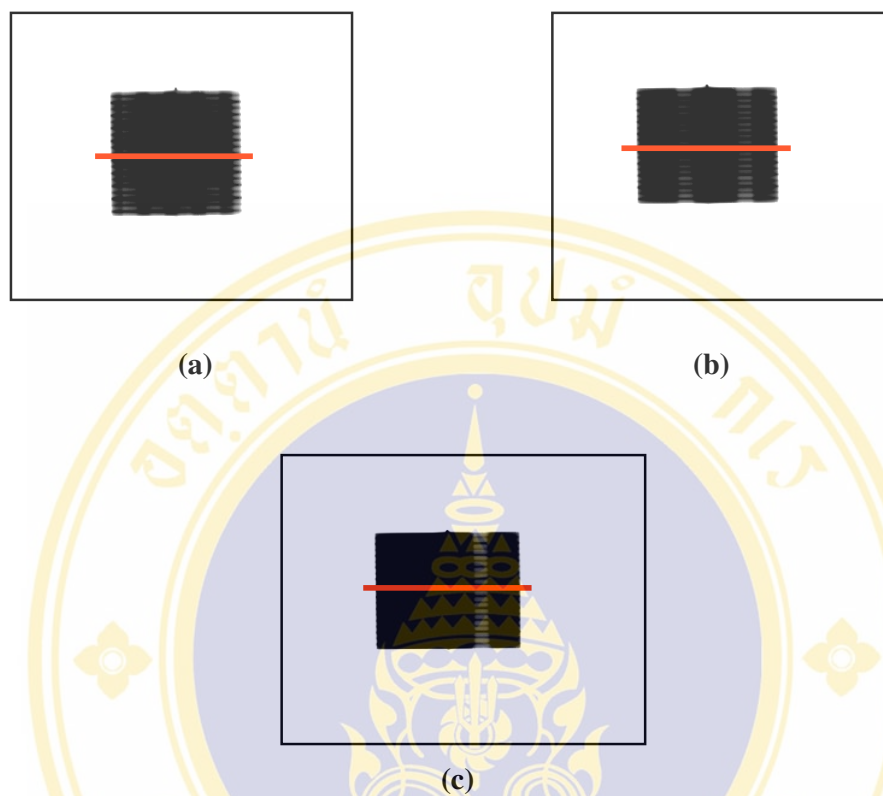


**Figure 17.** (a), (b) and (c) The exposed of uniform sliding window with a 1 cm leaf gap of MLC leaves for a 10x10 cm<sup>2</sup> field with leaf speed of 0.25, 0.5 and 1.0 cm s<sup>-1</sup>, respectively.

#### 4.2.2.4 Response with leaf speed

Leaf speeds of up to  $3.0 \text{ cm s}^{-1}$  are utilized at our center for DMLC delivery. If the EPID pixel integrate the dose between consecutive frame read-outs, then leaf speed or frame rate should not affect the acquired signal. However, if signal is collected for only a portion of the frame time, or if the pixel saturate before frame readout then errors in the signal may occur. It is important therefore to ensure that the EPID accurately records the rapid changes in dose rate to a pixel that occur during DMLC radiation delivery.

The response with leaf speed was assessed by using sliding window deliveries that performed with a uniform 1 cm leaf gap between the two banks of MLC leaves for a  $10 \times 10 \text{ cm}^2$  field. The leaf speed of 0.25, 0.5, 1.0, 1.5, 2.0, 2.5 and  $3.0 \text{ cm s}^{-1}$  were calculated to the MU of 200, 100, 50, 34, 25, 20 and 17 MU, respectively. The detector was positioned at SDD 105.0 cm. One image was acquired for each leaf speed with multiple image acquisition mode and the pixel values multiplied by the number of frame acquired. The image of each leaf speed was shown in figure 18. Profiles under the center of the MLC leaf adjacent to the central axis were analyzed to obtain the EPID signal for each leaf speed. The results were compared to ionization chamber measurements, used 0.6 cc ion-chamber made in the solid water phantom for each leaf speed at the center of the field under the center of the same MLC leaf. These experiments were performed by 6 and 10 MV x-ray.

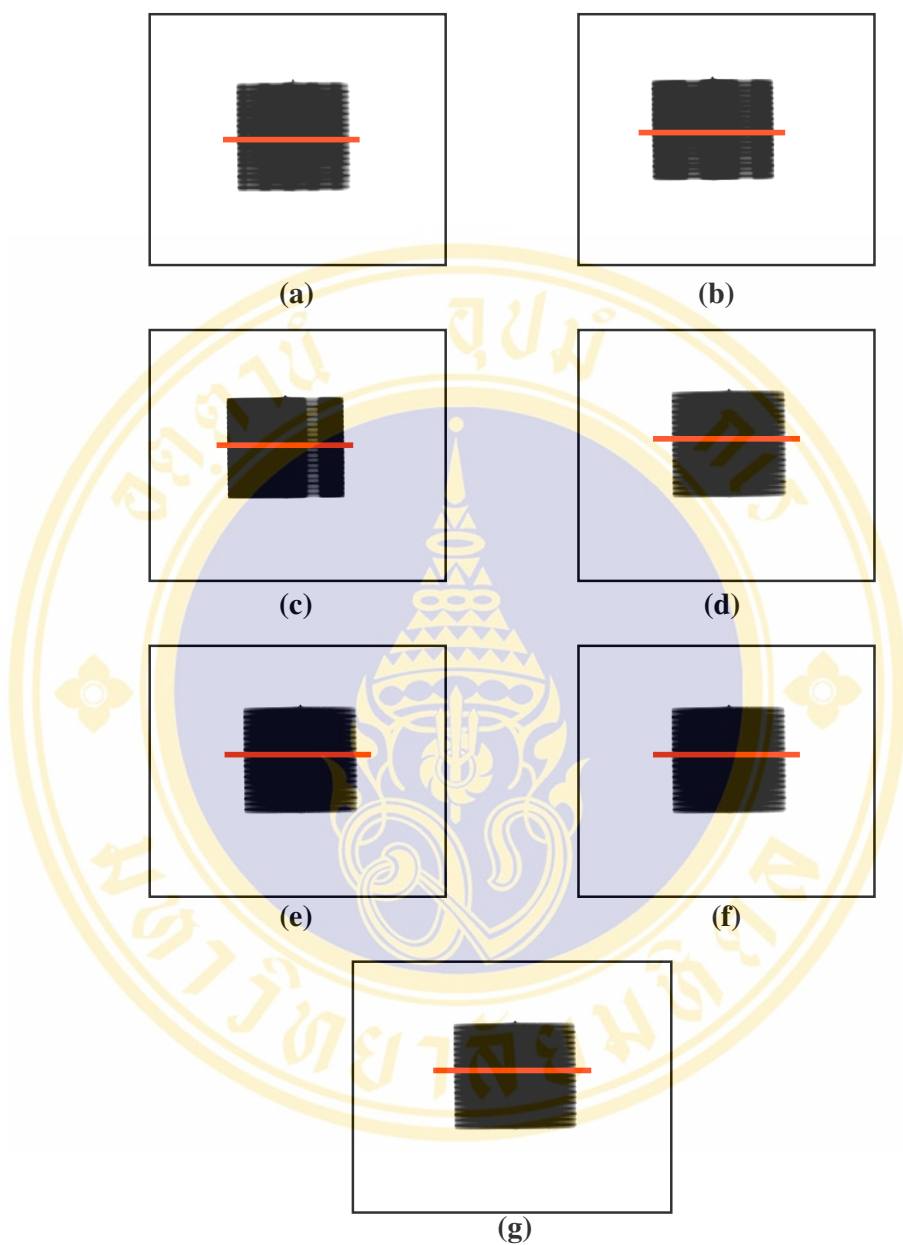


**Figure 18.** (a) The exposed EPID with leaf speed of  $0.25 \text{ cms}^{-1}$ , (b)  $0.5 \text{ cms}^{-1}$ , (c)  $1.0 \text{ cms}^{-1}$ , (d)  $1.5 \text{ cms}^{-1}$ , (e)  $2.0 \text{ cms}^{-1}$ , (f)  $2.5 \text{ cms}^{-1}$ , (g)  $3.0 \text{ cms}^{-1}$ .

#### 4.2.2.5 Response to dose-rate fluctuation

The readout of the amorphous silicon array is synchronized with the beam pulses. The EPID is also calibrated at each fixed accelerator dose rate (e.g., 300 MU/min) used for clinical imaging. The dark and flood-field images are different for each dose rate due to variation in the dose rate and image acquisition timing. During IMRT treatment if the MLC leaves cannot reach a pre-defined position with maximum leaf speed then beam hold-offs result where the accelerator reduces dose rate (holds-off beam) until the leaves have reached the desired position. This can result in large dose rate fluctuations during the delivery. Potentially these could affect the EPID signal where the EPID system is designed and calibrated with a fixed accelerator dose rate.

The effect of dose rate fluctuation or beam hold-offs on the EPID signal were performed by recording a step wedge IMRT pattern with and without beam hold-offs. The detector was positioned at 105.0 cm SDD. For the pattern, dose setting of 50 and 500 MU for 6 MV x-ray were utilized to deliver the field with and without beam hold-offs. Beam profiles directly under the leaf adjacent to the central axis were obtained from the EPID images and compared. The image was shown in figure 19. The test was repeated for 10 MV.



**Figure 19.** (a) The exposed EPID of the step-wedge IMRT pattern with 50 MU and 500 MU (b).

#### 4.2.2.6 Memory effect of the EPID or ghosting

The memory effect of the EPID detector, also referred to as ghosting, is a change in sensitivity due to short-term irradiation damage, with a time constant of several minutes.

The memory effect of the EPID performed by acquired an image with  $5 \times 5 \text{ cm}^2$  field size with 500 MU (6 MV x-ray), followed immediately by an image of  $15 \times 15 \text{ cm}^2$  field size with 10 MU (6MV x-ray). The time interval between the two images was approximately 15, 30 and 60s. A memory effect of the EPID will manifest as an increase in the pixel value for the  $15 \times 15 \text{ cm}^2$  field size in the region of irradiation of  $5 \times 5 \text{ cm}^2$  field. An image was acquired of the  $15 \times 15 \text{ cm}^2$  field after several minutes had elapsed for comparison. The image was shown in figure 20. Profile across the  $15 \times 15 \text{ cm}^2$  field images were compared to see whether the pixel value was elevated due to a memory effect. The test was repeated for 10 MV x-ray.



**Figure 20.** (a) The exposed EPID of the  $15 \times 15 \text{ cm}^2$  open field with 10 MU. (b) The exposed of the EPID of the  $15 \times 15 \text{ cm}^2$  field acquired shortly (~30s) after the  $5 \times 5 \text{ cm}^2$  field with 500 MU.

#### 4.2.2.7 Reproducibility

The reproducibility was assessed by recording a step wedge IMRT delivery on multiple occasions over a period of one month. The measurement was performed at 6 MV x-ray. At each measurement the EPID was set up at the same position. The differences between profile through the central axis of the field and the pixel value in a 10x10 pixel region were quantified and the differences percentage from the first month was calculated. The image was shown in figure 21. The test was repeated for 10 MV x-ray.

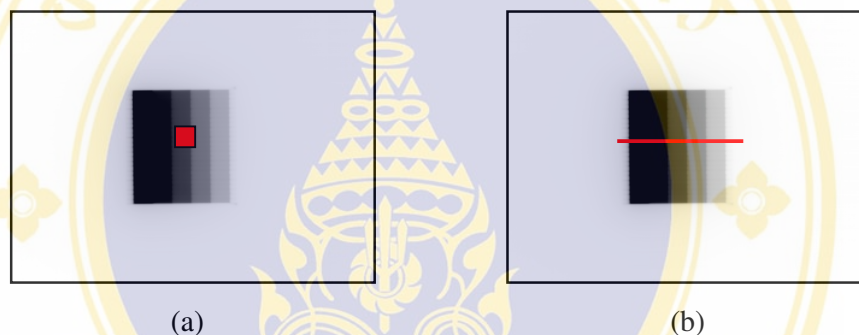


**Figure 21.** (a) The exposed EPID of the step-wedge IMRT pattern with the recording pixel values in a 10x10 pixel region and with the line profile through the central axis of the field (b).

#### 4.2.3 Relative dosimetry

##### 4.2.3.1 Open field

The measurement of EPID for recording open field was assessed by acquired image for open field of 10x10 and 20x20 cm<sup>2</sup>. Each image was acquired with multiple image acquisition mode and used 100 MU setting for 6 MV x-ray. The EPID was positioned at 105.0 cm SSD with no added buildup material. The EPID image was shown in figure 22. EPID profiles through the central axis for the open fields were compared to ion-chamber measurements (0.13 cm<sup>3</sup> compact cylindrical ionization chamber of Scanditronix Wellhofer) recorded at  $d_{\max}$  (1.5 cm) depth in a blue water phantom at 100.0 cm SSD and film measurements were performed at  $d_{\max}$  in a solid water phantom with 16 cm of backscatter, and 100.0 cm to the film. The

results of three measurements were normalized 100% at the center of the field to enable comparison. The test was repeated for 10 MV at  $d_{\max}$ , too.

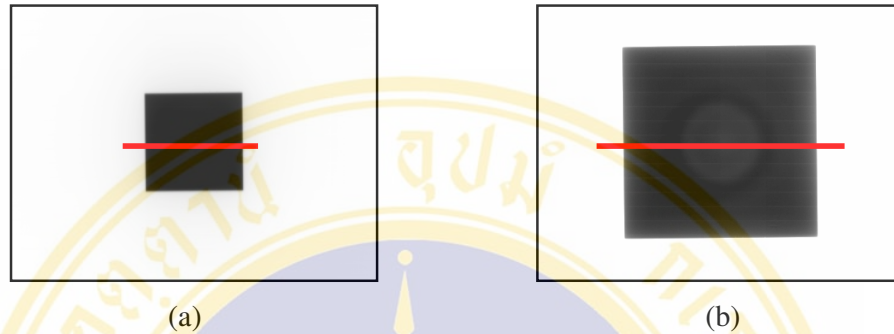


**Figure 22.** (a) The exposed EPID of 10x10 cm<sup>2</sup> open field and 20x20 cm<sup>2</sup> (b).

#### 4.2.3.2 Wedge field

The measurement of EPID in recording wedge static fields was assessed by acquired image with 45° and 60° steel wedges for field sizes 20x20 cm<sup>2</sup> and 15x15 cm<sup>2</sup>, respectively. Each image was acquired with multiple image acquisition and used 100 MU setting for 6 MV x-ray. The detector was positioned at 105.0 cm SSD. The image of the EPID was shown in figure 23. The profiles through the central axis for the wedges fields were compared to the ion-chamber measurements recorded at  $d_{\max}$  (1.5 cm) depth in a blue water phantom at 100.0 cm SSD. The results of both measurements were normalized 100 % at the center of the field to enable comparison. The test was repeated for 10 MV at  $d_{\max}$ , too.

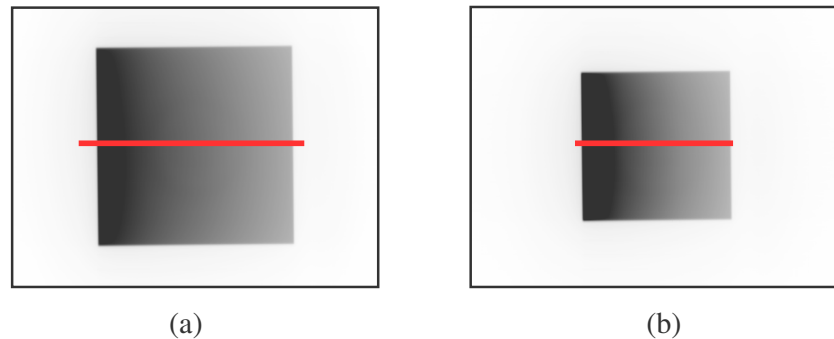


**Figure 23.** (a) The exposed EPID of 45° steel wedge for field sizes of 20x20 cm<sup>2</sup> and 60° wedge for 15x15 cm<sup>2</sup> field sizes.

#### 4.2.3.3 IMRT bar pattern

IMRT bar pattern were recorded with the EPID using multiple image acquisition mode and used 100 MU setting. The detector was positioned at 105.0 cm SDD. A bar-pattern test fluence was created with an in-house software package. This fluence consisted of bar pattern of different spatial frequencies, with the highest frequency having 1 cm bars spaced at 2 cm interval. This experiment was compared to the film measurements. These were recorded on the 6 MV x-ray accelerators with Kodak X-Omat V film at 3 cm depth in a solid water phantom with 16 cm backscatter, and 100.0 cm to the film. The films were digitized with a Vidar scanner (Vidar VXR-16 and OmniPro IMRT software) and converted to relative dose with a measured calibration curve. To enable comparison the results of both measurements were normalized to 100% at the center of the field. The image of the EPID was shown in figure 24. The test was repeated for 10 MV.

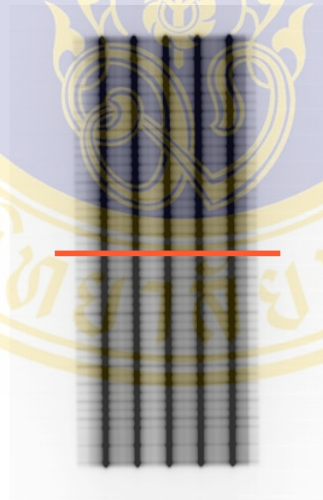


**Figure 24.** The exposed EPID of IMRT bar pattern.

#### 4.2.3.4 CadPlan fluence of clinical IMRT fields

For pre-treatment verification of the IMRT fluence delivery, the EPID image can either be compared to a predicted portal dose image (PDI), or converted to a fluence image for comparison to the expected fluence without the patient present. To investigate the potential of the EPID for this application, an image was acquired of a clinical IMRT fields. The EPID was positioned at 105.0 cm SDD. The image of the EPID was shown in figure 25. These experiments were compared to the fluence map utilized by the CadPlan RTPS for the dose distribution and film measurements. The film measurements were recorded with Kodak X-Omat V film at 1.0 cm depth in a solid water phantom with 16 cm backscatter, and 100.0 cm to the film. The films were digitized with a Vidar scanner (Vidar VXR-16 and Omnipro IMRT software). The field was from a clinical 6 fields prostate and nasopharynx plan. Profiles in the leaf motion direction were compared at the central axis planes

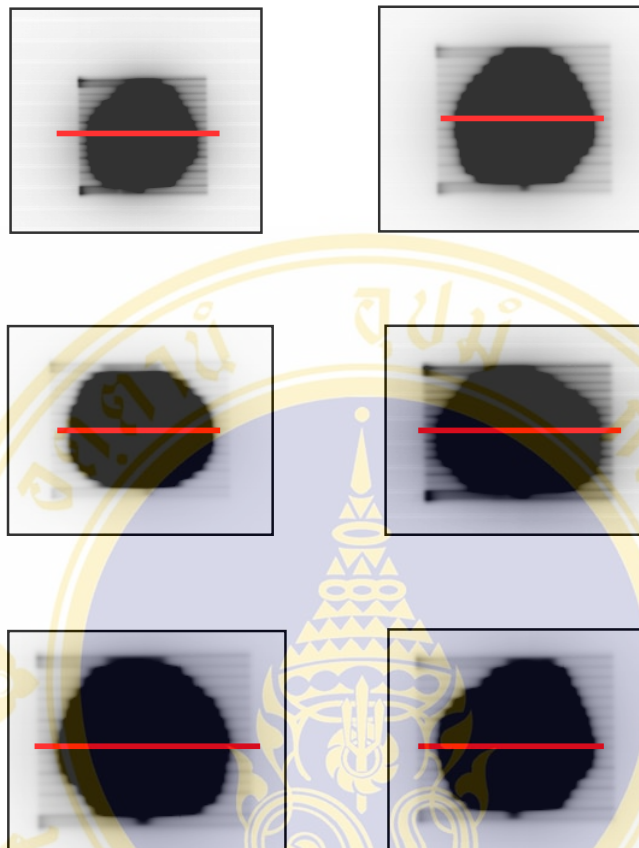


**Figure 25.** The exposed EPID of 6 prostate IMRT fields.

## CHAPTER V

### RESULTS AND DISCUSSIONS

#### 5.1 Determination of the dosimetric characterization of the aSi EPID

Dosimetric properties of the aSi EPID were investigated in the current study for the purpose of understanding the EPID response behavior, prior to calibration for EPID dosimetry and patient treatment evaluation.

##### 5.1.1 Dose response

##### 5.1.1.1 Linearity with respect to dose rate

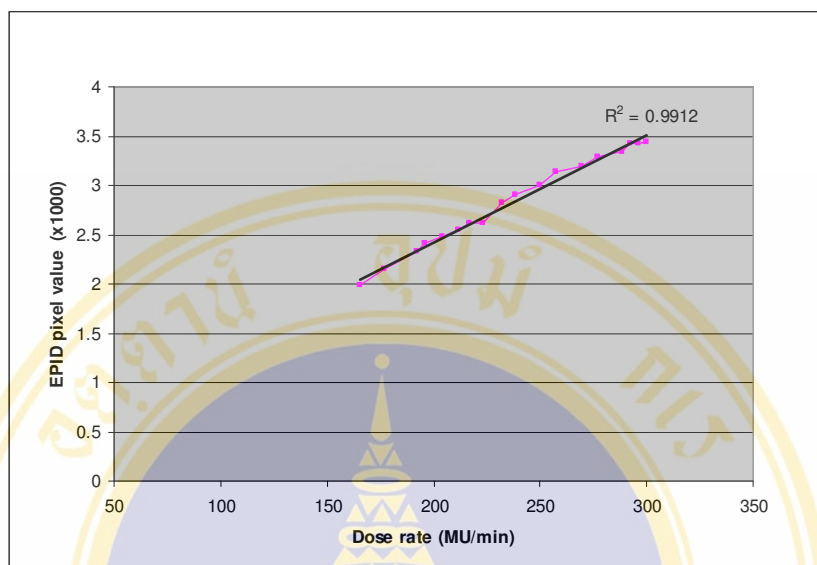
The linearity of the aSi500 EPID respect to relative dose rate of 6 MV and 10 MV x-ray which compared to the ionization chamber measurements are shown in table 1 and 2 and figure 26 a and b, respectively. The relative dose-rate axis is expressed in terms of nominal accelerator dose rate with a dose rate of 300 MU/min at 100.0 cm from the source. The linearity of EPID measurement with respect to dose rate at each SDD was found to be linear by  $R^2$  less than 1 for both 6 and 10 MV photon beams. The dose rate dependence with varying SDD was recently investigated by Greer and Popescu (20) and found to be linear by less than 1% as well.

**Table 1.** The EPID and ionization chamber measured data for the linearity with respect to dose rate for 6 MV-photon by varying SDD.

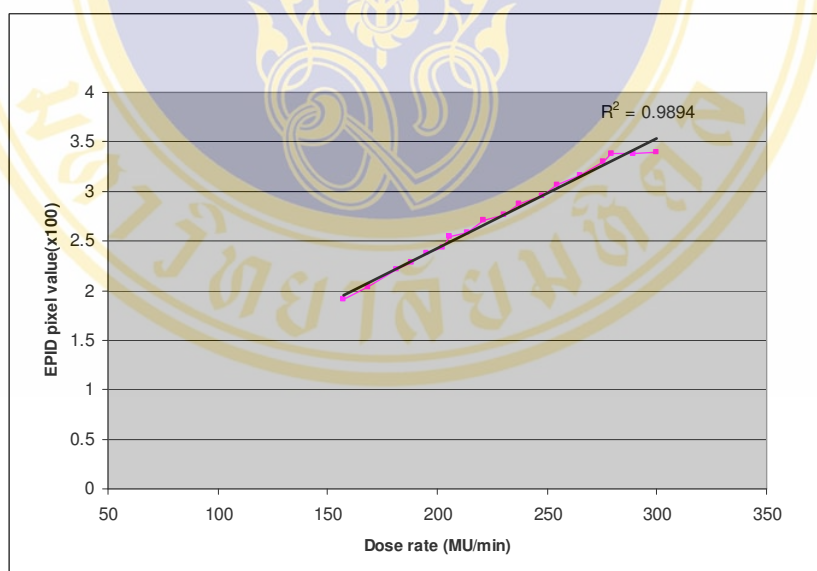
| Distance(cm) | Reading                |                          | Dose rate          |        |
|--------------|------------------------|--------------------------|--------------------|--------|
|              | Ionization Chamber(nC) | EPID pixel value (x1000) | Ionization Chamber | EPID   |
| 100          | 3.93                   | 3.44                     | 300.00             | 300.00 |
| 102          | 3.87                   | 3.43                     | 296.10             | 299.56 |
| 105          | 3.82                   | 3.43                     | 292.28             | 299.13 |
| 106          | 3.77                   | 3.34                     | 288.46             | 291.70 |
| 108          | 3.62                   | 3.29                     | 276.92             | 287.25 |
| 110          | 3.52                   | 3.19                     | 269.20             | 278.17 |
| 112          | 3.37                   | 3.13                     | 257.66             | 273.45 |
| 114          | 3.27                   | 3.00                     | 250.01             | 262.18 |
| 116          | 3.12                   | 2.90                     | 238.47             | 253.45 |
| 118          | 3.04                   | 2.82                     | 232.05             | 246.03 |
| 120          | 2.92                   | 2.62                     | 223.11             | 228.82 |
| 122          | 2.84                   | 2.62                     | 216.69             | 228.73 |
| 124          | 2.77                   | 2.54                     | 211.57             | 222.18 |
| 126          | 2.67                   | 2.48                     | 203.85             | 216.16 |
| 128          | 2.57                   | 2.41                     | 196.13             | 210.31 |
| 130          | 2.52                   | 2.32                     | 192.31             | 202.88 |
| 135          | 2.32                   | 2.15                     | 176.94             | 187.60 |
| 140          | 2.16                   | 1.98                     | 165.40             | 173.10 |

**Table 2.** The EPID and ionization chamber measured data for the linearity with respect to dose rate for 10 MV-photon by varying SDD.

| Distance(cm) | Reading                |                          | Dose rate          |        |
|--------------|------------------------|--------------------------|--------------------|--------|
|              | Ionization Chamber(nC) | EPID pixel value (x1000) | Ionization Chamber | EPID   |
| 100          | 4.33                   | 3.39                     | 300.00             | 300.00 |
| 102          | 4.18                   | 3.39                     | 289.53             | 299.65 |
| 105          | 4.03                   | 3.38                     | 279.07             | 299.12 |
| 106          | 3.98                   | 3.31                     | 275.53             | 292.39 |
| 108          | 3.82                   | 3.17                     | 265.06             | 280.01 |
| 110          | 3.67                   | 3.06                     | 254.60             | 270.72 |
| 112          | 3.57                   | 2.96                     | 247.67             | 261.78 |
| 114          | 3.42                   | 2.88                     | 237.20             | 254.70 |
| 116          | 3.32                   | 2.76                     | 230.20             | 244.53 |
| 118          | 3.19                   | 2.71                     | 220.91             | 239.58 |
| 120          | 3.09                   | 2.59                     | 213.91             | 228.87 |
| 122          | 2.97                   | 2.54                     | 205.66             | 224.45 |
| 124          | 2.92                   | 2.44                     | 202.33             | 215.51 |
| 126          | 2.82                   | 2.37                     | 195.33             | 209.94 |
| 128          | 2.72                   | 2.29                     | 188.33             | 202.33 |
| 130          | 2.62                   | 2.21                     | 181.40             | 195.43 |
| 135          | 2.43                   | 2.04                     | 168.58             | 180.21 |
| 140          | 2.26                   | 1.90                     | 156.93             | 168.45 |



(a)



(b)

**Figure 26.** (a) and (b) The linearity of the EPID with respect to relative dose rate of 6 MV and 10 MV photon beams, respectively.

### 5.1.1.2 Linearity with respect to dose

The linearity of the EPID respect to integrated dose of 6 MV and 10 MV photon beams which compared to the ionization chamber measurements are shown in table 3 and 4 and figure 27 a and b, respectively. The data of EPID in figure 27 (a and b) shows the pixel values multiplied by the number of frames. Because of the dead time in image frame acquisition, these number of frames for the increasing dose settings was reduction of 2.5 frames for each dead time occurring during the acquisition. In table 5 and 6 shown the MU setting, the number of frames acquired, the acquisition time and the reduction of frames for each dead time for 6 MV and 10 MV, respectively. Five frames were missing for the 100 MU (2 dead times) and 12.5 frames for 200 MU (5 dead times), with the dead time occurring at 64 frames (~40 MU) interval. Therefore, to produce the accurate dosimetry of EPID for static fields, the calculated integrated dose obtained by multiplication of the pixel values by the number of frames or multiplied by the total time for the irradiation. The results are agreed with Greer and Popescu's results (20).

**Table 3.** The EPID and ionization chamber measured data for the linearity with respect to dose for 6 MV-photon by varying MU setting.

| Monitor Unit (MU) | Reading                |                           |
|-------------------|------------------------|---------------------------|
|                   | Ionization Chamber(nC) | EPID pixel value (x10e+5) |
| 10                | 2.01                   | 0.79                      |
| 20                | 4.03                   | 1.59                      |
| 30                | 6.04                   | 2.41                      |
| 40                | 8.06                   | 3.12                      |
| 50                | 10.12                  | 3.96                      |
| 60                | 12.12                  | 4.79                      |
| 70                | 14.15                  | 5.54                      |
| 80                | 16.19                  | 6.31                      |
| 90                | 18.23                  | 7.15                      |
| 100               | 20.24                  | 7.96                      |
| 130               | 26.31                  | 10.34                     |
| 150               | 30.39                  | 11.85                     |
| 170               | 34.44                  | 13.54                     |
| 200               | 40.55                  | 15.91                     |

**Table 4.** The EPID and ionization chamber measured data for the linearity with respect to dose for 10 MV-photon by varying MU setting.

| Monitor Unit (MU) | Reading                |                           |
|-------------------|------------------------|---------------------------|
|                   | Ionization Chamber(nC) | EPID pixel value (x10e+5) |
| 10                | 2.11                   | 0.71                      |
| 20                | 4.27                   | 1.48                      |
| 30                | 6.38                   | 2.26                      |
| 40                | 8.54                   | 2.92                      |
| 50                | 10.65                  | 3.68                      |
| 60                | 12.82                  | 4.46                      |
| 70                | 14.93                  | 5.24                      |
| 80                | 17.09                  | 5.9                       |
| 90                | 19.10                  | 6.68                      |
| 100               | 21.31                  | 7.75                      |
| 130               | 27.72                  | 9.66                      |
| 150               | 31.98                  | 11.11                     |
| 170               | 36.28                  | 12.64                     |
| 200               | 42.67                  | 14.86                     |

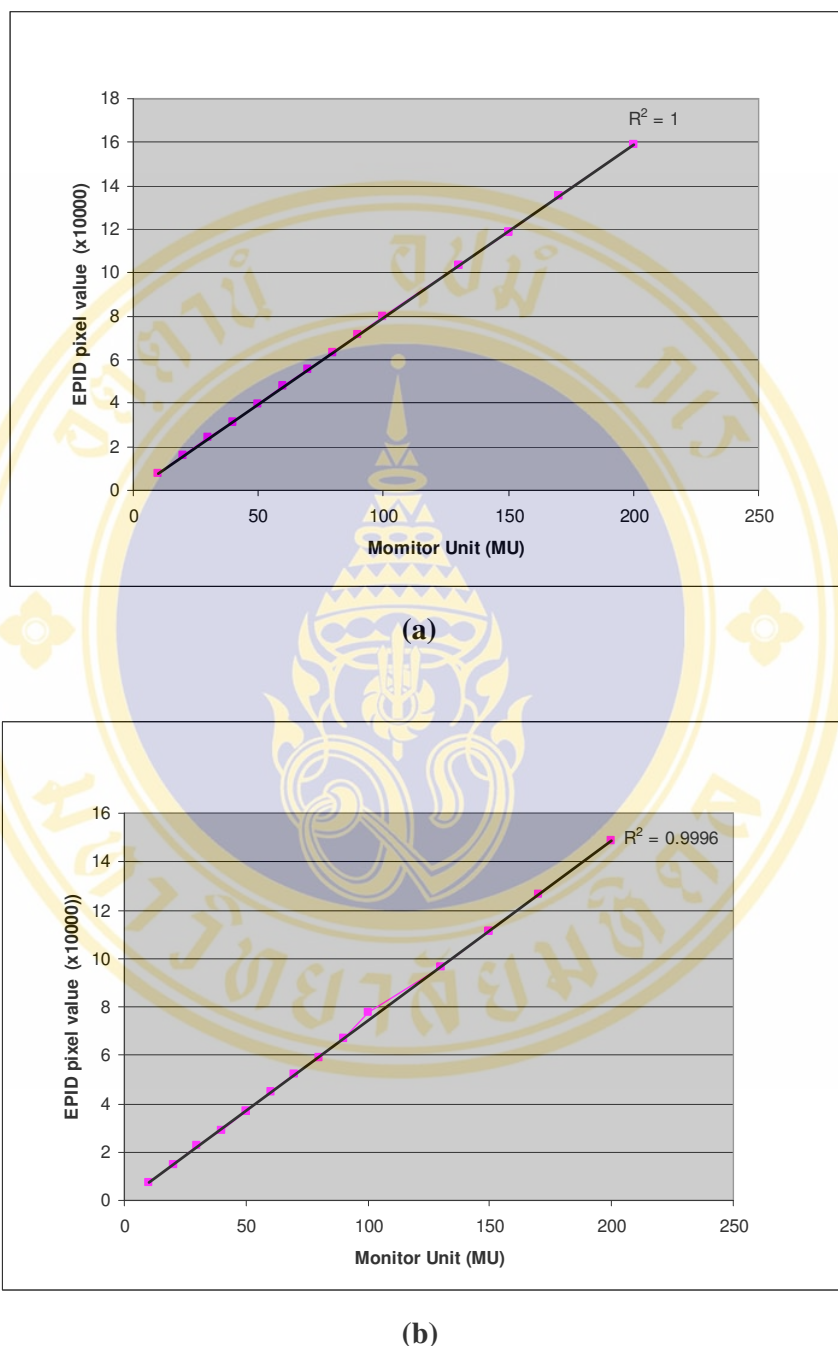


**Figure 27.** (a) and (b) the linearity of the EPID respect to integrated dose of 6 MV and 10 MV, respectively.

**Table 5.** The missing frame number is due to the dead time in frame acquisition for EPID measurement of 6 MV photon beam energy.

| MU setting | Number of frames acquisition | Acquisition time (s) | Time/frame (s) | Real acquisition frames | Missing frame due to dead time |
|------------|------------------------------|----------------------|----------------|-------------------------|--------------------------------|
| 10         | 20                           | 2.223                | 0.111          | 20.03                   | -                              |
| 20         | 38                           | 4.219                | 0.111          | 38.01                   | -                              |
| 30         | 55                           | 6.111                | 0.111          | 55.05                   | -                              |
| 40         | 72                           | 8.269                | 0.115          | 74.50                   | 2.50                           |
| 50         | 88                           | 10.049               | 0.114          | 90.53                   | 2.50                           |
| 60         | 106                          | 12.043               | 0.114          | 108.50                  | 2.50                           |
| 70         | 125                          | 14.152               | 0.113          | 127.50                  | 2.50                           |
| 80         | 138                          | 15.878               | 0.115          | 143.05                  | 5.00                           |
| 90         | 156                          | 17.876               | 0.115          | 161.05                  | 5.00                           |
| 100        | 175                          | 19.987               | 0.114          | 180.06                  | 5.00                           |
| 130        | 225                          | 25.809               | 0.115          | 232.51                  | 7.50                           |
| 150        | 258                          | 29.754               | 0.115          | 268.05                  | 10.00                          |
| 170        | 293                          | 33.642               | 0.115          | 303.08                  | 10.00                          |
| 200        | 344                          | 39.579               | 0.115          | 356.57                  | 12.50                          |

**Table 6.** The missing the frame number is due to the dead time in frame acquisition for EPID measurement of 10 MV photon beam energy.

| MU setting | Number of frames acquisition | Acquisition time (s) | Time/frame (s) | Real acquisition frames | Missing frame due to dead time |
|------------|------------------------------|----------------------|----------------|-------------------------|--------------------------------|
| 10         | 19                           | 2.110                | 0.111          | 19.01                   | -                              |
| 20         | 37                           | 4.109                | 0.111          | 37.02                   | -                              |
| 30         | 55                           | 6.104                | 0.111          | 54.99                   | -                              |
| 40         | 70                           | 8.043                | 0.115          | 72.46                   | 2.50                           |
| 50         | 87                           | 9.938                | 0.114          | 89.53                   | 2.50                           |
| 60         | 105                          | 11.937               | 0.114          | 107.54                  | 2.50                           |
| 70         | 123                          | 13.930               | 0.113          | 125.50                  | 2.50                           |
| 80         | 138                          | 15.873               | 0.115          | 143.00                  | 5.00                           |
| 90         | 155                          | 17.764               | 0.115          | 160.04                  | 5.00                           |
| 100        | 173                          | 19.763               | 0.114          | 178.05                  | 5.00                           |
| 130        | 223                          | 25.595               | 0.115          | 230.59                  | 7.50                           |
| 150        | 256                          | 29.530               | 0.115          | 266.04                  | 10.00                          |
| 170        | 291                          | 33.417               | 0.115          | 301.05                  | 10.00                          |
| 200        | 341                          | 39.247               | 0.115          | 353.58                  | 12.50                          |

### 5.1.2 Field size response

The EPID and the ionization chamber readings with field size normalized to the  $10 \times 10 \text{ cm}^2$  values are shown in table 7 and 8 and figure 28 a and b for 6 MV and 10 MV, respectively. The EPID shows a field size response compared to ionization chamber of  $-3.7\%$  for a  $4 \times 4 \text{ cm}^2$  field and  $3.2\%$  for a  $24 \times 24 \text{ cm}^2$  field for 6 MV and  $-2.7\%$  for a  $4 \times 4 \text{ cm}^2$  field and  $5.3\%$  for a  $24 \times 24 \text{ cm}^2$  field for 10 MV, when compared to reading in solid water phantom. The field size response results for 6 MV were similar to 10 MV. In the small field size, the EPID readings were less than the ionization chamber readings. When the field size increased, the EPID readings were more than the ionization chamber readings. The differences results probably due to the increase in scattered radiation with increasing field size. Since the scatter has a low energy component, its effect on the EPID's phosphor response is enhanced compared to ionization chamber due to presence of high atomic number component in the phosphor of EPID. A field size dependent response of up to 5% relative to  $d_{\text{max}}$  ionization chamber measurement for 6 MV x-ray was found (20). Also the discrepancies up to 9% was observed when compared the field size dependence of the aSi-based EPID to the ionization chamber measurement in water for 18 MV x-ray photon beams. (21).

**Table 7.** The comparison of EPID and ionization chamber data of field size response for 6 MV photon.

| Field Size(cm <sup>2</sup> ) | % Normalize            |                  | % Difference |
|------------------------------|------------------------|------------------|--------------|
|                              | Ionization Chamber(nC) | EPID pixel value |              |
| 3x3                          | 0.92                   | 0.88             | -3.39        |
| 4x4                          | 0.94                   | 0.90             | -3.73        |
| 5x5                          | 0.95                   | 0.93             | -2.73        |
| 6x6                          | 0.96                   | 0.96             | -0.31        |
| 8x8                          | 0.98                   | 0.97             | -0.31        |
| 10x10                        | 1.00                   | 1.00             | 0.00         |
| 12x12                        | 1.02                   | 1.02             | 0.00         |
| 15x15                        | 1.04                   | 1.05             | 1.54         |
| 18x18                        | 1.05                   | 1.07             | 2.38         |
| 20x20                        | 1.05                   | 1.08             | 2.56         |
| 22x22                        | 1.06                   | 1.09             | 2.73         |
| 24x24                        | 1.07                   | 1.10             | 3.18         |

**Table 8.** The comparison of EPID and ionization chamber data of field size response for 10 MV photon.

| Field Size(cm <sup>2</sup> ) | % Normalize            |                  | % Difference |
|------------------------------|------------------------|------------------|--------------|
|                              | Ionization Chamber(nC) | EPID pixel value |              |
| 3x3                          | 0.88                   | 0.87             | -1.92        |
| 4x4                          | 0.92                   | 0.89             | -2.72        |
| 5x5                          | 0.93                   | 0.92             | -1.08        |
| 6x6                          | 0.95                   | 0.94             | -1.26        |
| 8x8                          | 0.98                   | 0.97             | -0.31        |
| 10x10                        | 1.00                   | 1.00             | 0.00         |
| 12x12                        | 1.01                   | 1.03             | 1.98         |
| 15x15                        | 1.02                   | 1.06             | 3.23         |
| 18x18                        | 1.04                   | 1.08             | 3.96         |
| 20x20                        | 1.05                   | 1.09             | 4.39         |
| 22x22                        | 1.05                   | 1.10             | 5.25         |
| 24x24                        | 1.06                   | 1.11             | 5.29         |

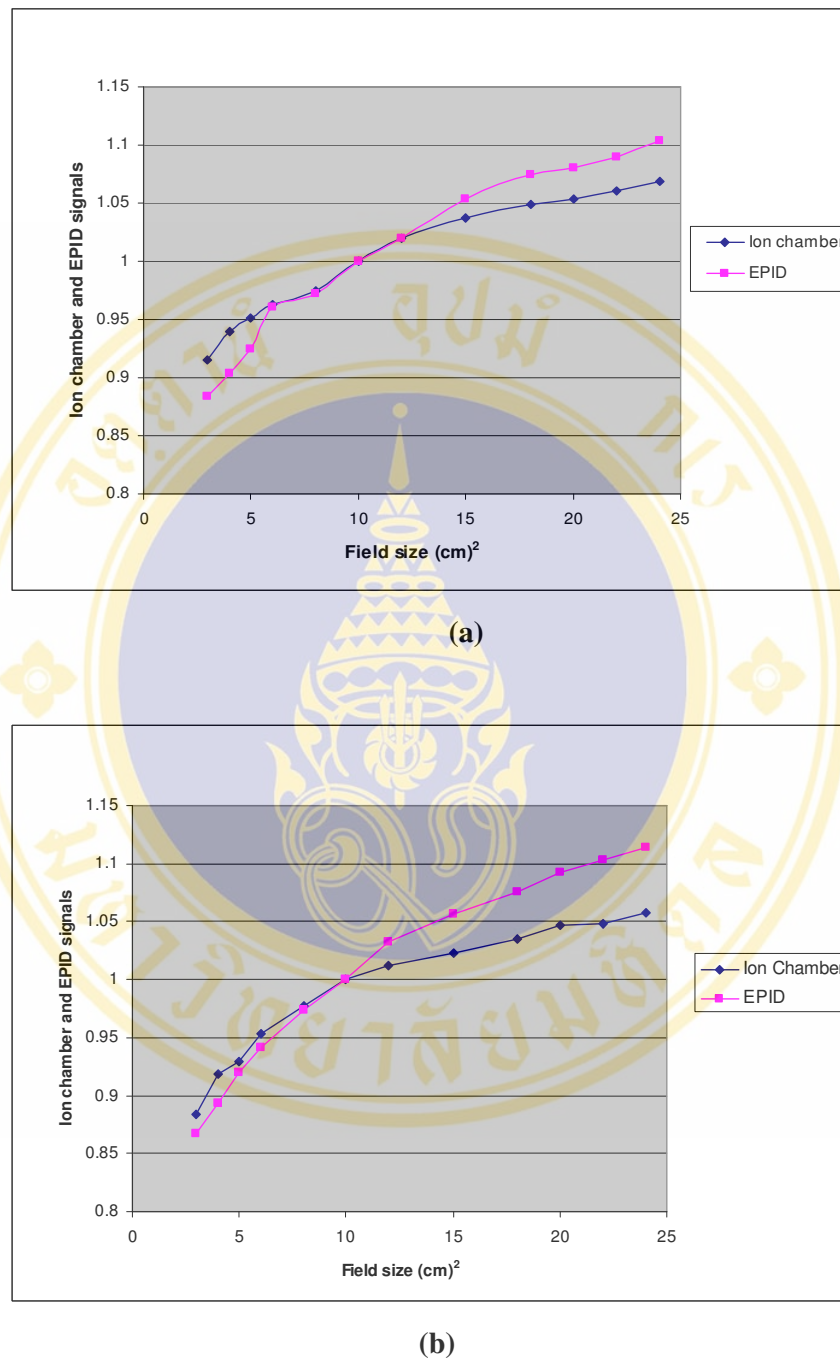
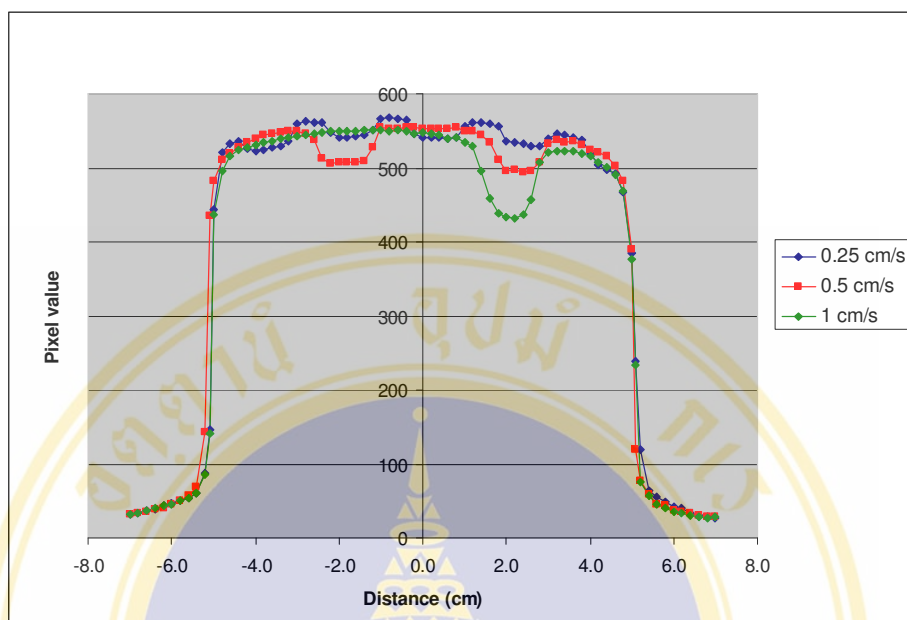


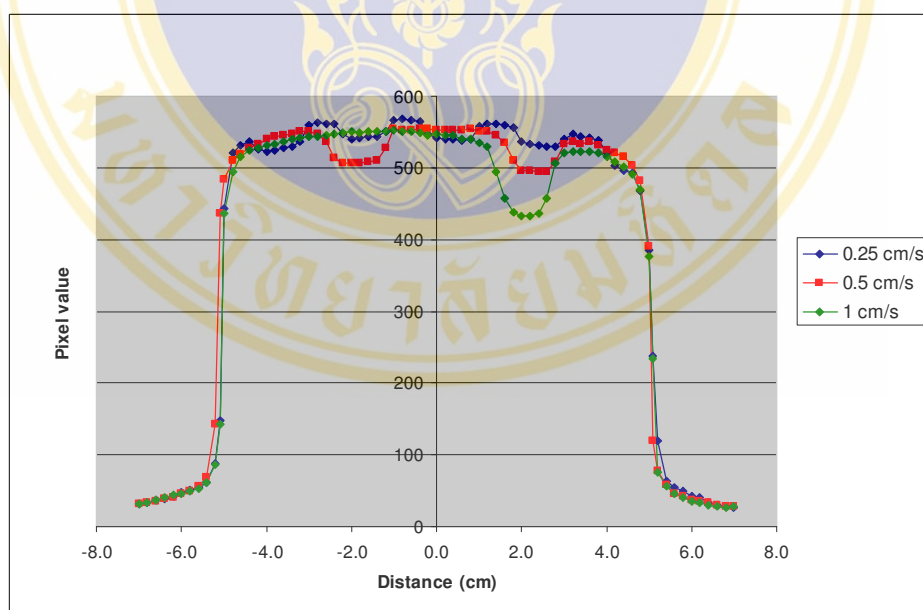
**Figure 28.** (a) Field size response of the EPID for 6 MV, and (b) field size response of the EPID for 10 MV photon beams. The EPID signal change with field size is compared to the change in dose with field size measured with an ionization chamber. The data are normalized to the 10x10 cm<sup>2</sup> field.

### 5.1.3 Effect of dead time in frame acquisition

The beam profile of the dead time in frame acquisition for 6 MV and 10 MV photon beams are shown in figure 29 a and b, respectively. The profiles were obtained under a center MLC leaf along the dissection of leaf motion. The profiles of 0.25, 0.5 and 1.0  $\text{cm s}^{-1}$  were found the evident reduction of EPID signal for 5, 2 and 1 dead time, respectively. The reduction of signal are evident with  $\sim 1$  cm width at intervals that correspond to 64 frame intervals in the image acquisition. The errors in this case are large even for the relatively low leaf speeds. The measured maximum errors as a function of the leaf speed of 6 MV and 10 MV are shown in figure 30 a and b, respectively. Due to the dead time in frame acquisition, the error in the EPID signal that increased with leaf speed and were over 21% and 20% for a 1 cm leaf gap moving at 1.0  $\text{cm s}^{-1}$  leaf speed for 6 MV and 10 MV, respectively. These are due to the fact that when the leaves are moving rapidly, each portion of the detector is irradiated for only a short time. Each 1 cm width region on the detector is only irradiated for 1s. The maximum error in signal for the 1.0  $\text{cm s}^{-1}$  leaf speed observed here corresponds reasonably well with a dead time of  $\sim 0.28$  s. Therefore even a small dead time can result in a large loss of signal. When less than 64 frames were utilized for image acquisition there was no nonuniformity of the profile observed. The similar results was reported by Greer and Popescu (20). They observed that the dead time in frame acquisition resulted in error in the EPID over 20% for a leaf speed of 1.0  $\text{cm s}^{-1}$  with a 1 cm leaf gap. The error increased linearly with increasing leaf speed as displayed in figure 30.

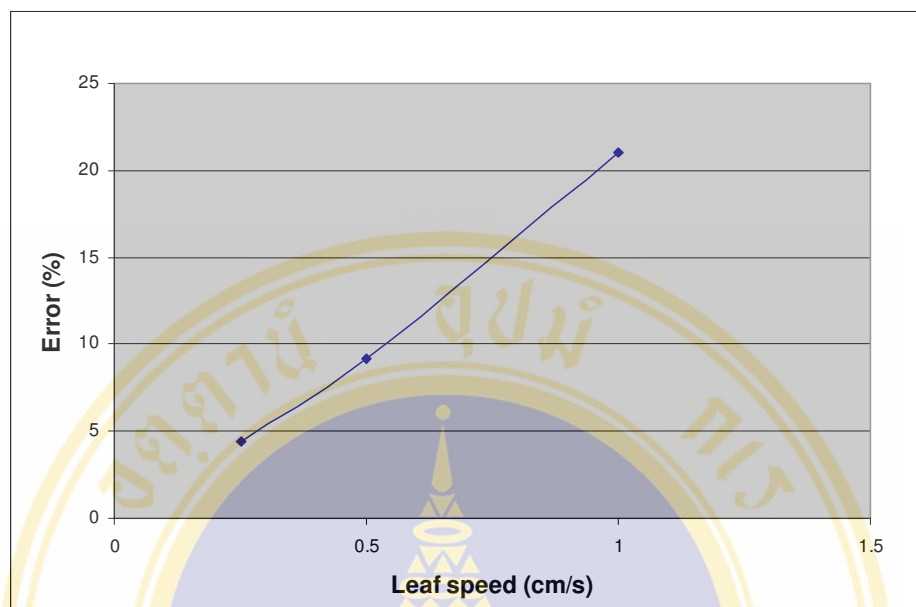


(a)

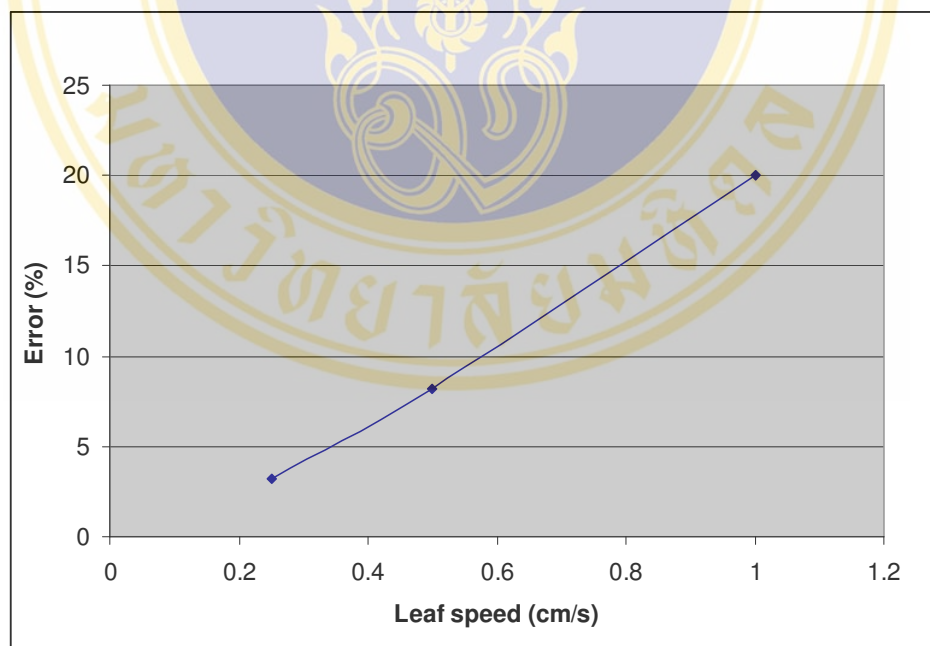


(b)

**Figure 29.** (a) and (b) The effect of the EPID dead time on recorded signal of 6 MV and 10 MV, respectively.



(a)



(b)

**Figure 30.** The error in EPID due to dead time as a function of the leaf speed for a 1 cm gap sliding window delivery with leaf speeds of 0.25, 0.5 and 1.0  $\text{cm s}^{-1}$  for 6 MV (a) and 10 MV (b).

#### 5.1.4 Response with leaf speed

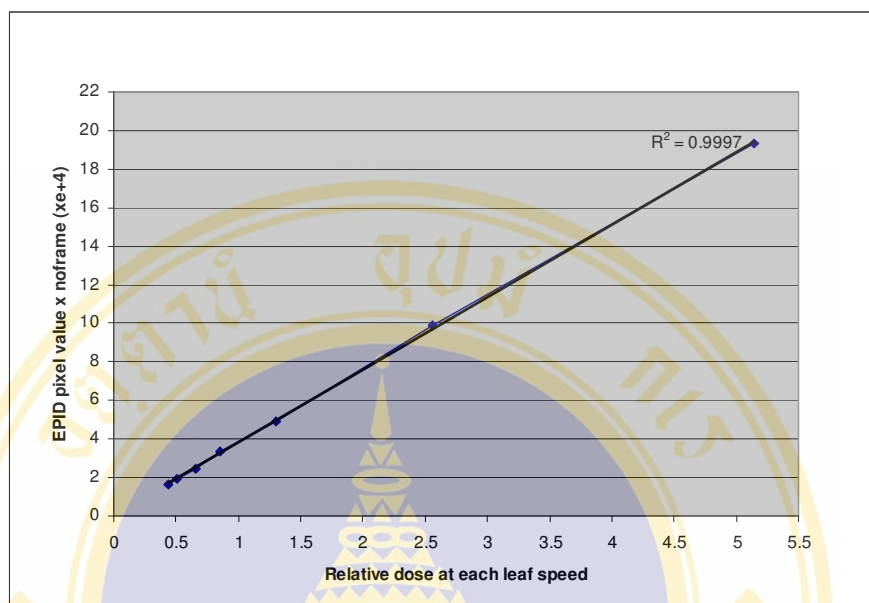
The EPID signal linearity with leaf speed of 6 MV and 10 MV are shown in table 9 and 10 and figure 31 a and b, respectively. The EPID pixel values have been multiplied by the number of frames to obtain an integrated pixel values. This shows that EPID is accurately recording the rapid changes in dose rate. These results were obtained by analysis of profiles across sliding window deliveries, and compared to ionization chamber reading in a solid water phantom. These profiles exhibited reductions in signal in the region of the image under the open MLC leaf gap due to the dead time of the EPID every 64 frames. The values utilized for figure 19 a and b were obtained from regions of the image that during the dead time were irradiated only by MLC transmission, and hence only slightly affected. The current study gave the similar result as Greer and Popescu's investigation (20).

**Table 9.** The EPID and ionization chamber measured data that show the linearity of signal of response with leaf speed for 6 MV photon.

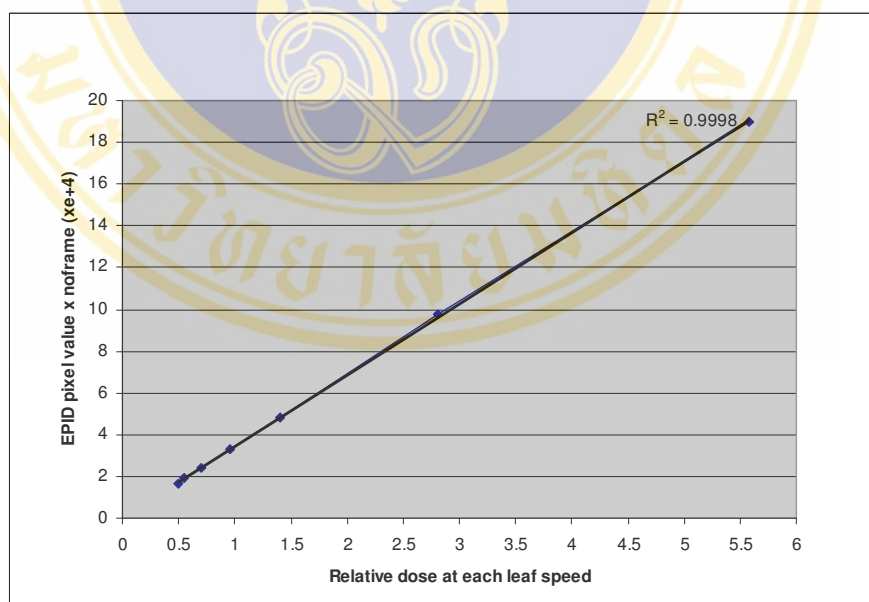
| Monitor Unit (MU) | Reading                |                           |
|-------------------|------------------------|---------------------------|
|                   | Ionization Chamber(nC) | EPID pixel value (x10e+4) |
| 3.00              | 0.44                   | 1.62                      |
| 2.50              | 0.50                   | 1.93                      |
| 2.00              | 0.65                   | 2.42                      |
| 1.50              | 0.85                   | 3.34                      |
| 1.00              | 1.31                   | 4.92                      |
| 0.50              | 2.56                   | 9.91                      |
| 0.25              | 5.14                   | 19.33                     |

**Table 10.** The EPID and ionization chamber measured data that show the linearity of signal of response with leaf speed for 10 MV photon.

| Monitor Unit (MU) | Reading                |                           |
|-------------------|------------------------|---------------------------|
|                   | Ionization Chamber(nC) | EPID pixel value (x10e+4) |
| 3.00              | 0.50                   | 1.62                      |
| 2.50              | 0.55                   | 1.91                      |
| 2.00              | 0.70                   | 2.40                      |
| 1.50              | 0.95                   | 3.28                      |
| 1.00              | 1.41                   | 4.80                      |
| 0.50              | 2.81                   | 9.75                      |
| 0.25              | 5.58                   | 18.94                     |



(a)



(b)

**Figure 31.** (a) and (b) The linearity of the EPID signal with leaf speed for 6 MV and 10 MV, respectively.

### 5.1.5 Response to dose-rate fluctuation

The agreement between the test pattern recorded by dose setting of 50 MU and 500 MU were utilized to deliver the field with and without beam hold-off of 6 MV and 10 MV are show in table 11 and 12 and figure 32 a and b, respectively. During the 50 MU setting irradiation, the beam dose rate fluctuated at the time during the beam delivery. The fluctuations in signal data of beam profile directly under the leaf adjacent to the central axis plane are evident for the pattern recorded with beam hold-offs more than the pattern recorded without beam hold-offs approximately 3.3% and 3.0% for 6 MV and 10 MV, respectively. These means that the synchronization of the image acquisition with beam pulses is crucial to accurate dosimetry, where an IMRT profile was recorded with and without dose-rate fluctuation.

**Table 11.** Comparison of measurement data of an IMRT test pattern with 50 MU and 500 MU for 6 MV photon.

| Distance(cm) | % Normalize       |                    | % Difference |
|--------------|-------------------|--------------------|--------------|
|              | Pixel value 50 MU | Pixel value 500 MU |              |
| -7.00        | 6.98              | 6.95               | 0.38         |
| -6.75        | 7.45              | 7.39               | 0.80         |
| -6.50        | 8.87              | 8.82               | 0.53         |
| -6.25        | 9.62              | 9.52               | 1.11         |
| -6.00        | 11.42             | 11.31              | 0.93         |
| -5.75        | 13.77             | 13.65              | 0.88         |
| -5.50        | 16.93             | 20.42              | -17.09       |
| -5.25        | 27.64             | 27.23              | 1.50         |
| -5.00        | 156.84            | 151.90             | 3.25         |
| -4.75        | 163.96            | 160.21             | 2.34         |
| -4.50        | 166.75            | 161.64             | 3.16         |
| -4.25        | 168.40            | 163.36             | 3.08         |
| -4.00        | 168.92            | 164.17             | 2.89         |
| -3.75        | 169.25            | 164.24             | 3.05         |
| -3.50        | 169.15            | 164.17             | 3.04         |
| -3.25        | 168.54            | 163.73             | 2.94         |
| -3.00        | 145.19            | 142.09             | 2.18         |
| -2.75        | 137.97            | 135.25             | 2.01         |
| -2.50        | 136.51            | 134.22             | 1.70         |
| -2.25        | 135.71            | 133.16             | 1.91         |
| -2.00        | 135.14            | 132.65             | 1.88         |
| -1.75        | 134.67            | 132.03             | 2.00         |
| -1.50        | 134.15            | 131.77             | 1.81         |
| -1.25        | 133.07            | 131.04             | 1.55         |
| -1.00        | 107.78            | 107.39             | 0.36         |
| -0.75        | 103.87            | 102.96             | 0.88         |
| -0.50        | 101.79            | 102.16             | -0.36        |
| -0.25        | 100.94            | 100.62             | 0.32         |
| 0.00         | 100.00            | 100.00             | 0.00         |

**Table 11.** Comparison of measurement data of an IMRT test pattern with 50 MU and 500 MU for 6 MV photon (Continued).

| Distance(cm) | % Normalize       |                    | % Difference |
|--------------|-------------------|--------------------|--------------|
|              | Pixel value 50 MU | Pixel value 500 MU |              |
| 0.25         | 99.39             | 99.45              | -0.06        |
| 0.50         | 98.63             | 98.90              | -0.27        |
| 0.75         | 97.64             | 97.62              | 0.02         |
| 1.00         | 79.43             | 78.07              | 1.74         |
| 1.25         | 73.21             | 71.49              | 2.41         |
| 1.50         | 71.18             | 68.92              | 3.27         |
| 1.75         | 69.67             | 67.86              | 2.66         |
| 2.00         | 69.06             | 67.42              | 2.42         |
| 2.25         | 68.49             | 66.58              | 2.87         |
| 2.50         | 68.16             | 66.03              | 3.22         |
| 2.75         | 67.41             | 65.23              | 3.34         |
| 3.00         | 56.18             | 54.76              | 2.59         |
| 3.25         | 39.43             | 40.41              | -2.42        |
| 3.50         | 37.64             | 37.48              | 0.43         |
| 3.75         | 35.90             | 36.02              | -0.34        |
| 4.00         | 35.09             | 35.25              | -0.44        |
| 4.25         | 34.72             | 34.44              | 0.79         |
| 4.50         | 34.20             | 33.82              | 1.11         |
| 4.75         | 33.54             | 33.46              | 0.25         |
| 5.00         | 18.11             | 18.16              | -0.23        |
| 5.25         | 8.07              | 8.09               | -0.29        |
| 5.50         | 6.32              | 6.33               | -0.18        |
| 5.75         | 5.09              | 4.54               | 12.24        |
| 6.00         | 4.01              | 3.99               | 0.49         |
| 6.25         | 3.58              | 3.59               | -0.06        |
| 6.50         | 3.25              | 3.18               | 2.21         |
| 6.75         | 2.88              | 2.86               | 0.78         |
| 7.00         | 2.64              | 2.67               | -1.14        |

**Table 12.** Comparison of measurement data of an IMRT test pattern with 50 MU and 500 MU for 10 MV photon.

| Distance(cm) | % Normalize       |                    | % Difference |
|--------------|-------------------|--------------------|--------------|
|              | Pixel value 50 MU | Pixel value 500 MU |              |
| -7.00        | 7.95              | 8.04               | 1.15         |
| -6.75        | 8.54              | 8.62               | 0.95         |
| -6.50        | 9.88              | 9.95               | 0.70         |
| -6.25        | 10.27             | 11.19              | 8.93         |
| -6.00        | 12.35             | 12.35              | 0.07         |
| -5.75        | 16.84             | 16.78              | -0.33        |
| -5.50        | 22.67             | 22.57              | -0.42        |
| -5.25        | 46.67             | 46.27              | -0.85        |
| -5.00        | 158.27            | 154.82             | -2.18        |
| -4.75        | 162.47            | 158.86             | -2.22        |
| -4.50        | 164.25            | 160.61             | -2.22        |
| -4.25        | 165.04            | 161.73             | -2.00        |
| -4.00        | 165.93            | 162.39             | -2.13        |
| -3.75        | 166.02            | 162.39             | -2.19        |
| -3.50        | 166.12            | 162.51             | -2.18        |
| -3.25        | 165.73            | 162.20             | -2.13        |
| -3.00        | 141.09            | 139.16             | -1.36        |
| -2.75        | 137.48            | 135.66             | -1.32        |
| -2.50        | 135.51            | 134.54             | -0.71        |
| -2.25        | 134.62            | 133.02             | -1.18        |
| -2.00        | 133.98            | 132.44             | -1.15        |
| -1.75        | 133.48            | 131.82             | -1.25        |
| -1.50        | 132.74            | 131.20             | -1.16        |
| -1.25        | 131.56            | 130.11             | -1.10        |
| -1.00        | 105.98            | 105.75             | -0.21        |
| -0.75        | 104.00            | 103.22             | -0.75        |
| -0.50        | 101.68            | 101.55             | -0.12        |
| -0.25        | 100.64            | 100.97             | 0.33         |
| 0.00         | 100.00            | 100.00             | 0.00         |

**Table 12.** Comparison of measurement data of an IMRT test pattern with 50 MU and 500 MU for 10 MV photon (continued).

| Distance(cm) | % Normalize       |                    | % Difference |
|--------------|-------------------|--------------------|--------------|
|              | Pixel value 50 MU | Pixel value 500 MU |              |
| 0.25         | 99.41             | 99.34              | -0.07        |
| 0.50         | 98.37             | 98.37              | 0.00         |
| 0.75         | 96.94             | 96.78              | -0.17        |
| 1.00         | 76.79             | 75.21              | -2.05        |
| 1.25         | 73.04             | 71.29              | -2.39        |
| 1.50         | 71.11             | 69.31              | -2.53        |
| 1.75         | 69.98             | 68.57              | -2.01        |
| 2.00         | 69.33             | 67.44              | -2.73        |
| 2.25         | 68.89             | 66.90              | -2.89        |
| 2.50         | 67.95             | 66.16              | -2.63        |
| 2.75         | 66.96             | 65.23              | -2.59        |
| 3.00         | 53.68             | 46.58              | -13.22       |
| 3.25         | 40.44             | 39.94              | -1.25        |
| 3.50         | 38.07             | 37.61              | -1.23        |
| 3.75         | 36.64             | 36.67              | 0.09         |
| 4.00         | 35.85             | 35.55              | -0.85        |
| 4.25         | 35.26             | 34.93              | -0.94        |
| 4.50         | 34.67             | 34.38              | -0.82        |
| 4.75         | 33.93             | 33.57              | -1.06        |
| 5.00         | 13.48             | 13.29              | -1.44        |
| 5.25         | 8.89              | 8.86               | -0.35        |
| 5.50         | 6.81              | 6.80               | -0.24        |
| 5.75         | 4.69              | 4.66               | -0.63        |
| 6.00         | 3.90              | 4.12               | 5.56         |
| 6.25         | 3.46              | 3.46               | 0.02         |
| 6.50         | 3.21              | 3.22               | 0.46         |
| 6.75         | 2.91              | 2.87               | -1.33        |
| 7.00         | 2.57              | 2.53               | -1.66        |

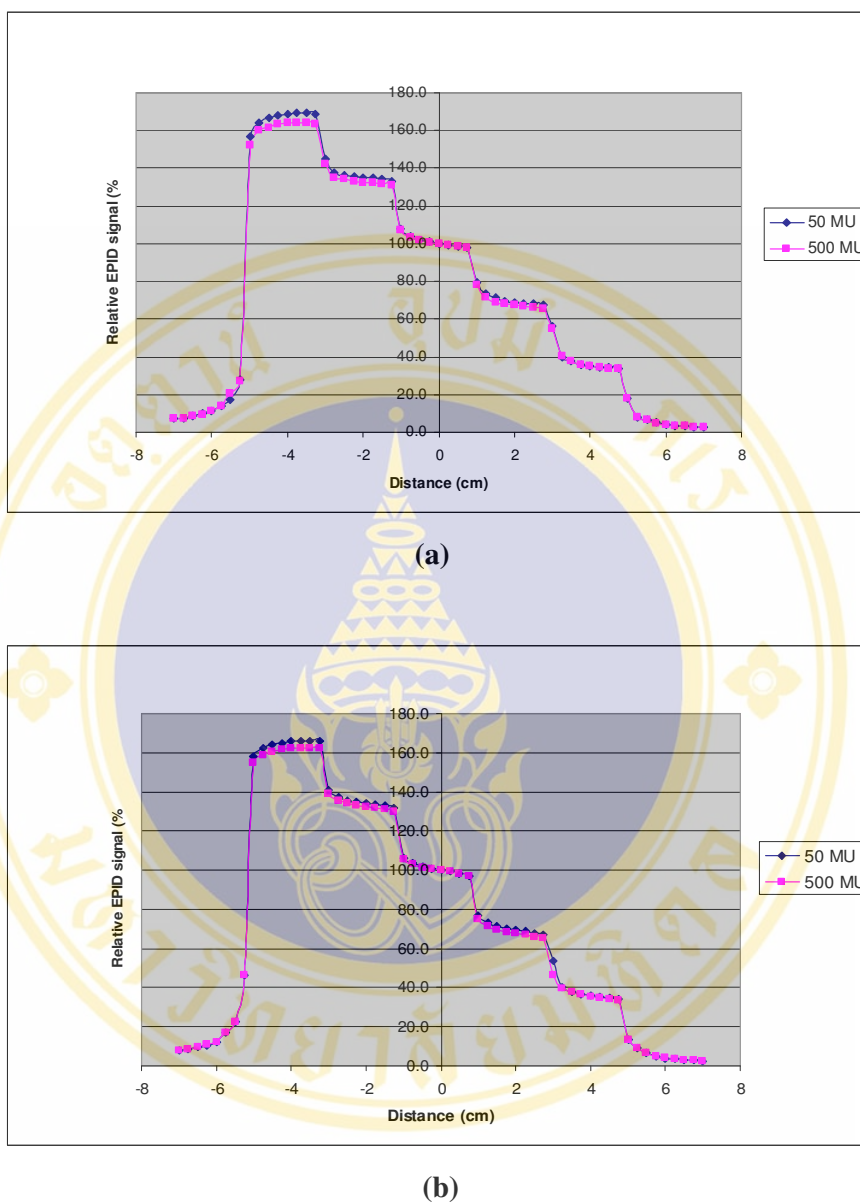


**Figure 32.** (a) and (b) Comparison of measured EPID profiles of an IMRT test pattern with an without beam hold-offs for 6 MV and 10 MV, respectively.

### 5.1.6 Memory effect

The ratio of line profile displays a signal remnant ~5%. When increased the time interval is 30s the ghosting was very small approximately 0.12%. The line profile as shown in figure 33 a and b are the memory effect for 6 MV and 10 MV, respectively, when used the time interval is 30s. Therefore, it is possible that the memory effect is greater for shorter time interval. From our results, the memory effect is negligible as a time interval of 30s.



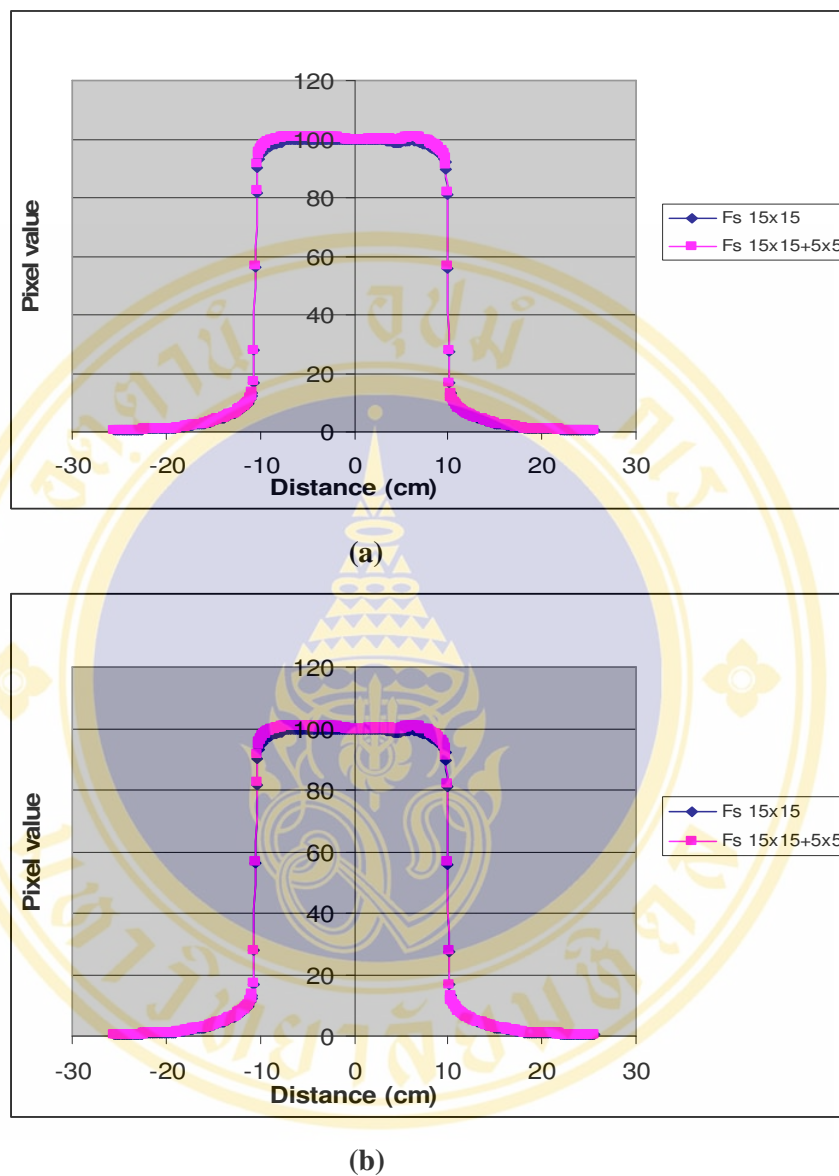


**Figure 33.** (a) and (b) The line profile of the memory effect for 6 MV and 10 MV, respectively. The time interval used for measured is 30s.

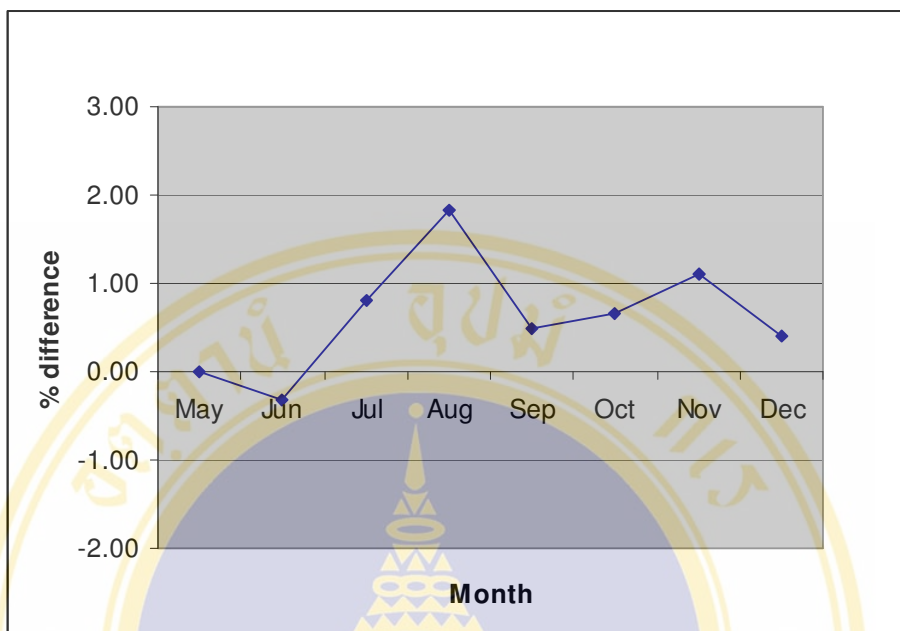
### 5.1.7 Reproducibility

Figure 34 a and b are shows the long term detector reproducibility was found to be within 2% for the same IMRT delivery recorded once a month at interval over a period of eight months in the region of relatively uniform irradiation. The reproducibility of EPID detector for 10 MV are similar to 6 MV which results as shown in table 13 and figure 34 c and d. Therefore, the EPID shows a high degree of reproducibility. Similar finding were reported in literature (20, 21).

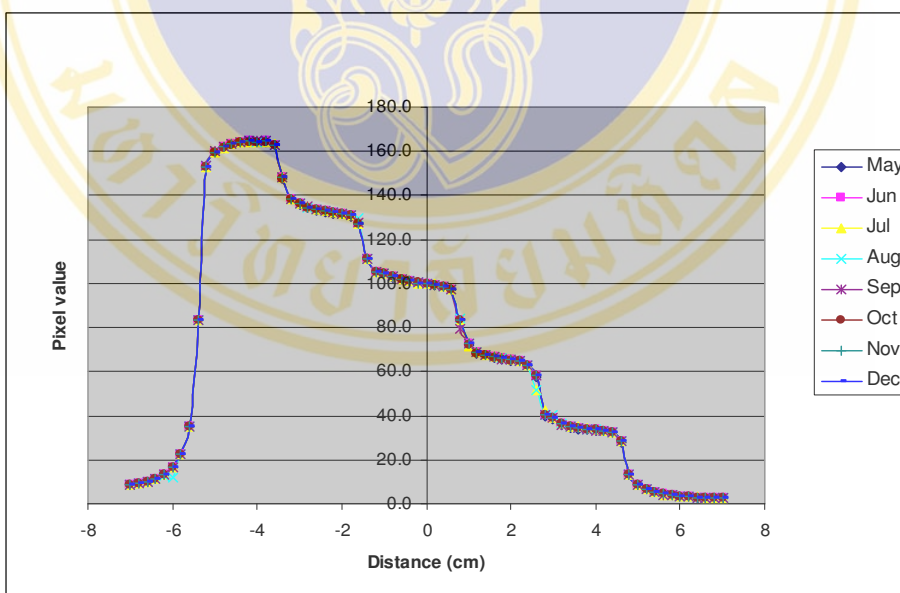


**Table 13.** The measurement data of EPID of reproducibility for 6 MV and 10 MV photons.

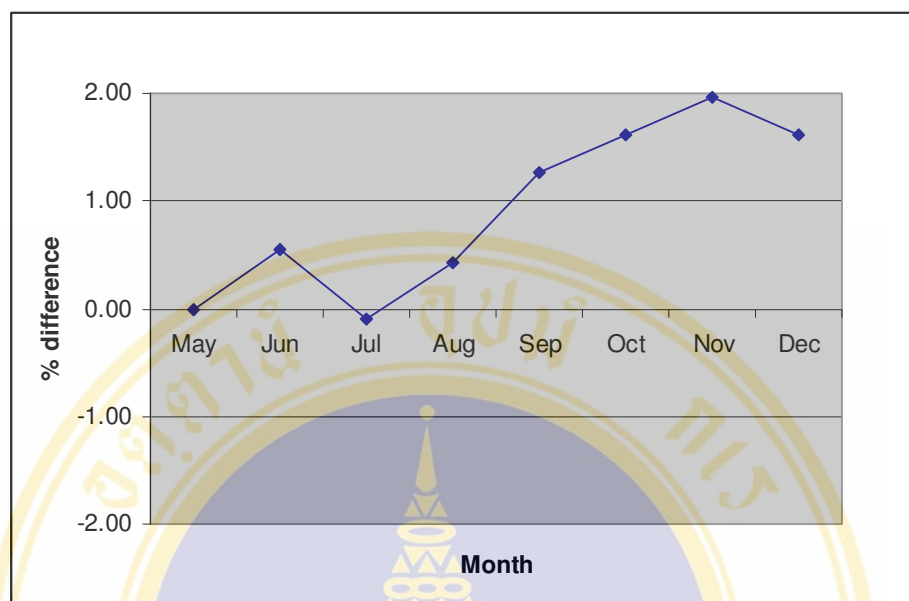
| Month | Reading |       | % difference from first month (May) |       |
|-------|---------|-------|-------------------------------------|-------|
|       | 6 MV    | 10 MV | 6 MV                                | 10 MV |
| May   | 2336.95 | 2463  | 0.00                                | 0.00  |
| Jun   | 2349.77 | 2455  | 0.55                                | -0.32 |
| Jul   | 2334.61 | 2483  | -0.10                               | 0.81  |
| Aug   | 2346.79 | 2508  | 0.42                                | 1.83  |
| Sep   | 2366.7  | 2475  | 1.27                                | 0.49  |
| Oct   | 2374.62 | 2479  | 1.61                                | 0.65  |
| Nov   | 2382.97 | 2490  | 1.97                                | 1.10  |
| Dec   | 2374.88 | 2473  | 1.62                                | 0.41  |



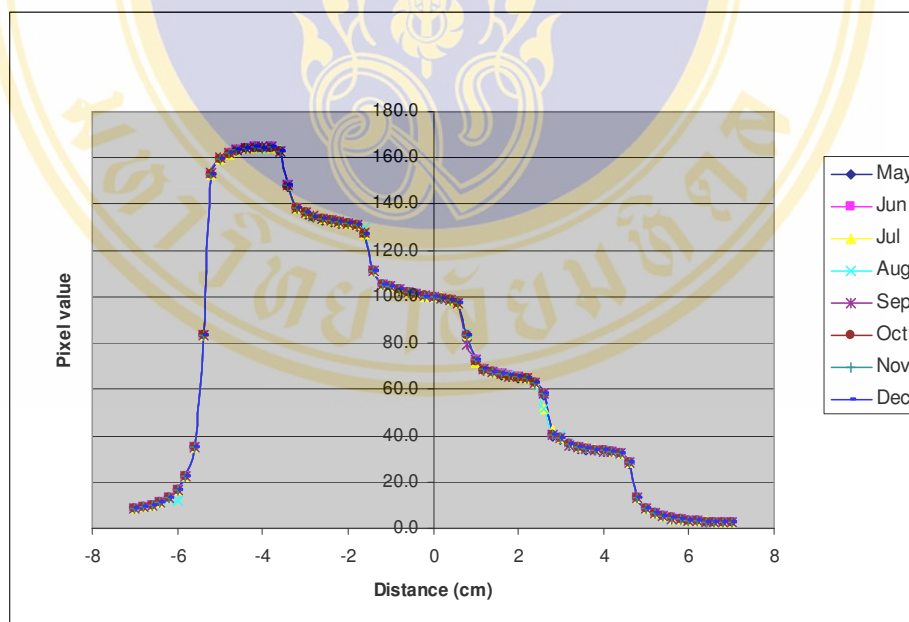
(a)



(b)



(c)



(d)

**Figure 34.** (a) and (b) The reproducibility of EPID detector for 6 MV, (c) and (d) for 10 MV.

## 5.2 Relative dosimetry

### 5.2.1 Open field

The EPID measurement was compared to ionization chamber and film measurement recorded at  $d_{\max}$ . The data in table 14 and 15 and figure 35 a and b show field profiles obtained at the central axis of  $10 \times 10 \text{ cm}^2$  and  $20 \times 20 \text{ cm}^2$  open field, respectively, for 6 MV. The differences are observed between EPID data and ionization chamber data of  $10 \times 10 \text{ cm}^2$  and  $20 \times 20 \text{ cm}^2$  field size, up to  $\pm 4\%$  inside the field boundaries but the outside the field boundaries can not compared. The field profile for 10 MV is shown in figure 35 c and d. For  $10 \times 10 \text{ cm}^2$  field size, the agreement between EPID and ionization chamber was up to  $\sim \pm 6\%$  inside the field boundaries but the outside the field boundaries can not compared. For  $20 \times 20 \text{ cm}^2$  field size, the agreement of EPID and ionization chamber measurements was up to  $\sim \pm 4\%$  inside the field boundaries but the outside the field boundaries can not compared. The differences of EPID data and ionization chamber data are probably due to the relatively higher signal response of the phosphor screen to the low energy scatter component of the radiation as compared to ionization chamber response. Compared to an air-filled ionization chamber, the higher average atomic number and density of the indirect detector ( $Z_{\text{eff}} \cong 60$  for  $\text{Gd}_2\text{O}_2\text{S: Tb}$ ) lead to a detector response which is more strongly dependent on the energy of the radiation interacting in the detector. In addition, the difference of condition to measurement between EPID and ionization chamber measurements are led to the difference of two data measurements. Which the ionization chamber measured in water phantom but the EPID measured in air and no build up on the detector.

**Table 14.** The comparison measurement data between EPID and ionization chamber measured data of 10x10 cm<sup>2</sup> field size for 6 MV photon.

| Distance(cm) | 100% Normalize at central axis |                        | % Difference |
|--------------|--------------------------------|------------------------|--------------|
|              | EPID                           | Ionization chamber(IC) |              |
| -7.0         | 4.73                           | 3.80                   | 24.45        |
| -6.8         | 5.28                           | 4.20                   | 25.76        |
| -6.6         | 5.46                           | 4.40                   | 24.06        |
| -6.4         | 6.21                           | 4.80                   | 29.37        |
| -6.2         | 6.56                           | 5.40                   | 21.55        |
| -6.0         | 7.54                           | 6.20                   | 21.55        |
| -5.8         | 8.20                           | 7.60                   | 7.88         |
| -5.6         | 9.48                           | 10.90                  | -13.02       |
| -5.4         | 11.18                          | 21.60                  | -48.23       |
| -5.2         | 39.36                          | 42.10                  | -6.51        |
| -5.1         | 87.76                          | 52.20                  | 68.12        |
| -5.0         | 93.28                          | 67.60                  | 37.99        |
| -4.8         | 96.91                          | 84.20                  | 15.09        |
| -4.6         | 97.33                          | 96.00                  | 1.38         |
| -4.4         | 98.17                          | 98.80                  | -0.64        |
| -4.2         | 98.50                          | 99.70                  | -1.21        |
| -4.0         | 98.85                          | 100.00                 | -1.15        |
| -3.8         | 98.81                          | 100.80                 | -1.98        |
| -3.6         | 99.23                          | 100.80                 | -1.56        |
| -3.4         | 99.27                          | 100.70                 | -1.42        |
| -3.2         | 99.65                          | 101.00                 | -1.34        |
| -3.0         | 99.73                          | 101.00                 | -1.25        |
| -2.8         | 100.11                         | 101.10                 | -0.98        |
| -2.6         | 100.22                         | 101.40                 | -1.16        |
| -2.4         | 100.38                         | 101.20                 | -0.81        |
| -2.2         | 100.55                         | 101.50                 | -0.93        |
| -2.0         | 100.62                         | 101.30                 | -0.67        |
| -1.8         | 100.60                         | 100.80                 | -0.20        |
| -1.6         | 100.66                         | 101.00                 | -0.33        |
| -1.4         | 100.66                         | 100.70                 | -0.04        |
| -1.2         | 100.51                         | 101.40                 | -0.88        |
| -1.0         | 100.49                         | 101.00                 | -0.51        |
| -0.8         | 100.35                         | 100.60                 | -0.24        |
| -0.6         | 100.42                         | 100.90                 | -0.48        |
| -0.4         | 100.40                         | 101.10                 | -0.69        |
| -0.2         | 100.20                         | 100.00                 | 0.20         |
| 0.0          | 100.00                         | 100.00                 | 0.00         |

**Table 14.** The comparison measurement data between EPID and ionization chamber measured data of 10x10 cm<sup>2</sup> field size for 6 MV photon (Continued).

| Distance(cm) | 100% Normalize at central axis |                        | % Difference |
|--------------|--------------------------------|------------------------|--------------|
|              | EPID                           | Ionization chamber(IC) |              |
| 0.2          | 100.02                         | 100.30                 | -0.28        |
| 0.4          | 100.00                         | 100.30                 | -0.30        |
| 0.6          | 99.98                          | 100.20                 | -0.22        |
| 0.8          | 100.00                         | 100.20                 | -0.20        |
| 1.0          | 100.11                         | 100.30                 | -0.19        |
| 1.2          | 100.11                         | 100.80                 | -0.68        |
| 1.4          | 100.04                         | 100.40                 | -0.35        |
| 1.6          | 99.93                          | 100.70                 | -0.76        |
| 1.8          | 100.07                         | 100.80                 | -0.73        |
| 2.0          | 99.85                          | 100.80                 | -0.95        |
| 2.2          | 99.71                          | 100.80                 | -1.08        |
| 2.4          | 99.56                          | 100.90                 | -1.33        |
| 2.6          | 99.43                          | 100.60                 | -1.17        |
| 2.8          | 99.16                          | 100.80                 | -1.63        |
| 3.0          | 99.03                          | 100.60                 | -1.56        |
| 3.2          | 98.48                          | 100.20                 | -1.72        |
| 3.4          | 98.28                          | 100.00                 | -1.72        |
| 3.6          | 98.03                          | 100.00                 | -1.97        |
| 3.8          | 97.92                          | 99.30                  | -1.39        |
| 4.0          | 97.28                          | 99.60                  | -2.33        |
| 4.2          | 97.06                          | 98.50                  | -1.46        |
| 4.4          | 96.22                          | 97.80                  | -1.61        |
| 4.6          | 97.22                          | 94.20                  | 3.20         |
| 4.8          | 81.57                          | 84.90                  | -3.92        |
| 5.0          | 28.49                          | 63.90                  | -55.42       |
| 5.1          | 15.85                          | 54.10                  | -70.71       |
| 5.2          | 10.63                          | 41.20                  | -74.20       |
| 5.4          | 9.19                           | 20.10                  | -54.26       |
| 5.6          | 7.91                           | 10.10                  | -21.67       |
| 5.8          | 7.07                           | 7.50                   | -5.71        |
| 6.0          | 6.36                           | 6.00                   | 6.08         |
| 6.2          | 5.94                           | 5.20                   | 14.32        |
| 6.4          | 5.30                           | 4.60                   | 15.30        |
| 6.6          | 4.99                           | 4.30                   | 16.15        |
| 6.8          | 4.46                           | 4.00                   | 11.60        |
| 7.0          | 4.46                           | 3.60                   | 24.00        |

**Table 15.** The comparison between EPID and ionization chamber measured data of 20x20 cm<sup>2</sup> field size for 6 MV photon.

| Distance(cm) | 100% Normalize at central axis |                        | % Difference |
|--------------|--------------------------------|------------------------|--------------|
|              | EPID                           | Ionization chamber(IC) |              |
| -14.0        | 4.75                           | 3.80                   | 25.73        |
| -13.0        | 6.05                           | 5.00                   | 21.69        |
| -12.0        | 8.02                           | 6.30                   | 28.02        |
| -11.0        | 8.95                           | 9.50                   | -5.22        |
| -10.8        | 9.54                           | 12.20                  | -21.34       |
| -10.6        | 11.10                          | 18.10                  | -38.29       |
| -10.4        | 12.60                          | 33.10                  | -61.69       |
| -10.2        | 14.67                          | 58.70                  | -74.85       |
| -10.0        | 92.71                          | 76.70                  | 21.60        |
| -9.5         | 97.73                          | 100.30                 | -1.98        |
| -9.0         | 99.33                          | 102.00                 | -2.03        |
| -8.5         | 100.39                         | 103.00                 | -1.95        |
| -8.0         | 100.89                         | 103.70                 | -2.12        |
| -7.5         | 101.18                         | 103.90                 | -2.04        |
| -7.0         | 101.40                         | 103.70                 | -1.63        |
| -6.5         | 101.73                         | 103.70                 | -1.32        |
| -6.0         | 101.87                         | 103.50                 | -0.99        |
| -5.5         | 102.23                         | 103.90                 | -1.01        |
| -5.0         | 102.39                         | 104.10                 | -1.05        |
| -4.5         | 101.89                         | 103.00                 | -0.49        |
| -4.0         | 101.36                         | 103.00                 | -1.00        |
| -3.5         | 100.87                         | 102.70                 | -1.19        |
| -3.0         | 100.95                         | 102.40                 | -0.82        |
| -2.5         | 100.87                         | 102.30                 | -0.80        |
| -2.0         | 101.04                         | 102.00                 | -0.35        |
| -1.5         | 100.91                         | 101.90                 | -0.37        |
| -1.0         | 100.55                         | 101.50                 | -0.34        |
| -0.5         | 100.43                         | 100.70                 | 0.33         |
| 0.0          | 100.00                         | 100.60                 | 0.00         |

**Table 15.** The comparison between EPID and ionization chamber measured data of 20x20 cm<sup>2</sup> field size for 6 MV photon (Continued).

| Distance(cm) | 100% Normalize at central axis |                        | % Difference |
|--------------|--------------------------------|------------------------|--------------|
|              | EPID                           | Ionization chamber(IC) |              |
| 0.5          | 100.10                         | 101.00                 | -0.29        |
| 1.0          | 100.10                         | 101.20                 | -0.49        |
| 1.5          | 100.18                         | 101.50                 | -0.71        |
| 2.0          | 100.32                         | 101.90                 | -0.96        |
| 2.5          | 100.24                         | 102.10                 | -1.23        |
| 3.0          | 100.26                         | 102.00                 | -1.11        |
| 3.5          | 100.41                         | 102.00                 | -0.97        |
| 4.0          | 100.93                         | 102.30                 | -0.74        |
| 4.5          | 101.32                         | 102.90                 | -0.95        |
| 5.0          | 101.46                         | 103.40                 | -1.29        |
| 5.5          | 100.97                         | 103.10                 | -1.47        |
| 6.0          | 100.71                         | 103.10                 | -1.73        |
| 6.5          | 100.63                         | 103.10                 | -1.81        |
| 7.0          | 100.45                         | 103.00                 | -1.89        |
| 7.5          | 99.96                          | 102.70                 | -2.08        |
| 8.0          | 99.74                          | 102.50                 | -2.11        |
| 8.5          | 99.09                          | 102.40                 | -2.66        |
| 9.0          | 97.93                          | 101.70                 | -3.13        |
| 9.5          | 95.70                          | 99.70                  | -3.44        |
| 10.0         | 62.80                          | 81.80                  | -22.77       |
| 10.2         | 13.48                          | 61.20                  | -77.85       |
| 10.4         | 11.53                          | 33.20                  | -65.07       |
| 10.6         | 10.31                          | 17.50                  | -40.73       |
| 10.8         | 9.13                           | 11.50                  | -20.10       |
| 11.0         | 8.52                           | 9.40                   | -8.77        |
| 12.0         | 7.55                           | 6.20                   | 22.51        |
| 13.0         | 5.74                           | 4.80                   | 20.38        |
| 14.0         | 4.63                           | 3.70                   | 25.82        |

**Table 16.** The comparison between EPID and ionization chamber measured data of 10x10 cm<sup>2</sup> field size for 10 MV photon.

| Distance(cm) | 100% Normalize at central axis |                        | % Difference |
|--------------|--------------------------------|------------------------|--------------|
|              | EPID                           | Ionization chamber(IC) |              |
| -7.0         | 5.67                           | 4.40                   | 28.93        |
| -6.8         | 6.30                           | 4.70                   | 27.14        |
| -6.6         | 6.58                           | 5.30                   | 18.88        |
| -6.4         | 6.95                           | 6.00                   | 15.86        |
| -6.2         | 7.58                           | 7.00                   | 8.28         |
| -6.0         | 8.30                           | 8.40                   | -1.19        |
| -5.8         | 9.32                           | 11.30                  | -20.99       |
| -5.6         | 10.32                          | 18.20                  | -43.28       |
| -5.4         | 21.60                          | 29.40                  | -48.83       |
| -5.2         | 61.52                          | 51.20                  | 20.16        |
| -5.1         | 90.10                          | 60.90                  | 33.28        |
| -5.0         | 93.05                          | 69.10                  | 34.66        |
| -4.8         | 96.16                          | 87.70                  | 8.78         |
| -4.6         | 97.07                          | 94.00                  | 2.90         |
| -4.4         | 97.72                          | 97.00                  | 0.74         |
| -4.2         | 98.30                          | 98.40                  | -0.24        |
| -4.0         | 98.77                          | 99.60                  | -0.98        |
| -3.8         | 99.21                          | 100.20                 | -1.34        |
| -3.6         | 99.21                          | 100.20                 | -0.99        |
| -3.4         | 99.35                          | 100.50                 | -1.15        |
| -3.2         | 99.67                          | 100.80                 | -1.21        |
| -3.0         | 99.84                          | 101.00                 | -1.27        |
| -2.8         | 100.05                         | 101.10                 | -1.16        |
| -2.6         | 100.09                         | 101.20                 | -1.02        |
| -2.4         | 100.26                         | 100.60                 | -0.34        |
| -2.2         | 100.26                         | 101.40                 | -1.04        |
| -2.0         | 100.33                         | 100.90                 | -0.64        |
| -1.8         | 100.42                         | 100.80                 | -0.38        |
| -1.6         | 100.47                         | 100.50                 | -0.03        |
| -1.4         | 100.37                         | 100.50                 | -0.13        |
| -1.2         | 100.21                         | 100.70                 | -0.28        |
| -1.0         | 100.44                         | 100.40                 | 0.04         |
| -0.8         | 100.26                         | 100.40                 | -0.12        |
| -0.6         | 100.44                         | 99.80                  | 0.64         |
| -0.4         | 100.19                         | 100.40                 | -0.17        |
| -0.2         | 100.19                         | 100.20                 | -0.01        |
| 0.0          | 100.00                         | 100.00                 | 0.00         |

**Table 16.** The comparison between EPID and ionization chamber measured data of 10x10 cm<sup>2</sup> field size for 10 MV photon (Continued).

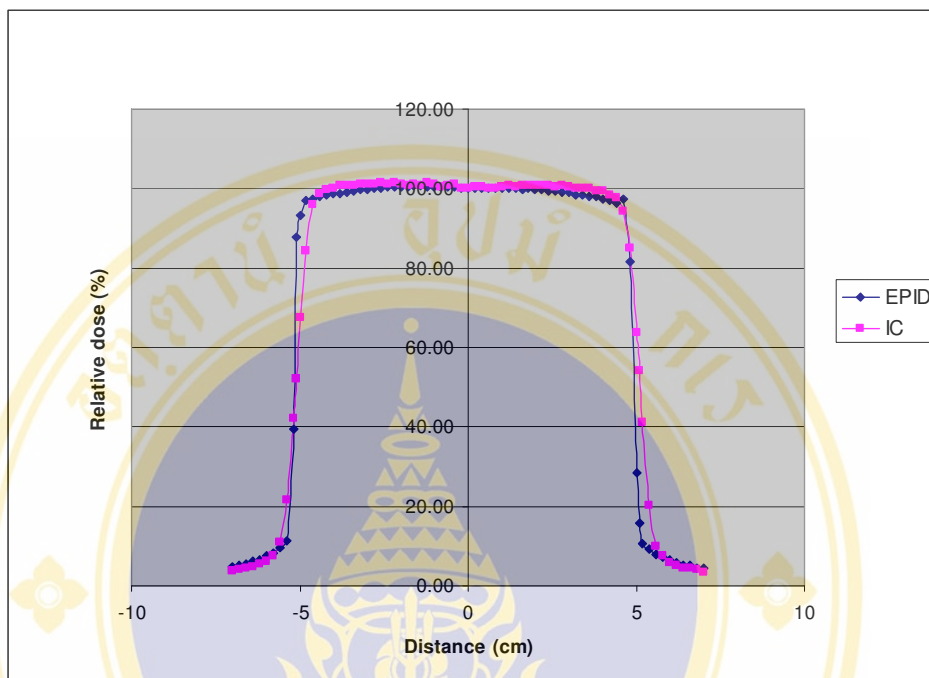
| Distance(cm) | 100% Normalize at central axis |                        | % Difference |
|--------------|--------------------------------|------------------------|--------------|
|              | EPID                           | Ionization chamber(IC) |              |
| 0.2          | 100.00                         | 100.50                 | -0.50        |
| 0.4          | 99.95                          | 100.20                 | -0.25        |
| 0.6          | 99.93                          | 99.70                  | 0.18         |
| 0.8          | 99.88                          | 100.60                 | -0.62        |
| 1.0          | 99.95                          | 100.30                 | -0.35        |
| 1.2          | 99.77                          | 100.00                 | -0.23        |
| 1.4          | 99.84                          | 100.10                 | -0.22        |
| 1.6          | 99.72                          | 100.80                 | -1.00        |
| 1.8          | 99.60                          | 100.70                 | -1.04        |
| 2.0          | 99.60                          | 100.20                 | -0.59        |
| 2.2          | 99.42                          | 100.60                 | -1.17        |
| 2.4          | 99.42                          | 99.80                  | -0.48        |
| 2.6          | 99.21                          | 100.20                 | -0.99        |
| 2.8          | 99.07                          | 100.50                 | -1.42        |
| 3.0          | 98.58                          | 100.50                 | -1.72        |
| 3.2          | 98.51                          | 100.30                 | -1.78        |
| 3.4          | 98.28                          | 99.80                  | -1.52        |
| 3.6          | 98.16                          | 99.70                  | -1.54        |
| 3.8          | 97.40                          | 99.40                  | -1.81        |
| 4.0          | 97.26                          | 98.60                  | -1.24        |
| 4.2          | 96.26                          | 98.40                  | -1.73        |
| 4.4          | 95.72                          | 96.00                  | -0.29        |
| 4.6          | 92.49                          | 92.40                  | 2.44         |
| 4.8          | 79.66                          | 84.50                  | 5.30         |
| 5.0          | 20.86                          | 67.30                  | -10.38       |
| 5.1          | 14.69                          | 55.50                  | -34.44       |
| 5.2          | 12.32                          | 49.90                  | -58.21       |
| 5.4          | 10.25                          | 26.60                  | -49.30       |
| 5.6          | 8.51                           | 15.80                  | -29.81       |
| 5.8          | 7.95                           | 10.70                  | -14.17       |
| 6.0          | 7.25                           | 7.80                   | 4.92         |
| 6.2          | 6.84                           | 6.60                   | 12.73        |
| 6.4          | 6.14                           | 5.80                   | 17.86        |
| 6.6          | 5.81                           | 5.20                   | 20.72        |
| 6.8          | 5.30                           | 4.60                   | 26.36        |
| 7.0          | 5.30                           | 4.20                   | 31.75        |

**Table 17.** The comparison measurement data between EPID and ionization chamber measured data of 20x20 cm<sup>2</sup> field size for 10 MV photon.

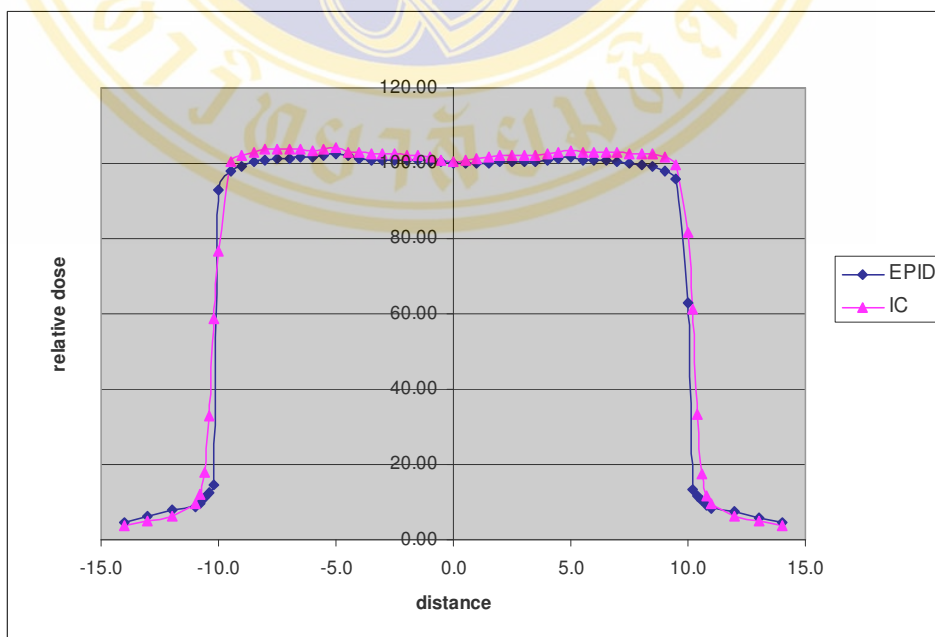
| Distance(cm) | 100% Normalize at central axis |                        | % Difference |
|--------------|--------------------------------|------------------------|--------------|
|              | EPID                           | Ionization chamber(IC) |              |
| -14.0        | 5.38                           | 3.90                   | 75.67        |
| -13.0        | 6.91                           | 5.20                   | 77.99        |
| -12.0        | 9.13                           | 7.10                   | 72.91        |
| -11.0        | 10.06                          | 13.60                  | -1.60        |
| -10.8        | 10.70                          | 18.70                  | -16.37       |
| -10.6        | 12.28                          | 31.60                  | -2.10        |
| -10.4        | 15.64                          | 47.90                  | 53.87        |
| -10.2        | 17.34                          | 68.00                  | 28.32        |
| -10.0        | 92.04                          | 85.70                  | 9.41         |
| -9.5         | 96.66                          | 98.60                  | -1.64        |
| -9.0         | 98.47                          | 101.10                 | -2.60        |
| -8.5         | 99.45                          | 101.60                 | -2.12        |
| -8.0         | 99.79                          | 102.00                 | -2.04        |
| -7.5         | 100.36                         | 102.70                 | -2.32        |
| -7.0         | 100.55                         | 102.60                 | -2.08        |
| -6.5         | 100.83                         | 102.60                 | -1.73        |
| -6.0         | 100.87                         | 103.00                 | -2.07        |
| -5.5         | 101.17                         | 103.00                 | -1.78        |
| -5.0         | 101.15                         | 102.40                 | -1.22        |
| -4.5         | 101.21                         | 102.60                 | -1.44        |
| -4.0         | 101.09                         | 102.20                 | -0.92        |
| -3.5         | 100.85                         | 101.90                 | -0.72        |
| -3.0         | 100.89                         | 101.80                 | -0.93        |
| -2.5         | 100.85                         | 101.60                 | -0.76        |
| -2.0         | 100.60                         | 101.40                 | -0.65        |
| -1.5         | 100.60                         | 101.30                 | -0.63        |
| -1.0         | 100.45                         | 100.30                 | 0.15         |
| -0.5         | 100.17                         | 100.20                 | 0.16         |
| 0.0          | 100.00                         | 100.00                 | 0.00         |

**Table 17.** The comparison measurement data between EPID and ionization chamber measured data of 20x20 cm<sup>2</sup> field size for 10 MV photon (Continued).

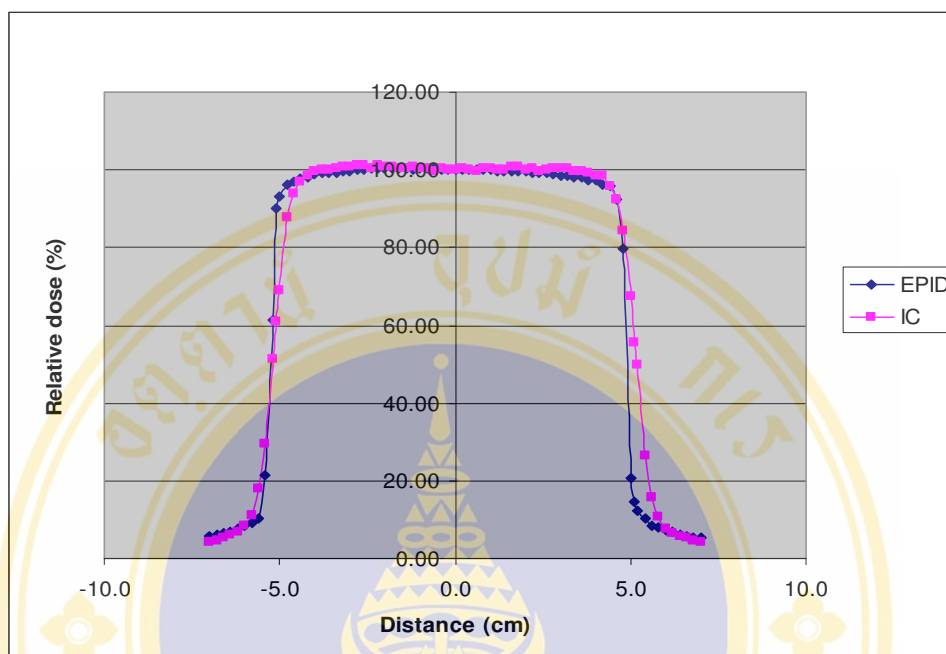
| Distance(cm) | 100% Normalize at central axis |                        | % Difference |
|--------------|--------------------------------|------------------------|--------------|
|              | EPID                           | Ionization chamber(IC) |              |
| 0.5          | 99.98                          | 100.10                 | -0.12        |
| 1.0          | 100.21                         | 100.40                 | -0.33        |
| 1.5          | 100.13                         | 100.50                 | -0.37        |
| 2.0          | 100.21                         | 101.30                 | -1.12        |
| 2.5          | 100.32                         | 101.40                 | -1.15        |
| 3.0          | 100.17                         | 101.80                 | -1.48        |
| 3.5          | 100.38                         | 101.70                 | -1.30        |
| 4.0          | 100.40                         | 102.20                 | -1.90        |
| 4.5          | 100.45                         | 102.40                 | -1.91        |
| 5.0          | 100.49                         | 102.70                 | -2.21        |
| 5.5          | 100.34                         | 102.80                 | -2.33        |
| 6.0          | 100.13                         | 102.80                 | -2.50        |
| 6.5          | 99.74                          | 102.90                 | -2.94        |
| 7.0          | 99.51                          | 103.30                 | -3.65        |
| 7.5          | 98.96                          | 102.10                 | -2.81        |
| 8.0          | 98.83                          | 102.10                 | -3.16        |
| 8.5          | 98.13                          | 101.80                 | -3.54        |
| 9.0          | 97.04                          | 100.80                 | -3.94        |
| 9.5          | 94.74                          | 97.90                  | -2.66        |
| 10.0         | 61.53                          | 85.70                  | 3.97         |
| 10.2         | 14.89                          | 70.80                  | -13.09       |
| 10.4         | 12.96                          | 45.80                  | -15.36       |
| 10.6         | 11.09                          | 28.20                  | -34.74       |
| 10.8         | 10.21                          | 17.20                  | -13.41       |
| 11.0         | 9.62                           | 12.50                  | 7.57         |
| 12.0         | 8.55                           | 6.80                   | 67.40        |
| 13.0         | 6.49                           | 4.90                   | 77.59        |
| 14.0         | 5.23                           | 3.70                   | 82.86        |



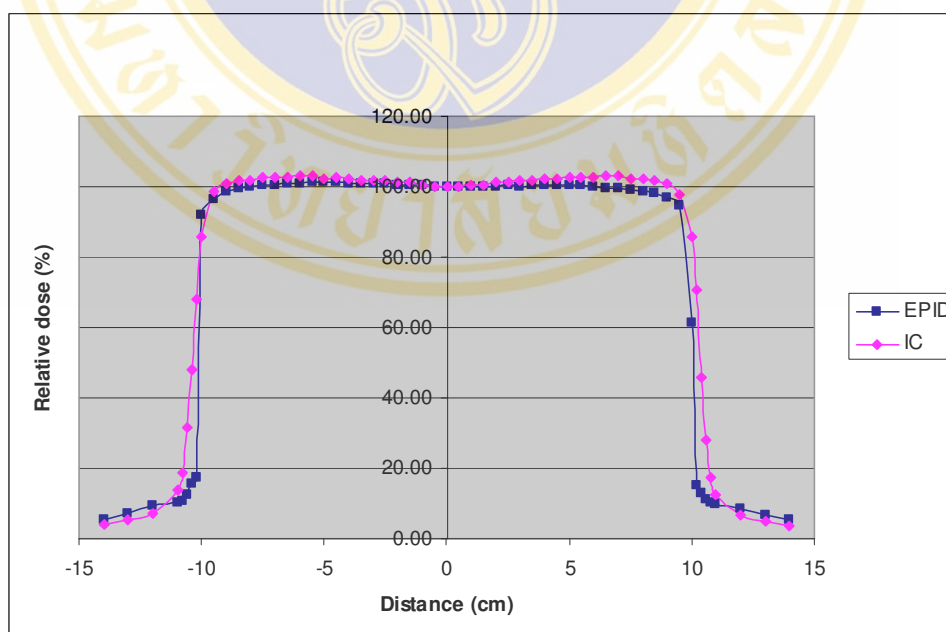
(a)



(b)



(c)



(d)

**Figure 35.** (a) and (b) Comparison of line profile between EPID, film and ionization chamber measurements for 6 MV, (c) and (d) for 10 MV.

### 5.2.2 Wedge field

The EPID measurements were compared to the ionization chamber measurement at  $d_{\max}$  for 6 MV and 10 MV. The profiles of  $45^\circ$  and  $60^\circ$  wedged static field for 6 MV as shown in table 18 and 19 and figure 36 a and b. The agreement between EPID and ionization chamber measurement was within 7% and 8% for  $45^\circ$  and  $60^\circ$  wedges, respectively. The profiles of 10 MV are shown in table 20 and 21 and figure 36 c and d. The agreement between EPID and ionization chamber measurements of  $45^\circ$  and  $60^\circ$  wedges were within 7.5% and 10%, respectively. The large error of this study was found, it is probably due to the same reason with the open field measurement.

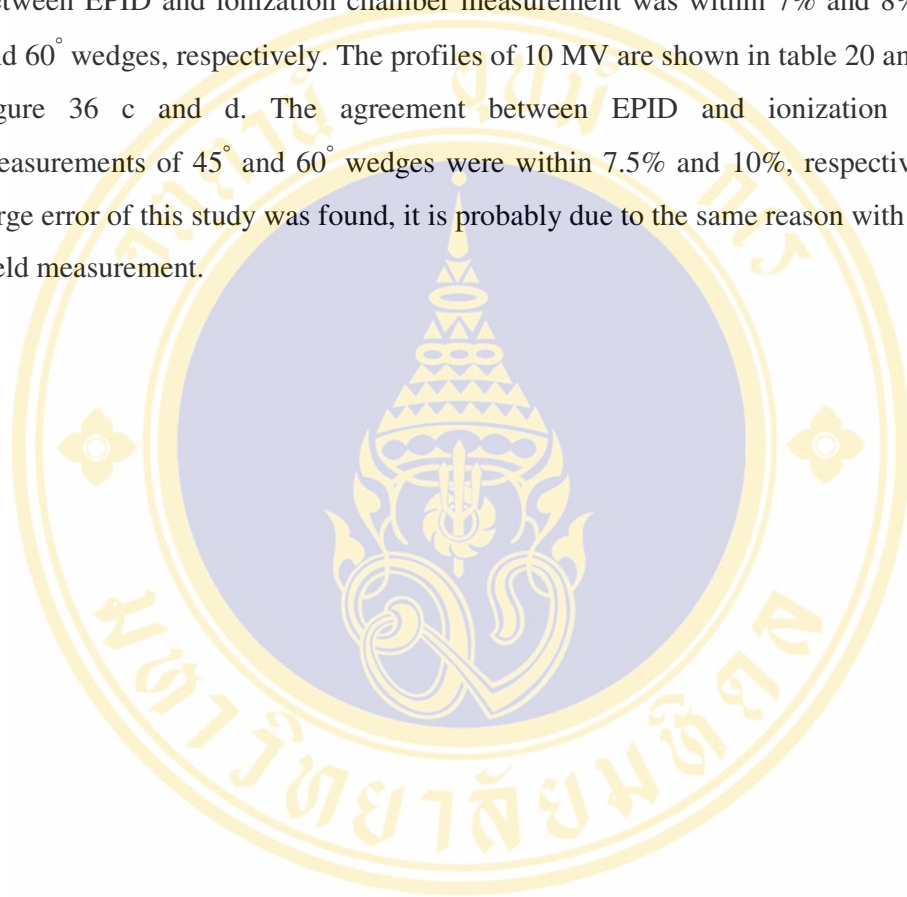


**Table18.** Comparison measurement data between EPID and ionization chamber of 45° wedge with 20x20 cm<sup>2</sup> field size for 6 MV photon.

| Distance(cm) | % Normalize |                    | % Difference |
|--------------|-------------|--------------------|--------------|
|              | EPID        | Ionization chamber |              |
| -12.00       | 12.23       | 11.54              | 5.92         |
| -11.50       | 13.83       | 12.94              | 6.94         |
| -11.00       | 15.73       | 16.02              | -1.79        |
| -10.50       | 23.09       | 42.69              | -45.91       |
| -10.00       | 154.51      | 119.60             | 29.18        |
| -9.75        | 155.58      | 150.95             | 3.07         |
| -9.50        | 153.43      | 154.43             | -0.64        |
| -9.00        | 150.90      | 153.63             | -1.78        |
| -8.50        | 146.47      | 150.95             | -2.97        |
| -8.00        | 144.13      | 146.47             | -1.60        |
| -7.50        | 139.41      | 143.08             | -2.57        |
| -7.00        | 136.39      | 139.60             | -2.30        |
| -6.50        | 132.49      | 135.82             | -2.45        |
| -6.00        | 130.15      | 132.44             | -1.73        |
| -5.50        | 127.28      | 129.45             | -1.68        |
| -5.00        | 124.01      | 125.17             | -0.93        |
| -4.50        | 121.04      | 122.49             | -1.18        |
| -4.00        | 117.92      | 119.70             | -1.48        |
| -3.50        | 115.68      | 116.52             | -0.71        |
| -3.00        | 112.66      | 113.93             | -1.11        |
| -2.50        | 110.72      | 111.14             | -0.39        |
| -2.00        | 108.96      | 109.05             | -0.08        |
| -1.50        | 106.87      | 107.16             | -0.28        |
| -1.00        | 104.24      | 104.48             | -0.23        |
| -0.50        | 102.24      | 101.49             | 0.74         |
| 0.00         | 100.00      | 100.00             | 0.00         |

**Table18.** Comparison measurement data between EPID and ionization chamber of 45° wedge with 20x20 cm<sup>2</sup> field size for 6 MV photon (Continued).

| Distance(cm) | % Normalize |                    | % Difference |
|--------------|-------------|--------------------|--------------|
|              | EPID        | Ionization chamber |              |
| 0.50         | 97.47       | 97.31              | 0.16         |
| 1.00         | 95.71       | 95.72              | -0.01        |
| 1.50         | 93.23       | 94.73              | -1.58        |
| 2.00         | 91.23       | 92.54              | -1.41        |
| 2.50         | 88.75       | 90.95              | -2.42        |
| 3.00         | 86.85       | 89.25              | -2.69        |
| 3.50         | 84.51       | 87.26              | -3.16        |
| 4.00         | 83.58       | 85.47              | -2.21        |
| 4.50         | 81.44       | 84.48              | -3.59        |
| 5.00         | 79.59       | 82.49              | -3.51        |
| 5.50         | 76.62       | 80.70              | -5.05        |
| 6.00         | 75.16       | 79.10              | -4.99        |
| 6.50         | 73.26       | 77.91              | -5.97        |
| 7.00         | 70.87       | 75.82              | -6.53        |
| 7.50         | 68.97       | 74.03              | -6.83        |
| 8.00         | 66.88       | 72.04              | -7.17        |
| 8.50         | 64.98       | 70.55              | -7.89        |
| 9.00         | 62.35       | 68.66              | -9.19        |
| 9.50         | 60.20       | 64.68              | -6.91        |
| 9.75         | 58.99       | 62.29              | -5.30        |
| 10.00        | 38.19       | 52.94              | -27.86       |
| 10.50        | 9.69        | 19.60              | -50.55       |
| 11.00        | 8.48        | 9.55               | -11.27       |
| 11.50        | 7.99        | 8.26               | -3.27        |
| 12.00        | 7.70        | 7.96               | -3.32        |

**Table 19.** Comparison measurement data between EPID and ionization chamber of 45° wedge with 20x20 cm<sup>2</sup> field size for 10 MV photon.

| Distance(cm) | % Normalize |                    | % Difference |
|--------------|-------------|--------------------|--------------|
|              | EPID        | Ionization chamber |              |
| -12.00       | 11.56       | 12.14              | 6.75         |
| -11.50       | 13.93       | 14.63              | -0.37        |
| -11.00       | 19.91       | 20.90              | -21.28       |
| -10.50       | 55.73       | 58.51              | -50.41       |
| -10.00       | 122.84      | 128.96             | 11.89        |
| -9.75        | 136.02      | 142.79             | 2.36         |
| -9.50        | 139.15      | 146.07             | -0.77        |
| -9.00        | 139.72      | 146.67             | -2.64        |
| -8.50        | 136.97      | 143.78             | -2.65        |
| -8.00        | 134.88      | 141.59             | -2.87        |
| -7.50        | 131.94      | 138.51             | -2.60        |
| -7.00        | 129.67      | 136.12             | -3.49        |
| -6.50        | 126.64      | 132.94             | -3.15        |
| -6.00        | 122.84      | 128.96             | -2.36        |
| -5.50        | 119.91      | 125.87             | -1.87        |
| -5.00        | 116.87      | 122.69             | -1.78        |
| -4.50        | 114.69      | 120.40             | -2.01        |
| -4.00        | 112.04      | 117.61             | -0.84        |
| -3.50        | 109.48      | 114.93             | -0.88        |
| -3.00        | 107.20      | 112.54             | -0.63        |
| -2.50        | 104.64      | 109.85             | -0.23        |
| -2.00        | 102.56      | 107.66             | 0.06         |
| -1.50        | 100.57      | 105.57             | 0.47         |
| -1.00        | 98.86       | 103.78             | 0.06         |
| -0.50        | 97.16       | 101.99             | 0.36         |
| 0.00         | 95.26       | 100.00             | 0.00         |

**Table19.** Comparison measurement data between EPID and ionization chamber of 45° wedge with 20x20 cm<sup>2</sup> field size for 10 MV photon (Continued).

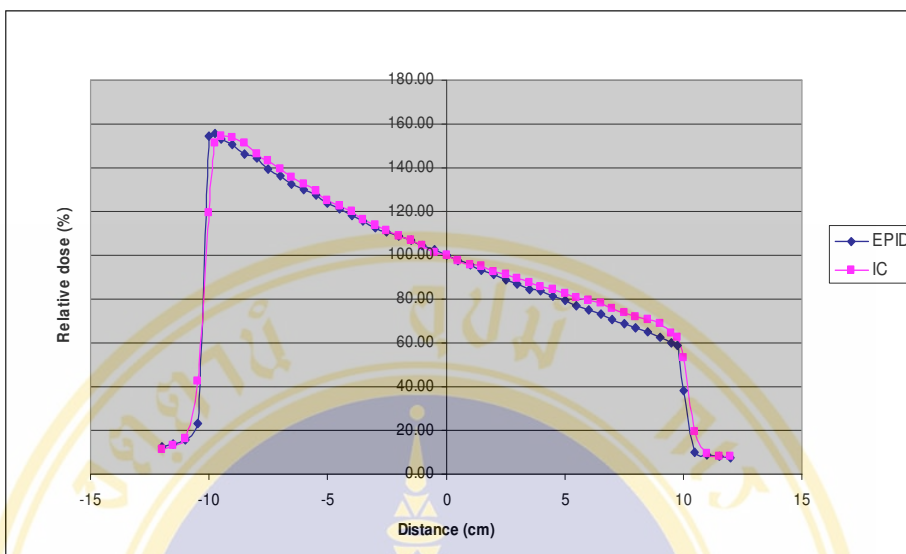
| Distance(cm) | % Normalize |                    | % Difference |
|--------------|-------------|--------------------|--------------|
|              | EPID        | Ionization chamber |              |
| 0.50         | 97.69       | 97.31              | 0.38         |
| 1.00         | 96.03       | 96.52              | -0.51        |
| 1.50         | 93.89       | 94.73              | -0.88        |
| 2.00         | 92.32       | 92.94              | -0.66        |
| 2.50         | 90.10       | 92.14              | -2.22        |
| 3.00         | 88.39       | 90.15              | -1.95        |
| 3.50         | 86.69       | 88.76              | -2.32        |
| 4.00         | 84.95       | 86.77              | -2.10        |
| 4.50         | 83.20       | 85.47              | -2.66        |
| 5.00         | 81.06       | 84.18              | -3.70        |
| 5.50         | 79.28       | 82.79              | -4.24        |
| 6.00         | 77.92       | 80.80              | -3.56        |
| 6.50         | 75.61       | 78.81              | -4.05        |
| 7.00         | 73.82       | 77.51              | -4.76        |
| 7.50         | 71.64       | 75.52              | -5.14        |
| 8.00         | 70.24       | 74.33              | -5.49        |
| 8.50         | 67.80       | 72.44              | -6.40        |
| 9.00         | 65.53       | 70.45              | -6.98        |
| 9.50         | 63.53       | 66.17              | -4.00        |
| 9.75         | 61.26       | 63.28              | -3.20        |
| 10.00        | 40.62       | 56.72              | -28.38       |
| 10.50        | 11.13       | 25.97              | -57.16       |
| 11.00        | 9.51        | 11.64              | -18.30       |
| 11.50        | 8.99        | 8.96               | 0.36         |
| 12.00        | 8.68        | 8.16               | 6.41         |

**Table 20.** Comparison measurement data between EPID and ionization chamber of 60° wedge with 15x15 cm<sup>2</sup> field size for 6 MV photon.

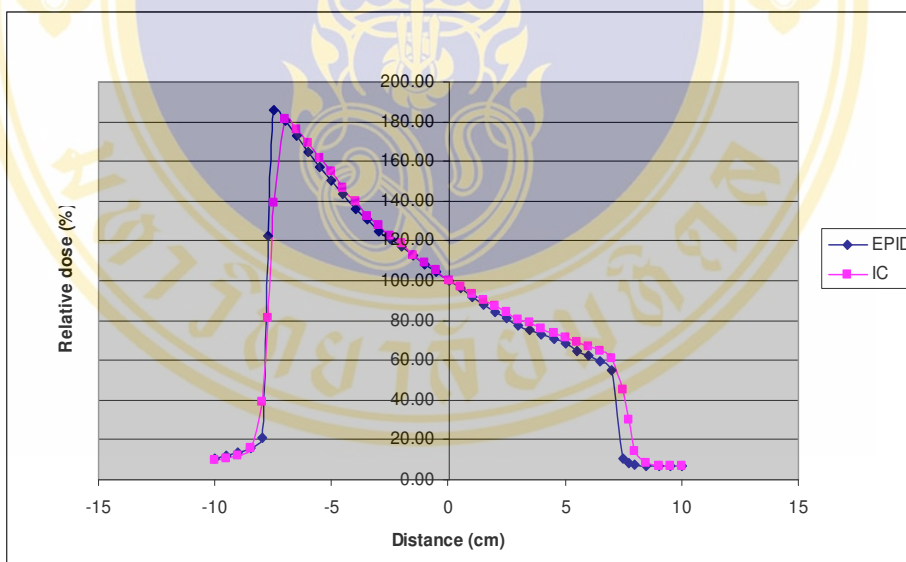
| Distance(cm) | % Normalize |                    | % Difference |
|--------------|-------------|--------------------|--------------|
|              | EPID        | Ionization chamber |              |
| -9.00        | 13.72       | 39.10              | -64.9        |
| -8.50        | 15.81       | 42.90              | -63.2        |
| -8.00        | 24.20       | 58.60              | -58.7        |
| -7.75        | 127.72      | 88.70              | 44.0         |
| -7.50        | 172.61      | 127.20             | 35.7         |
| -7.00        | 168.99      | 170.10             | -0.7         |
| -6.50        | 162.73      | 166.30             | -2.1         |
| -6.00        | 156.48      | 161.20             | -2.9         |
| -5.50        | 150.77      | 153.30             | -1.7         |
| -5.00        | 143.52      | 146.20             | -1.8         |
| -4.50        | 137.32      | 138.60             | -0.9         |
| -4.00        | 133.26      | 134.80             | -1.1         |
| -3.50        | 127.44      | 127.50             | 0.0          |
| -3.00        | 122.83      | 122.90             | -0.1         |
| -2.50        | 119.05      | 118.30             | 0.6          |
| -2.00        | 115.37      | 114.80             | 0.5          |
| -1.50        | 111.36      | 109.30             | 1.9          |
| -1.00        | 107.24      | 106.90             | 0.3          |
| -0.50        | 103.18      | 102.80             | 0.4          |
| 0.00         | 100.00      | 100.10             | -0.1         |
| 0.50         | 96.16       | 97.70              | -1.6         |
| 1.00         | 92.65       | 93.30              | -0.7         |
| 1.50         | 89.13       | 92.20              | -3.3         |
| 2.00         | 85.73       | 88.40              | -3.0         |
| 2.50         | 82.55       | 87.40              | -5.6         |
| 3.00         | 79.25       | 85.70              | -7.5         |
| 3.50         | 76.67       | 83.30              | -8.0         |
| 4.00         | 75.14       | 81.40              | -7.7         |
| 4.50         | 72.34       | 78.40              | -7.7         |
| 5.00         | 69.87       | 75.70              | -7.7         |
| 5.50         | 66.79       | 74.10              | -9.9         |
| 6.00         | 65.15       | 71.40              | -8.8         |
| 6.50         | 61.03       | 69.20              | -11.8        |
| 7.00         | 57.41       | 64.30              | -10.7        |
| 7.50         | 12.62       | 49.40              | -74.4        |
| 7.75         | 9.44        | 37.70              | -75.0        |
| 8.00         | 8.51        | 30.70              | -72.3        |
| 8.50         | 7.79        | 28.20              | -72.4        |
| 9.00         | 7.35        | 27.10              | -72.9        |

**Table 21.** Comparison measurement data between EPID and ionization chamber of 60° wedge with 15x15 cm<sup>2</sup> field size for 10 MV photon.

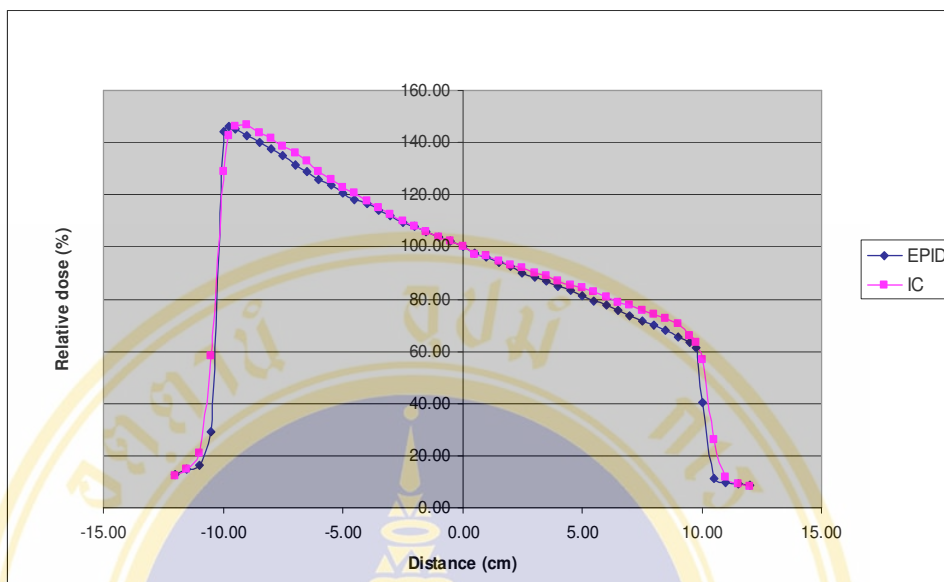
| Distance(cm) | % Normalize |                    | % Difference |
|--------------|-------------|--------------------|--------------|
|              | EPID        | Ionization chamber |              |
| -9.00        | 13.47       | 12.36              | 8.98         |
| -8.50        | 15.45       | 15.65              | -1.29        |
| -8.00        | 21.20       | 38.88              | -45.48       |
| -7.75        | 122.37      | 80.86              | 51.34        |
| -7.50        | 185.91      | 138.98             | 33.76        |
| -7.00        | 180.22      | 180.56             | -0.19        |
| -6.50        | 172.56      | 175.07             | -1.44        |
| -6.00        | 164.65      | 168.39             | -2.23        |
| -5.50        | 157.29      | 161.02             | -2.31        |
| -5.00        | 150.62      | 154.44             | -2.47        |
| -4.50        | 143.33      | 145.96             | -1.81        |
| -4.00        | 136.34      | 139.38             | -2.18        |
| -3.50        | 130.84      | 131.61             | -0.58        |
| -3.00        | 124.66      | 127.62             | -2.32        |
| -2.50        | 120.89      | 122.43             | -1.26        |
| -2.00        | 117.12      | 118.34             | -1.04        |
| -1.50        | 112.61      | 112.56             | 0.04         |
| -1.00        | 107.97      | 108.77             | -0.74        |
| -0.50        | 104.20      | 104.89             | -0.65        |
| 0.00         | 100.00      | 100.00             | 0.00         |
| 0.50         | 95.92       | 96.81              | -0.92        |
| 1.00         | 91.47       | 92.92              | -1.56        |
| 1.50         | 87.76       | 89.93              | -2.41        |
| 2.00         | 83.99       | 87.24              | -3.72        |
| 2.50         | 81.03       | 84.25              | -3.82        |
| 3.00         | 77.69       | 80.56              | -3.56        |
| 3.50         | 75.22       | 78.36              | -4.02        |
| 4.00         | 73.11       | 75.67              | -3.38        |
| 4.50         | 70.77       | 73.38              | -3.56        |
| 5.00         | 68.05       | 71.09              | -4.28        |
| 5.50         | 64.96       | 69.19              | -6.12        |
| 6.00         | 62.42       | 66.60              | -6.27        |
| 6.50         | 59.02       | 64.31              | -8.22        |
| 7.00         | 55.19       | 60.82              | -9.25        |
| 7.50         | 10.44       | 44.67              | -76.62       |
| 7.75         | 8.16        | 30.21              | -72.99       |
| 8.00         | 7.54        | 14.06              | -46.36       |
| 8.50         | 6.86        | 7.98               | -13.99       |
| 9.00         | 6.49        | 6.78               | -4.28        |



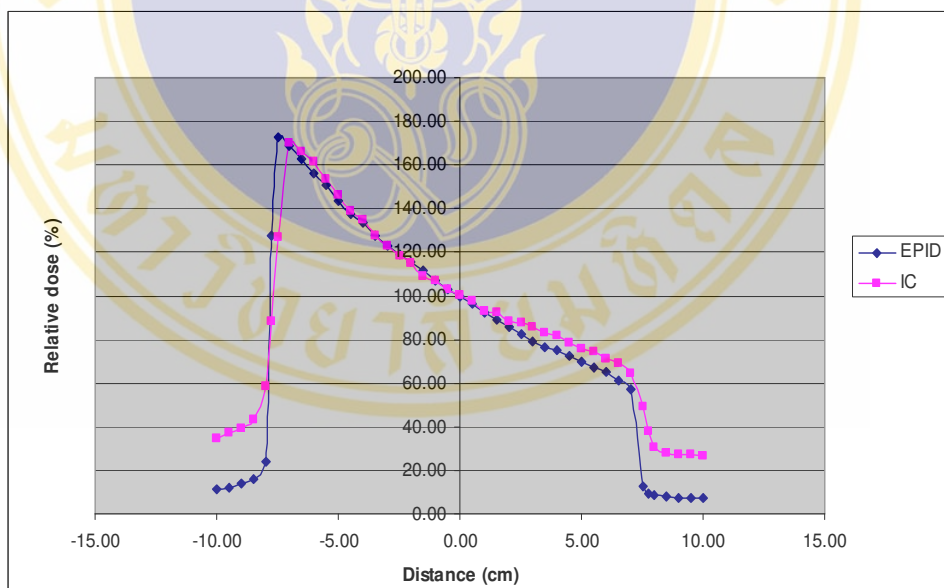
(a)



(b)



(c)



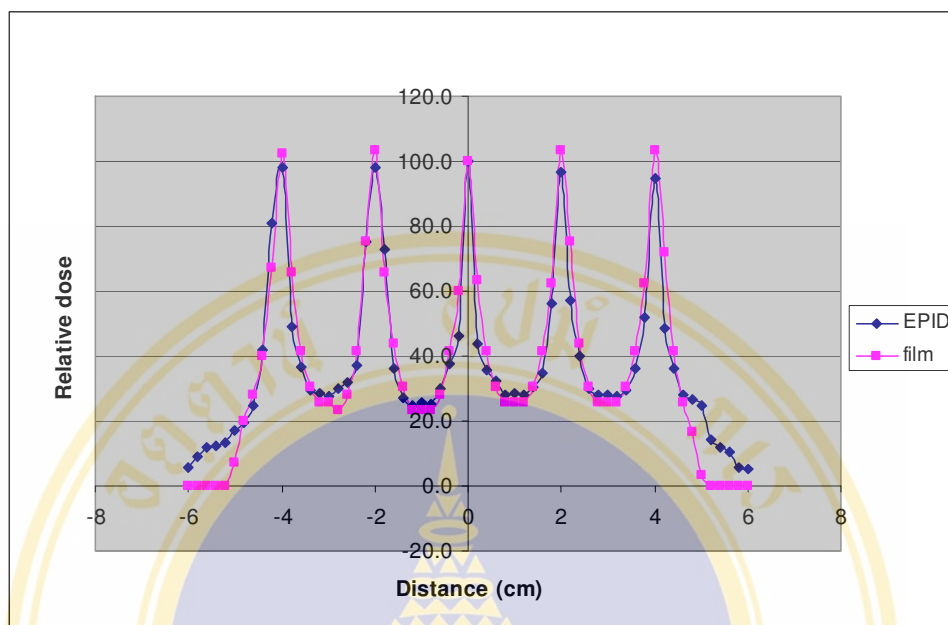
(d)

**Figure 36.** (a) and (b) Comparison line profile between EPID and ionization chamber measurements for 6 MV, (c) and (d) for 10 MV.

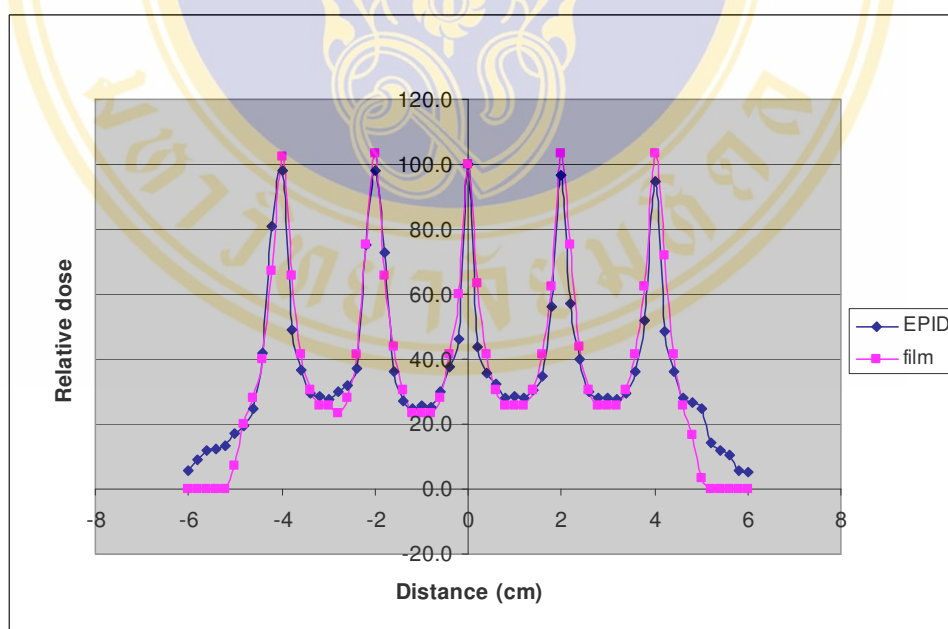
### 5.2.3 IMRT bar pattern test

The EPID measurements were compared to the film measurements at depth 3 cm, and both data were normalized to the central axis. The comparison of line profiles between EPID and film measurement for 6 MV and 10 MV as shown in figure 37 a and b, respectively. The line profile of EPID and film was similarly but the difference percentage can not be compared. This agreement is promising considering the EPID signal in this study is essentially the raw response of the system. Further work is required to improve this for quantitative verification of IMRT.





(a)

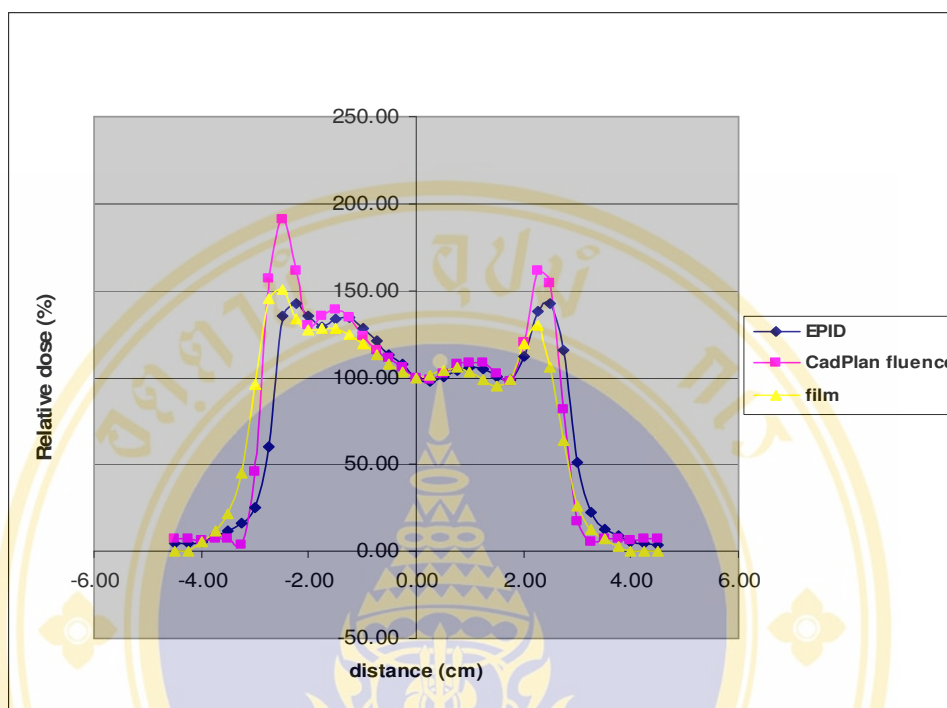


(b)

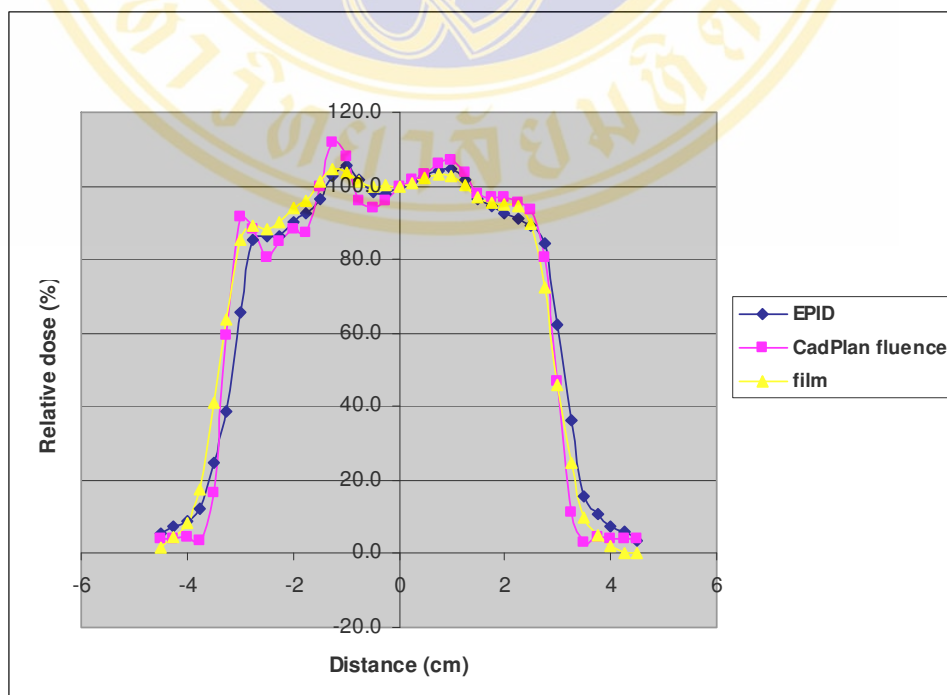
**Figure 37.** (a) and (b) Comparison between line profile of EPID and ionization chamber measurements for 6 MV and 10 MV, respectively.

#### 5.2.4 Clinical fluence of IMRT field

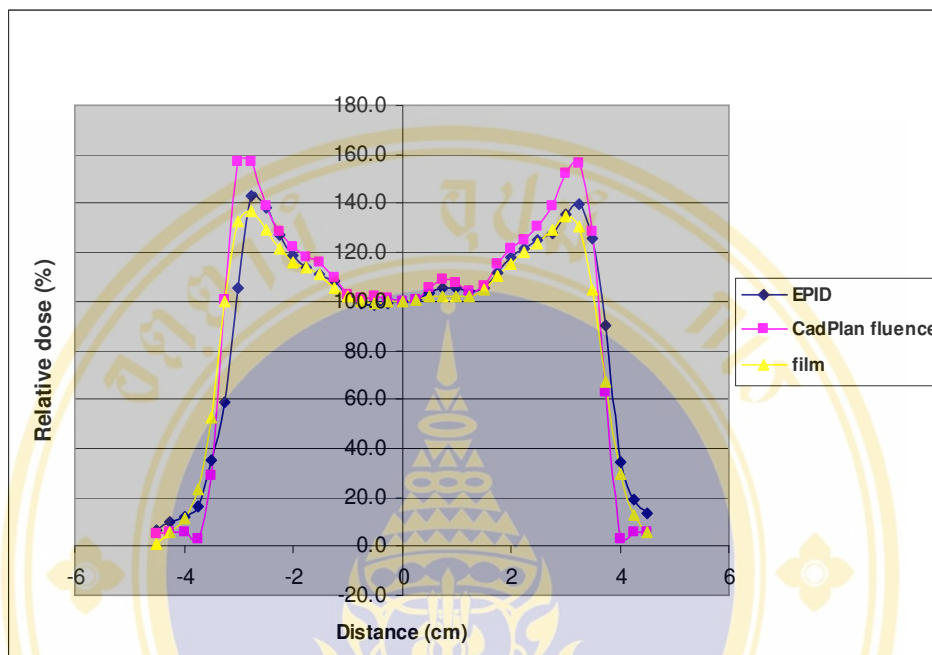
The line profiles of EPID measurement of 6 prostate IMRT fields were compared to the CadPlan fluence file utilized by the CadPlan RTPS and the film measurements as shown in figure 38 a, b, c, d, e, f and g. The agreement is reasonable considering that the EPID is compared with the raw fluence map, with no explicit calculation of the PDI at the EPID plane. The differences between actual fluence profile and EPID profile was very high especially the peak dose area. But the EPID profile and the film profile was similar. The large differences are probably due to that the mode of operation for the EPID is multiple image acquisition. This acquisition mode is not applicable to dosimetry of dynamic IMRT where leaf speeds of up to 3  $\text{cm s}^{-1}$ . The second, the EPID data was measured in air and without optimal build up material but the CadPlan fluence and film data are absorbed dose. The different condition for measurements gave the inaccurate results. From our experiment, we found that the EPID is possible to used in IMRT field verification and further work is required to improve this for IMRT verification.



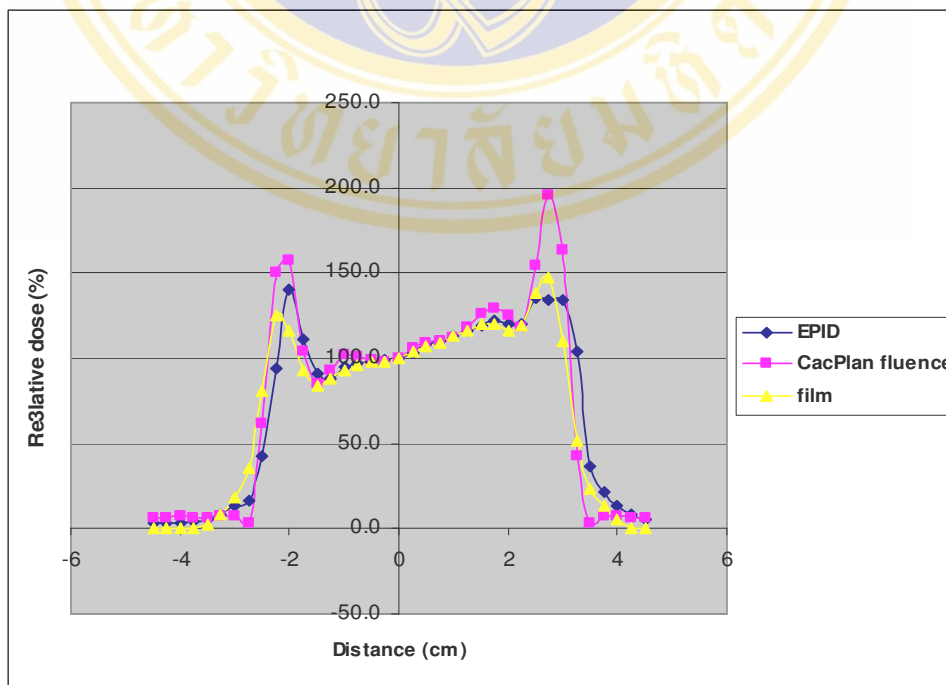
(a)



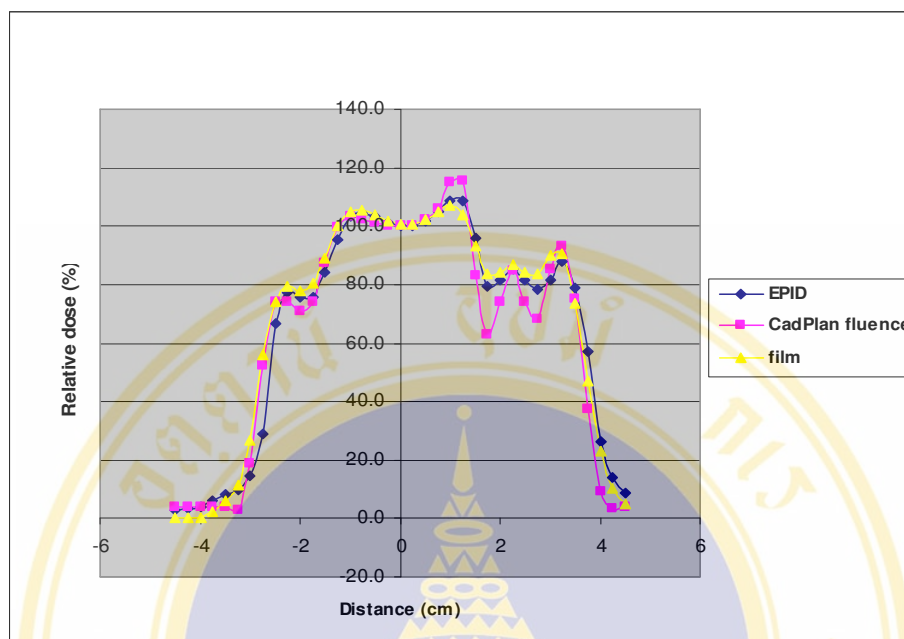
(b)



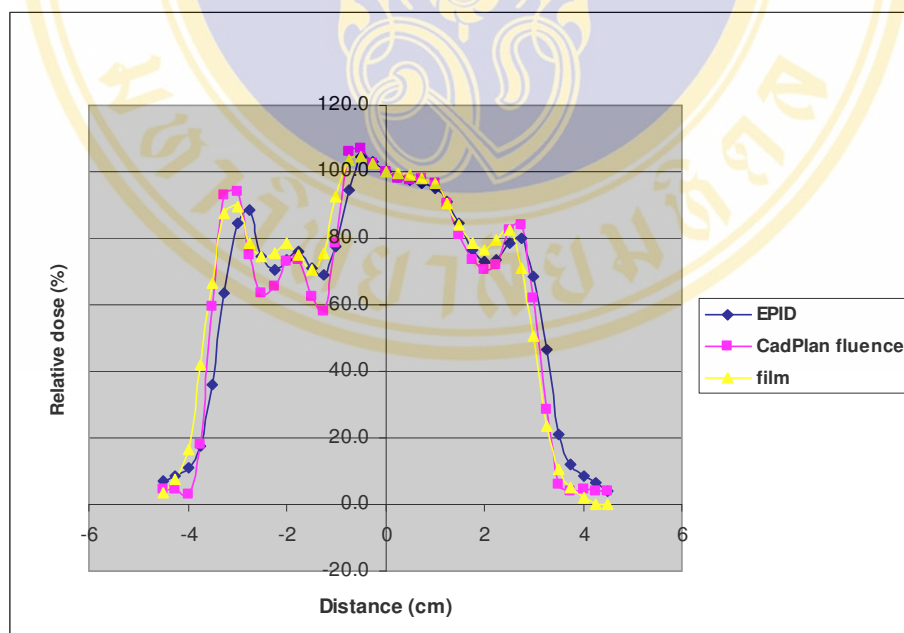
(c)



(d)



(e)



(f)

**Figure 38.** Comparison of the line profile between EPID, actual fluence from CadPlan and film measurements of 6 prostate IMRT fields.

## CHAPTER VI

### CONCLUSION

The dosimetric characterization of an amorphous silicon EPID at Siriraj Hospital for IMRT fields verification was investigated. The EPID has linear with dose and dose rate response. The EPID can record the rapid dose-rate changes that occur with leaf speeds during IMRT delivery. The memory effect is not significant in this suitable time interval between image acquisition. The signal from EPID is highly reproducible for IMRT verification. The energy response is not limitation for EPID dosimetry. Limitation of the EPID systems were identified including a field size dependent response, the effect of beam hold-offs during the delivery is limited the accuracy of the EPID for dosimetry, and errors due to a dead time in frame acquisition. The amorphous silicon EPID was found to be suitable for measuring relative transmission curve as well as beam profiles for both open and wedge static fields. With several dosimetric characteristic of an amorphous silicon EPID that we assessed and the results were explained above. We believe that this technology can be practically implemented an amorphous silicon EPID for pre-treatment QA.

For pre-treatment verification of IMRT fields, the EPID shows the possible for the delivery fluence verification. Therefore, to minimized the workload for QA of IMRT fields, this device can replaced the current method which used the radiographic film. Furthermore, the addition of the continuous-frame averaging acquisition mode, the dosimetric workspace and the calibration procedure and the improvement of PDI software were necessary not only for actual fluence line profile but also for the dose distribution of fluence map to provide accurate portal dose measurement for pre-treatment QA of IMRT fields.

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