VOLUME AVERAGING CORRECTION FACTOR OF SEVERAL DETECTORS IN SMALL FIELD RADIOTHERAPY DOSIMETRY

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Abstract: Various type of detector, such as ionization chamber, has been used in small field radiotherapy dosimetry. There is a limitation in detector's dimension which can produce the volume averaging effect. Detector will average the measured dose because of fluence perturbation that happens in gas-filled cavity around detector's active volume. Purpose of this study is to calculate volume averaging correction factor of some detectors. Volume averaging correction factor can be calculated using MATLAB based algorithm. The result shows that detector with the lowest volume averaging correction factor is SFD diode detector with volume averaging correction factor value is 1,0086 in 4 cm x 4 cm field size. Whereas GD-302 has the largest volume averaging correction, 1,6083 in 0,8 cm x 0,8 cm field size. The larger size of detector, the greater volume averaging correction factor will be produced. Therefore, detector with small enough dimension is required in order to minimize the effect of volume averaging.

Keywords: *volume averaging, small field, dosimetry, detector, radiotherapy*

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I. INTRODUCTION

Small field radiotherapy techniques, such as stereotactic or intensity-modulated radiation therapy, has been widely used in modern cancer treatment [1]. This radiotherapy technique uses small radiation field below 4 cm^2. Small radiation field will produce beam that conforms to the tumour target, so the healthy tissue around target can be spared.

Beside the advantages of using small field technique, there are some complications in small field radiotherapy dosimetry, for example source partial blocking that produces overlaping penumbra and the avaliability of detectors for dosimetry [2]. The output factor from LINAC will drop as the radiation field is getting smaller. The detector with large dimension will perturb the fluence on position of measurement [3]. The perturbation effect of detector is caused by the presence of gas-filled cavity inside detector resulting volume averaging effect [2].

GafChromic film is used in this study for calculating volume averaging correction factor and small beam characterization because GafChromic film is the best dosimeter for 2D dosimetry with high spatial resolution.

II. MATERIALS AND METHODS

A. GafChromic Film Calibration

Calibration data was obtained by radiating film with nine fields, 4 cm^2 field size with 1 cm gap between each field. The given dose for each field was varied from 0 cGy to 794 cGy [5].

Pixel value from each field was measured and converted to the determined gray value. The mean pixel value of each field was measured on MATLAB and plotted with the dose value (cGy). Afterwards, the calibration value was interpolated with the film pixel value for both PDD and beam profile calculation.

B. PDD and Beam Profile Calculation

To obtain the PDD curve for each radiation fields on MATLAB, pixel value of film has to be measured first and then interpolated with calibration value in the form of dose value (cGy). The maximum value of interpolated dose value was normalised to 100 % representing the value of relative dose. All interpolated values were plotted against the length of the film representing depth (cm) with X axis representing depth (cm) and Y axis representing dose (%).

Similar process had been done in calculating beam profile on MATLAB. The additional process was the measurement of full width half maximum (FWHM) or actual field size. FWHM was obtained by measuring the gap between two points of 50 % relative dose on beam profile.

C. Volume Averaging Correction Factor (VACF) Calculation

VACF was determined by processing beam profile data on MATLAB. The pixel value of beam profile data was measured and interpolated with the calibration data. After being interpolated, the contour of all film pixel value representing the relative dose distribution was obtained.

The relative dose distribution was used to calculate the value of volume averaging for each detectors. The value of volume averaging was calculated by inserting the 2D dimension of detector as a border on beam profile isocenter area. All the pixel values inside the dimension border were averaged to obtain the volume averaging value. Thus, the volume averaging correction factor can be calculated using equation:

$$\text{VACF} = 1 / \text{volume averaging value} \qquad (1)$$

III. RESULTS AND DISCUSSION

A. Film Pixel Value Calibration

Film pixel value calibration had been done on two softwares; MATLAB and ImageJ. The pixel value of exposed film was determined and converted into dose value (cGy). Figures 1 and 2 show the calibration curve that was obtained by using ImageJ and MATLAB-based algorithm.

The calibration curve shows that the dose value will become smaller as the pixel value is getting greater. Polynomial equation for calibration data of 6 MV x-ray was obtained as

$$y = -0{,}00008x^3 + 0{,}0139x^2 - 79{,}573x + 29587 \quad (2)$$

while the relation of pixel value (Y) and dose value (X) on 10 MV x-ray can be expressed as

$$y = -0{,}0001x^3 + 0{,}186x^2 - 92{,}339x + 30240 \quad (3)$$

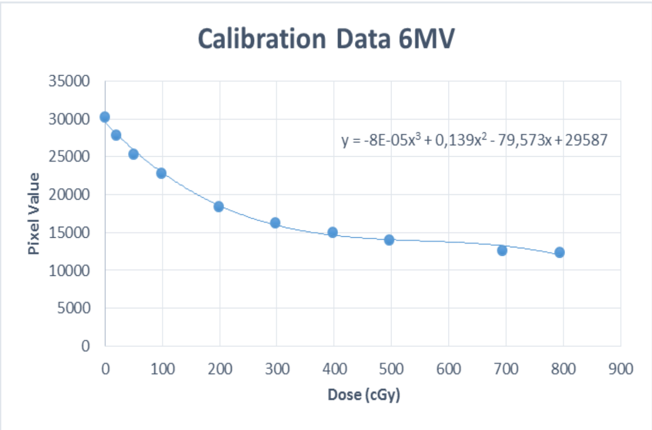

Figure 1. Pixel value calibration curve 6 MV x-ray (MATLAB)

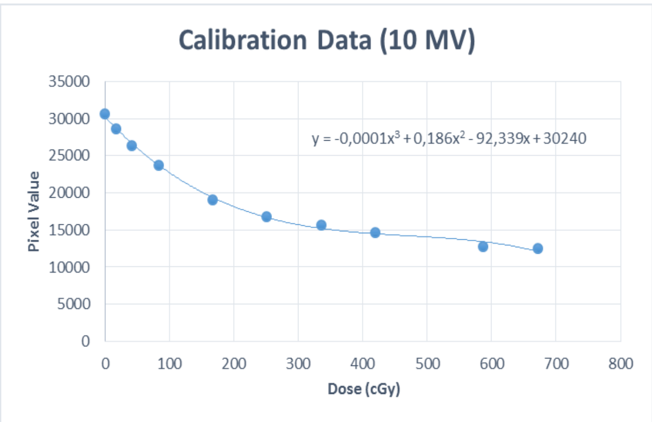

Figure 2. Pixel value calibration curve 10 MV x-ray (ImageJ)

B. Percentage Depth Dose (PDD) Calculation

PDD was calculated using MATLAB-based algorithm and compared with PDD calculation using ImageJ for validation. The resulting PDD was also compared with the result of PDD calculation using pin-point microchamber detector (Nuruddin, 2012).

1. 6 MV x-ray Beam PDD Calculation

The depth of maximum dose (d_{max}), relative dose at depth 10 cm and 20 cm (D_{10} and D_{20}), dose ratio at D_{10} and D_{20}, and tissue phantom ratio ($TPR_{20,10}$) of the calculated PDD was analyzed. $TPR_{20,10}$ is the absorbed dose ratio at depth 20 cm and 10 cm in water phantom measured with 100 cm SSD and 10 cm x 10 cm field size parallel with the detector [7]. TPR also represents the curve derivation exponentially after depth of maximum dose. The equation of $TPR_{20,10}$ on 10 cm x 10 cm field size is:

$$TPR_{20,10} = 1{,}2661 \times D_{20,10} - 0{,}0595 \quad (4)$$

The value of $TPR_{20,10}$ for small field had been determined by *Sauer et. al.*:

$$TPR_{20,10} = \frac{TPR_{20,10(s)} - b_1 - A_1(1-e^{-s/t})}{b_2 - A_2(1-e^{-s/t})} \quad (5)$$

with the value of b_1 is -0,208, b_2 is 1,213, A_1 is 0,625, A_2 is –0,679 and t is 19,5.

The value of d_{max} tends to move toward surface when the field size is getting smaller [6]. But on Table 1 shows the tendency of d_{max} depending on the field size does not move consistently toward the surface. The inconsistency of d_{max} is caused by the presence of high data ripple that affects the normalising process of relative dose value. The use of high resolution (300 dpi) when scanning the GafChromic film causes quite much ripples.

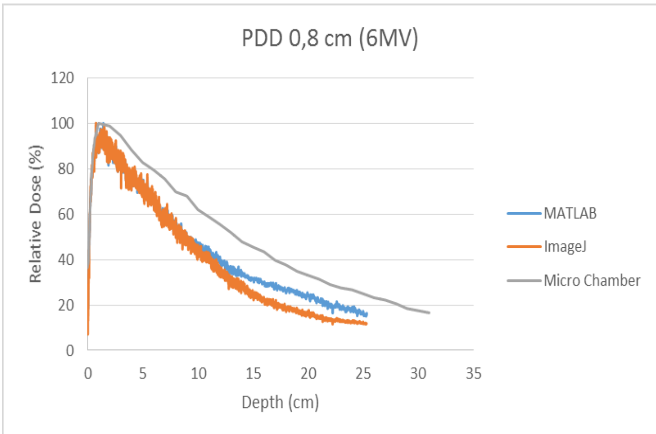

Figure 3. PDD curve (field size 0,8 cm², 6 MV x-ray).

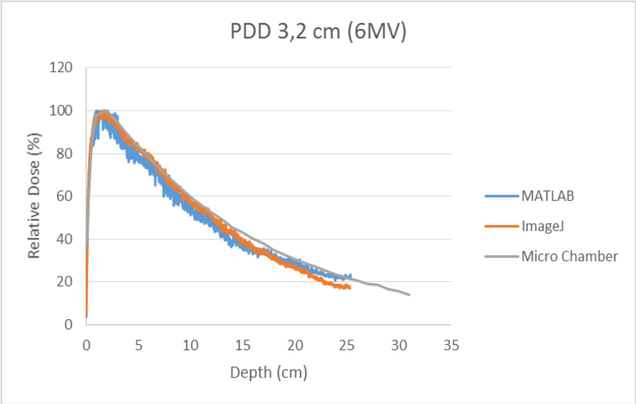

Figure 4. PDD curve (field size 3,2 cm², 6 MV x-ray).

Table 1. d_{max} and $TPR_{20,10}$ PDD GafChromic film analysis (MATLAB)

Field Size (cm)	d_{max} (cm)	D_{10} (%)	D_{20} (%)	$D_{20,10}$ (%)	$TPR_{20,10}$ (Sauer) (%)	$TPR_{20,10}$ (%)
0,8	0,74	46,39	15,8	0,34	0,62	0,46
1,6	1,23	55,58	24,33	0,44	0,63	0,56
2,4	1,42	54,86	23,93	0,44	0,63	0,56
3,2	1,69	56,94	26,66	0,47	0,64	0,59
4	1,5	58,14	23,7	0,41	0,64	0,53

Table 2. d_{max} and $TPR_{20,10}$ PDD GafChromic film analysis (ImageJ)

Field Size (cm)	d_{max} (cm)	D_{10} (%)	D_{20} (%)	$D_{20,10}$ (%)	$TPR_{20,10}$ (Sauer) (%)	$TPR_{20,10}$ (%)
0,8	1,41	46,49	24,06	0,52	0,62	0,64
1,6	1,01	55,68	26,58	0,48	0,63	0,60
2,4	1,47	51,76	26,1	0,50	0,63	0,62
3,2	1,66	56,2	28,57	0,51	0,64	0,63
4	1,31	56,07	30,06	0,54	0,64	0,65

Table 3. d_{max} and $TPR_{20,10}$ PDD micro chamber analysis

Field Size (cm)	d_{max} (cm)	D_{10} (%)	D_{20} (%)	$D_{20,10}$ (%)	$TPR_{20,10}$ (Sauer) (%)	$TPR_{20,10}$ (%)
0,8	0,99	62	33,1	0,53	0,62	0,65
1,6	1,98	58,7	29,8	0,51	0,63	0,63
2,4	0,99	60,3	30,8	0,51	0,63	0,63
3,2	1,98	59,8	30,7	0,51	0,64	0,63
4	1,98	61,8	32,1	0,52	0,64	0,64

Table 2 also shows the inconsistency of d_{max} movement tendency depending on field size. But d_{max} tends to move toward surface as field size is getting smaller (calculation with MATLAB, ImageJ and micro chamber).

The result of $TPR_{20,10}$ calculation, shown in Tables 1 and 3, is quite similar with value range between 0,60 to 0,64. It shown that the accuracy of calculation on MATLAB is acceptable. But the calculation with ImageJ is not quite similar to MATLAB and micro chamber bercause of the interpolation order on ImageJ is smaller than MATLAB.

The mean relative error on $TPR_{20,10}$ calculation (refering to *Sauer et. al.*) for MATLAB is 2,28 %, ImageJ is 14,58 % and micro chamber is 0,64 %.

2. 10 MV x-ray Beam PDD Calculation

Tables 4 and 5 shows the tendency of d_{max} movement toward surface as the field size becomes smaller. But there is a incongruity d_{max} value at field size 1,6 cm². It is caused by the presence of ripple on the curve that affects the measurement.

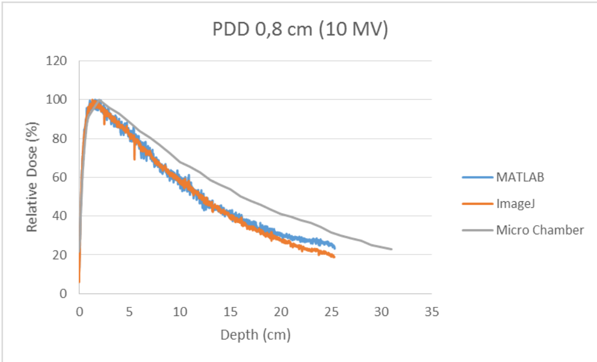

Figure 5. PDD curve (field size 0,8 cm², 10 MV x-ray)

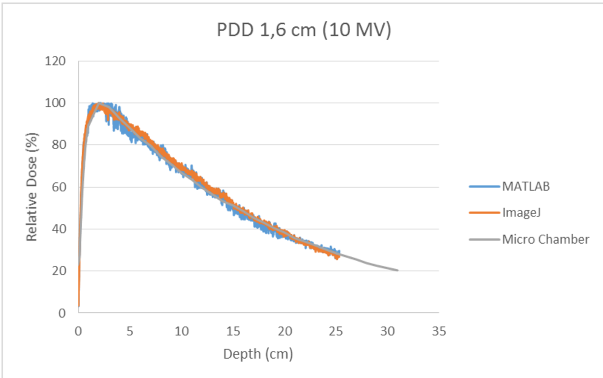

Figure 6. PDD curve (field size 1,6 cm², 10 MV x-ray)

Table 6 shown the consistency of d_{max} value in each field size. But that is not matched with Tables 4 and 5 which d_{max} tends to move toward the surface when the field size is getting smaller.

The result of $TPR_{20,10}$ on Tables 4, 5, and 6 shown consistency value range between 0,63 to 0,74. Therefore, the results of calculation using all three methods are quite similar.

The mean relative error on $TPR_{20,10}$ calculation (refering to *Sauer et. al.*) for MATLAB is 5,18 %, ImageJ is 4,31 % and micro chamber is 1,45 %.

C. Beam Profile Calculation

The calculation of beam profiles with various radiation fields has been done in this work. Beam profiles were obtained with MATLAB-based algorithm.

1. 6 MV x-ray Beam Profile

The result of 6 MV x-ray beam profile for each radiation fields is displayed on Table 4. Full Width Half Maximum (FWHM) represents the exact radiation field size. The mean deviation of the measured FWHM to the field size is 7,04 %. Whereas the mean deviation value from previous researcher (Nurrudin, 2012) is 2,3 %.

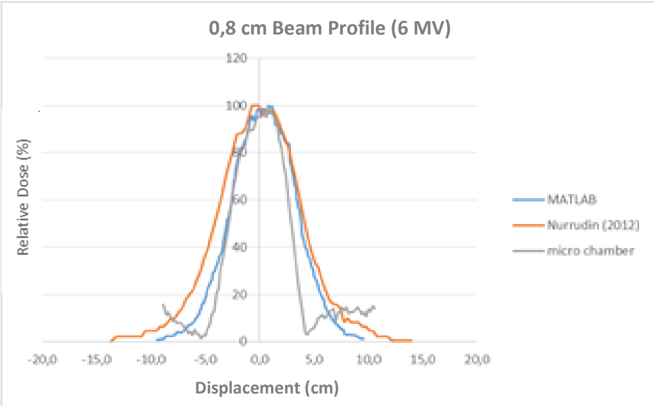

Figure 7. Beam Profile (0,8 cm^2; 6 MV)

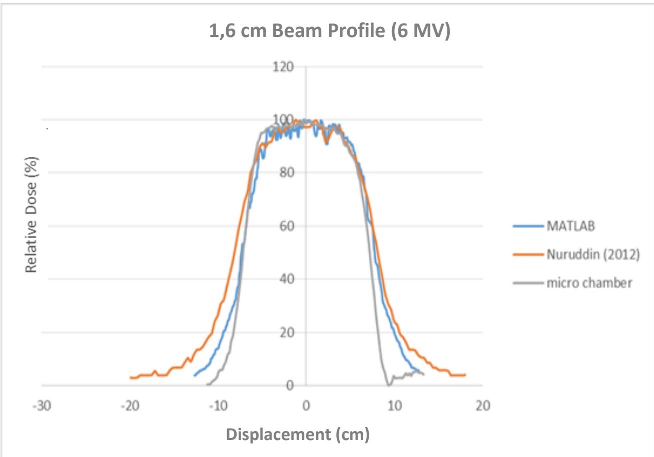

Figure 8. Beam Profile (1,6 cm^2; 6 MV)

The result of penumbra measurement shown that the size of penumbra will get longer when the field size gets larger. The longer penumbra means there are numerous scattered radiation produced by large radiation field.

2. 10 MV x-ray Beam Profile

The result shown that the mean deviation of FWHM is 4,58 % while the previous research was 1,36 %. The difference is caused by the use of two different methods which are MATLAB and ImageJ. The penumbra measurement also shown the tendency of penumbra gets longer when field size is getting larger.

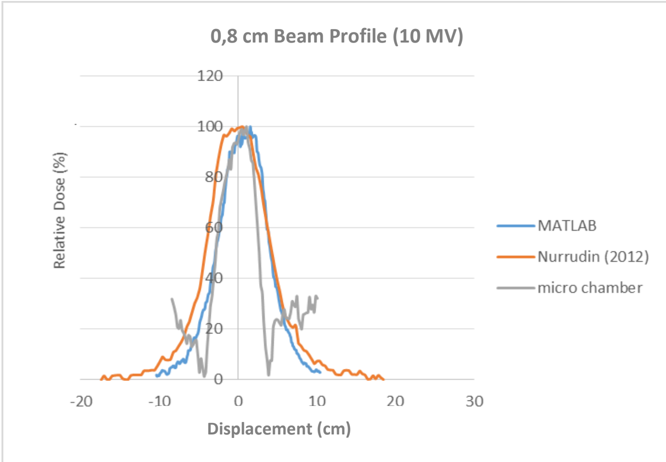

Figure 9. Beam Profile (0,8 cm^2; 10 MV)

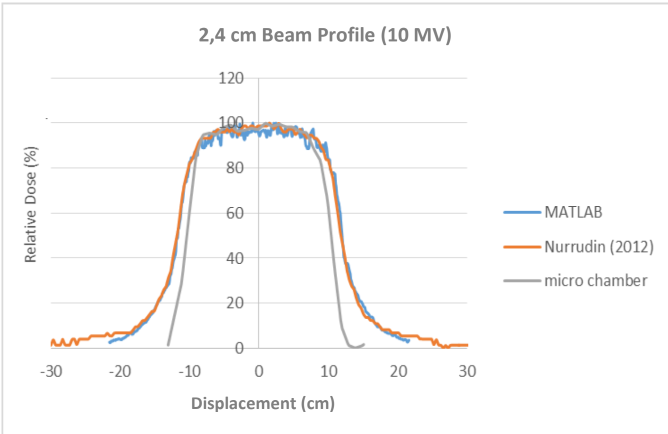

Figure 10. Beam Profile (2,4 cm^2; 10 MV)

Table 4. 6 MV Beam Profile FWHM (*field size*) and Penumbra

	Result (MATLAB)		Nurrudin (2012) (ImageJ)		Nurrudin (2012) (ppmc)	
Field Size (cm^2)	FWHM (cm)	Penumbra (mm)	FWHM (cm)	Penumbra (mm)	FWHM (cm)	Penumbra (mm)
0,8	0,68	3,18	0,83	3,9	0,70	2,4
1,6	1,49	3,77	1,64	4,4	1,53	2,5
2,4	2,29	3,89	2,36	3,0	2,36	4,8
3,2	3,04	4,06	3,26	4,0	3,13	2,6
4	3,85	5,17	3,92	3,1	4,00	3,2

Table 5. 10 MV Beam Profile FWHM (field size) and Penumbra

Result (MATLAB)			Nurrudin (2012) (ImageJ)		Nurrudin (2012) (ppmc)	
Field size (cm^2)	FWHM (cm)	Penumbra (mm)	FWHM (cm)	Penumbra (mm)	FWHM (cm)	Penumbra (mm)
0,8	0,71	3,51	0,77	3,8	0,74	2,6
1,6	1,54	3,64	1,61	3,8	1,53	2,2
2,4	2,33	5,33	2,37	2,8	2,32	2,6
3,2	3,12	5,33	3,23	4,6	3,11	2,5
4	3,90	5,33	3,99	5,9	3,90	3,3

D. Volume Averaging Correction Factor Calculation

Figure 11 and Figure 12 shown that the larger radiation field size, the volume averaging correction factor is nearly one. In large field size there was no overlapping penumbra read on dosimeter. The volume averaging correction factor will rise if the radiation field size got smaller. The fluence reading will be averaged by the dosimeter if the dimension of field size is very small. Therefore, the size of dosimeter must be smaller than the radiation field size in order to decrease the volume averaging effect.

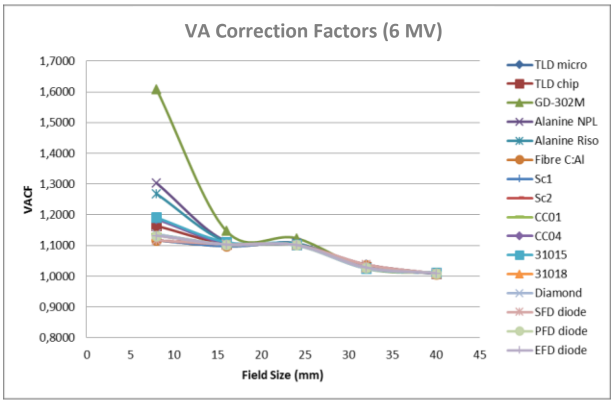

Figure 11. 6 MV Volume Averaging Correction Factor

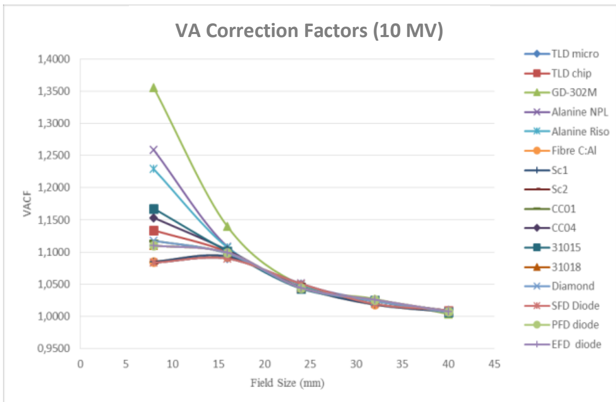

Figure 12. 10 MV Volume Averaging Correction Factor

Dosimeter with the highest volume averaging factor in the smallest field size was GD- 302M. The dosimeter has 1,5 mm x 12 mm dimension.

The volume averaging correction factor of this dosimeter is up to 1,6083. The SFD diode dosimeter has the smallest volume averaging correction factor which is up to 1,0833. The dimension of SFD diode is 0,95 mm x 0,95 mm. Therefore, the SFD diode is the most effective dosimeter for small field dosimeter.

IV. CONCLUSION

The basic algorithm for PDD, beam profile and volume averaging correction factor has been successfully developed based on the comparison of the previous research. The volume averaging correction factor will rise if the radiation field size is getting smaller. SFD diode dosimeter has the smallest volume averaging correction factor which is up to 1,0833, whereas the largest volume averaging correction factor, up to 1,6083, is on GD-302 M dosimeter.

REFERENCES

[1] Followill. S. D. The Radiological Physics Center's standard dataset for small field size output factors. Journal of Applied Clinical Medical Physics, Vol. 13, No. 5. 2012.

[2] Das et. al.. Small Field : Nonequilibrium Radiation Dosimetry. Med. Phys. 35 (1), 206 - 215. 2007.

[3] Aspradakis. M. M. Challenges in small field MV photon dosimetry. Cantonal Hospital of Lucerne. Lucerne. 2010.

[4] Low et. al.. Dosimetry tools and techniques for IMRT. Med. Phys. 38, 1313-1332. 2011.

[5] Nuruddin. Perbandingan Pengukuran PDD dan Beam Profile antara Detektor Pin Point Microchamber dan GafChromic Film pada Lapangan Kecil. Fakultas Matematika dan Ilmu Pengetahuan Alam, Universitas Indonesia. Depok. 2012.

[6] Palta. J.R. Dosimetric Characteristics of Clinical Photon Beams. University of Florida. 2011.

[7] International Atomic Energy Agency. Absorbed Dose in External Radiotherapy. Technical Report Series 398. Vienna: IAEA. 2000.

[8] Institute of Physics and Engineering in Medicine. Small Field MV Photon Dosimetry. IPEM Report 103. UK. 2010.