Diode Dosimetric Characteristics Assessment for In-Vivo Dosimetry in Radiotherapy Treatment

R Marzuki¹, A A Rahman¹, I S Mustafa¹ and A N Shabandi²

¹School of Physics, Universiti Sains Malaysia Main Campus, 11800 Minden, Penang, Malaysia.
²National Cancer Institute, No. 4, Jalan P7, Presint 7, 62250, Putrajaya, Malaysia

rffadli@yahoo.com

Abstract. Diodes are radiation dosimetry system that has been applied widely in radiotherapy treatment and very useful for in-vivo dosimetry (IVD). It is duly important to understand the characteristic of detector before it can be used in clinical treatment. In this study, characteristics of diode model IBA dosimetry EDP-153G diode were analysed and compared to calibrated ionization chamber. 6 MV linear accelerator (Linac) was used with different field sizes (FS), Linac monitor unit (MU), tray field (TF), wedge field (WF) and source to surface distance (SSD). Actual diode thickness, diode reproducibility, perturbation effect and diode effect with radiation beam angle and temperature were performed. From the determination of diode dosimetric characteristic, a clinical treatment planning system (TPS) model Elekta Monaco and calibrated ionization chamber (IC) were used to verify the accuracy of diode reading in different setup conditions. Results of study showed wedge, SSD, angle of incidents and temperature were affected the accuracy of diode reading. Phantom measurement and simulation of patient treatment were less than 3%.

1. Introduction
IVD is an important method to monitor and compare dose measured from the detector such as diode with the theoretical values, as calculated by TPS or manual calculation. IVD is also a tool for the detection of systematic errors and prevention of unintended exposures to patients.

A silicon diode dosimeter is a p-n junction. The diodes are produced by taking n-type or p-type silicon and counter-doping the surface to produce the opposite type material. These diodes are referred to as n–Si or p–Si dosimeters, depending upon the base material [1]. An n-type diode is formed by doping acceptor impurities into a region of n-type silicon. A p-type diode is formed by doping donor impurities into a p-type substrate [2]. This study was aimed to study diode characteristics and to understand its capabilities and limitation when it is used as IVD in radiotherapy treatment. This characterization will give guidance on correction method and evaluate its efficacy.

2. Material and Method.
2.1. Diode Characteristics.
Measurements were performed using 6 MV photon beams of Linac model Elekta Synergy, Sweden. The beams was calibrated using an IC (FC65-G Farmer Type IBA dosimetry, Germany) placed at 10
cm depth in a water phantom according to IAEA TRS-398 protocol [3]. The IC dosimetry system was calibrated at the Secondary Standard Dosimetry Laboratory (SSDL), Malaysian Nuclear Agency.

Preliminary testing for diodes was perturbation effect. Diode perturbation effect was studied using a 3D water phantom system, Model Blue Phantom2, IBA Dosimetry, Germany with stereotactic field diode (SFD). Inline and crossline profile was studied at depth of maximum dose \(d_{\text{max}}\), 5 cm, and 10 cm depth as shown in Figure 1. SFD diode was chosen due to sensitivity with small field.

![Figure 1. 3D water phantom for inline and crossline profile measurements.](image)

Protocol for diode dose entrance calibration was based on IAEA [4], Estro [5] and AAPM TG-62 [2]. Solid Water (Gammex, Wisconsin, USA) was used for the calibration of the IVD system with solid phantom to water correction factor. Three diodes were taped onto the surface of the phantom. Diode perturbation effect results were taken into account during calibration. Diodes are relative dosimeters and therefore, these need calibration to present the dose at the \(d_{\text{max}}\). This system calculated linear factor between dose and ADU unit (diode reading).

The IVD system used in this study consisted of Model DPD-12pc (electrometer, IBA Dosimetry, Germany) and p-type diodes (EDP-15G, IBA Dosimetry, Germany). The build-up cap material of the diodes is made of stainless steel with epoxy encapsulation that is equivalent to 15 mm water-equivalent thickness and primarily designed for 6 to 12 MV photon [6]. Actual thickness of diode was studied using 10 MV photon. Solid Phantom slabs of 1 mm, 2 mm and 5 mm are used to cover the diodes dose till maximum is reached. Air gaps are eliminated by using a perforated slab for diode. Diode reading with solid phantom to water correction factor was plotted and compared to \(d_{\text{max}}\) (22 mm) water depth for 10 MV, which was based on baseline value during commissioning. Fluctuate reading from linac also taken into account by using IC, where it was placed at the head of gantry.

Reproducibility was determined according to the procedure stated in the ESTRO Booklet [7]. Signal stability and leakage were measured as outlined in the IAEA Human Health reports No. 8 guidelines [8]. Correction factors (dose non-linearity of the response (different MU), field size and angle of incidence, SSD correction, wedge correction) for entrance setup for all diodes were determined according to literature [8]. Fluctuate reading from linac taken into account by using IC where it was placed at the head of gantry for angle of incidence correction factor. Relation diode with temperature was studied according to the procedure defined in the literature [9,10].

2.2. Phantom measurements.

Measurements were made in a Thorax Phantom Model CIRS 002LFC (30 cm long x 30 cm wide x 20 cm thick) [11]. The phantom is constructed of proprietary tissue equivalent epoxy materials. Tissue equivalent interchangeable rod inserts accommodate IC allowing for point dose measurements.

The experiments were performed for single field (200 Monitor Unit (MU), 100 cm source to surface distance (SSD) with different field size (FS)), wedge field (300 MU, 100 cm source to axis distance (SAD), with different FS), two field (Anterior Posterior/Posterior Anterior (APPA), 150 MU for AP
and PA, 100 cm SAD with different field size) and lateral opposed (400 MU, 100 cm SAD, with different FS). The phantom measurements were compared with TPS model Monaco, Elekta, Sweden, Ver. 5.10 and calibrated IC.

Patient simulation treatment was done using Alderson Rando Phantom. TPS was planned as standard patient treatment as shown in Table 1. Measurement was performed as planned and diodes reading were compared with TPS.

### Table 1. Simulation of patient treatment using.

| No. | Case name and prescription | Setup | Treatment field | Field Size (cm) |
|-----|-----------------------------|-------|-----------------|-----------------|
| 1   | Spine, Single field         | SSD 100 cm | Posterior Anterior | 8x12            |
| 2   | Ca Rectum, 3 fields         | SAD 100 cm | Anterior Posterior | 14x17          |
|     |                             |       | Right Lateral   | 14x17           |
|     |                             |       | Left Lateral    | 14x17           |
| 3   | Ca Endometrium, 4 fields    | SAD 100 cm | Anterior Posterior | 13x14         |
|     |                             |       | Posterior Anterior | 13x14         |
|     |                             |       | Right Lateral   | 13x14           |
|     |                             |       | Left Lateral    | 13x14           |
| 4   | Whole brain, 2 fields       | SAD 100 cm | Right Lateral   | 22x18           |
|     |                             |       | Left Lateral    | 22x18           |
| 5   | Nasopharyngeal Cancer       | SAD 100 cm | Right Lateral facial | 14x10     |
|     | Facial : 40 Gy / 20# to 100% isodose line (IL) |       | Left Lateral facial | 14x10     |
|     | Neck : 40 Gy / 20# to d_{max} |       | Anterior Neck Right | 10x7     |
|     |                             |       | Anterior Neck Left | 10x7          |
| 6   | Rt Chest Wall               | SAD 100 cm | Right Mediastinum | 8x16           |
|     |                             |       | Right Lateral   | 8x16           |
| 7   | Lt Chest Wall and supraclavicular (SCF) | SAD 100 cm | Left Mediastinum | 8x15           |
|     | Chest : 40 Gy / 15# to 100% IL |       | Left Lateral   | 8x15           |
|     | SCF : 40 Gy / 15# to d_{max} |       | Anterior SCF    | 9x8            |

### 3. Results and Discussions

#### 3.1. Diode Perturbation

Inline profile shown that diodes perturbations is at d_{max}, 5, 10 cm were 5.4%, 6.1% and 5.8%, respectively and crossline were 6.1%, 6.5% and 5.6%, respectively. It was also observed that the cable is affecting the amount dose at 1.9%. Measurement of perturbation effect for 5 cm was higher 0.5% compared to manufacturer technical specification 5-6%. This study will preserve as guidelines towards the effect of diode to the treatment area and frequency of diodes measurements. Furthermore, 1.3 cm square field area was affected throughout the measurement.

#### 3.2. Actual thickness

A study was performed and confirmed that build-up cap material of the EDP-153G diodes for all diodes were 1.5 cm. These results were follow manufacturer technical specification. Thicknesses of diodes are equivalent with d_{max} for 6 MV, which make it suitable with the amount of energy.

#### 3.3. Reproducibility, Signal stability and leakage

Two types of reading measurements were performed, consisted of i) 20 readings at the same days, and ii) 15 readings at different days with 1 day gap, observed that the standard deviation (SD) was less 0.1% and 1.0%, respectively. These results are within the acceptable limits and follows IAEA guidelines.
[8]. Signal stability after radiation was observed for 5, 10, 15 and 20 minutes. Results presented in figure 2 shown that Diode 1 (D1) and Diode 2 (D2) increase linearly with time, while Diode 3 (D3) do not have any significant changes. Signal stability is crucial for longer treatment time, especially in total body irradiation. Signal does not exceed 1% for 20 minutes is acceptable. Furthermore, leakage measurement was negligible.

![Figure 2. Signal stability after radiation.](image)

### 3.4. Correction factors
Correction factor for different dose rate, MU, field size (symmetry and asymmetry jaw) and tray is less than 1.0%. Correction factor are in range 0.99 – 1.01, which is considered can be ignore and no need to use it. Based on the analysis performed, the diode sensitivity was affected by angle, wedges and SSD. Result for axial and tilt angle of incidence were illustrated in figure 3. Referring to the vendor technical specification, angle of incidence (axial and tilt) are supposed to be less than 2% for angle ± 45°. Therefore, it was found that only diode 3 has confirmed within the specification requirement. The measured angle for diode 1 and 2 were less than 2% at angle ± 41° and ± 37°, respectively.

![Figure 3. Correction factor for different angle (a) axial and (b) tilt.](image)

Elekta Linac (used in this study) is equipped with motorised wedge. It has single physical wedge angle of 60° and attach permanently in the gantry head. Different wedge angle can be produced by TPS by combination of physical wedge and open field. The results were shown in Figure 4(a). Wedge correction factor has increased proportionally by wedge angle. Wedge correction factor was calculated from the average reading of 3 different field sizes (5 x 5 cm, 10 x 10 cm and 15 x 15 cm). Diodes also
affected by different SSD, which was shown in figure 4(b). SSD correction has increased proportionally by increased SSD.

![Figure 4. Correction factor for (a) wedge and (b) SSD.](image)

Analysis of diodes with temperature deviation showed that diode is sensitive with temperature. Diode produced signal or readout even though there are no radiations occurring in the circumference. Analysis was performed with temperature 25-34°C. Results showed that higher temperature will increase the readout. Temperature correction factor can be avoided when insulator, such as paper was placed between diode and patient.

Based on the diode characteristics analysis, it was concluded that only three factors (angles wedge and SSD) were applied for correction. The placement of diode orientation should be recorded to ensure the angle correction factor is correct.

3.5. Thorax phantom measurements

For diode verification, thorax phantom was used in this study to measure dose with IC. The phantom consisted of lung and spine tissue, which is very useful to verify the accuracy of TPS algorithm [12]. Manual calculation was done in order to get the value for $d_{max}$. The results of mean percentage difference and standard deviation for individual diode measurement besides having comparison with IC and TPS are tabulated in Table 2. Mean percentage between ionization chamber reading and TPS for single, wedge, APPA and Lateral Opposed were 0.17 (Std Dev 1.45), 1.58 (Std Dev 0.6), 1.83 (Std Dev 0.8) and 0.66 (Std Dev 0.62), respectively.

**Table 2.** Mean percentage different and standard deviation between diode vs ionisation chamber and diode versus TPS.

| Plan         | Diode | Diode vs Ionization chamber | Diode vs TPS |
|--------------|-------|-----------------------------|--------------|
|               |       | Mean % | Std Dev | Mean % | Std Dev |
| Single field  | D1    | 0.20   | 1.65    | 0.36   | 0.42    |
|               | D2    | 0.78   | 1.43    | 0.94   | 0.32    |
|               | D3    | 1.21   | 1.22    | 1.38   | 0.33    |
|               | Average | 0.73 | 1.43    | 0.89   | 0.36    |
| Wedge field   | D1    | 1.39   | 0.55    | 2.99   | 0.05    |
|               | D2    | 1.03   | 0.71    | 2.62   | 0.12    |
|               | D3    | 1.05   | 1.00    | 2.64   | 0.41    |
|               | Average | 1.15 | 0.75    | 2.75   | 0.19    |
| APPA          | D1    | -0.02  | 0.97    | -1.85  | 0.33    |
|               | D2    | -0.44  | 0.99    | -2.26  | 0.40    |
|               | D3    | 0.43   | 1.04    | -1.41  | 0.45    |
|               | Average | -0.01 | 1.00    | -1.84  | 0.39    |
| Lateral Opposed | D1   | -1.01  | 0.51    | -1.67  | 0.40    |
|                | D2    | -0.89  | 0.48    | -1.55  | 0.48    |
|                | D3    | 0.15   | 0.48    | -0.51  | 0.44    |
|                | Average | -0.58 | 0.49    | -1.24  | 0.44    |
3.6. Aldersons Rando Phantom results
Analysis with rando phantom was performed in order to simulate the real clinical cases. Different prescription, body area, treatment method and treatment parameter were chosen in order to evaluate accuracy of diode. Generally, all measured datas were having less than 3% of acceptable limit (mean percentage 0.3, Std Dev 1.9). Results are tolerable based on LINAC acceptable daily output tolerance, which is ± 3% [13].

4. Conclusion
In this study, EDP-153G diode was sensitive with angle of incidence, wedge, SSD and temperature. Each diode has their own characteristics and should analyse individually to avoid any inaccurate data. From the patients simulation results, it can be concluded that by applying proper calibration and correction factors, ± 3% reading able to achieve.

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