4. Results&Discussions:

4.1 Machine Data Collection:

Every treatment planning system (TPS) has its own dataset; this data is different from TPS to another depending on the need of the TPS data calculation algorithm. This data are measured from the treatment machine using the proper tools and taking into account all the conditions for extracting an accurate measurement.

Before measuring the data from the machine it has to be checked, just to be sure that all the mechanical and electrical component are working efficiently. These checks start with calibration. and acceptance of the machine. After the necessary data were collected for the machine, the data were loaded into PlanW2000 TPS (Reference) which based on pencil beam algorithm, this treatment planning system has its own data requirement. The data were collected from Varian MDX 2100 Linear accelerator machine for 6 MV photon beam. The following data were measured and loaded into TPS according to the TPS manufacturer specification and requirements:

- Absolute Dose at standard condition (standard SSD, depth, and field size)
- PDD curves for square fields ,
- Profiles with and without the wedges
- Wedge Factors.
- Spectral distribution Data.
- Back scatter Factors.
- Output Factors.

4.1.1 Absolute Dose data:

4.1.2 Percentage depth dose (PDD) data:

Figure 4.1 show the PDDs for all square fields start from 4x4 to 40x40 cm^2. This PDDs were measured according to IAEA 398 for 6 MV Photon for open field, wedges in all inserting directions, 100 SSD, with 0.0 º Gantry.

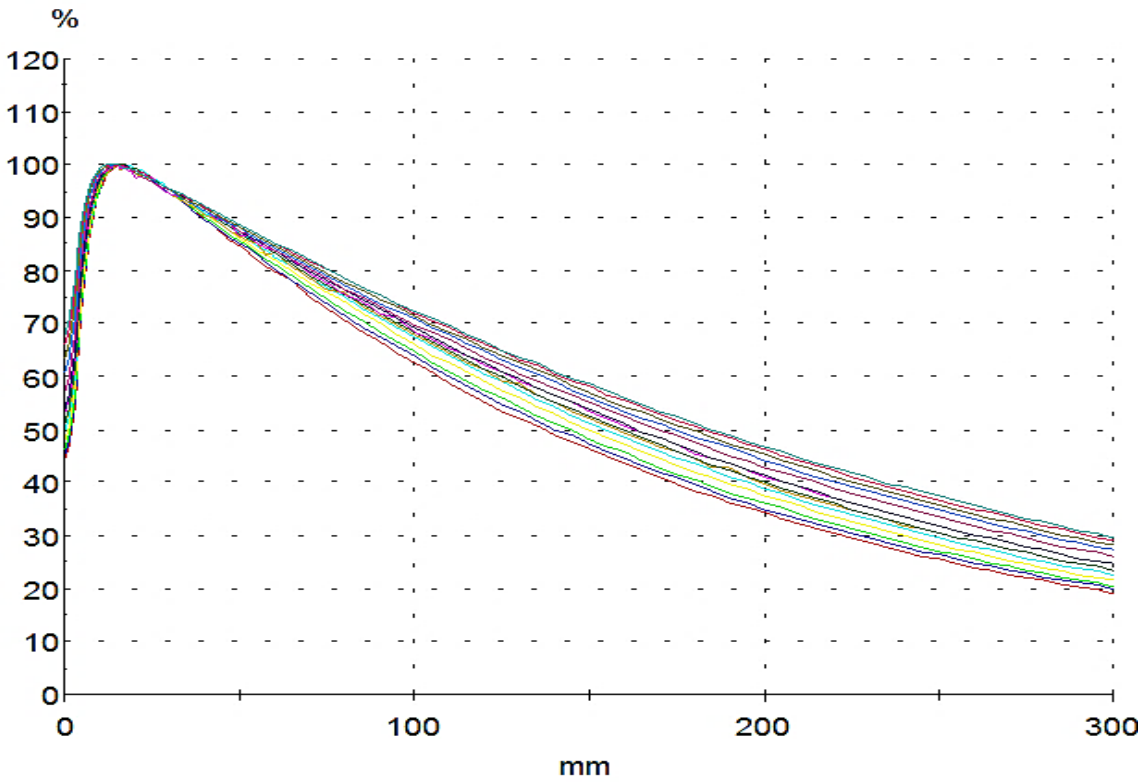

Figure 4.1: PDDs for all square fields start from 4x4 to 40x40 cm^2.

PDDs were measured with PTW 10010 Semiflex ionization chamber as a phantom reference chamber and proof chamber. These PDDs are compared with the golden Beam PDD data for the same energy and field sizes for machine, and we notice the congruency between them.

4.1.3 Photon Beam Profiles:

Figure 4.2 Show the measurement for all profile with open beam 6 MV photon beam radiation. These profiles were measured according to IAEA 398 for 6 MV Photon for open field, wedges in all inserting directions, 95 SSD, At depth 5 cm with 0.0 º Gantry. These profiles are compared with the golden Beam data for the same energy and field sizes profiles for the machine, and we notice the congruency between them.

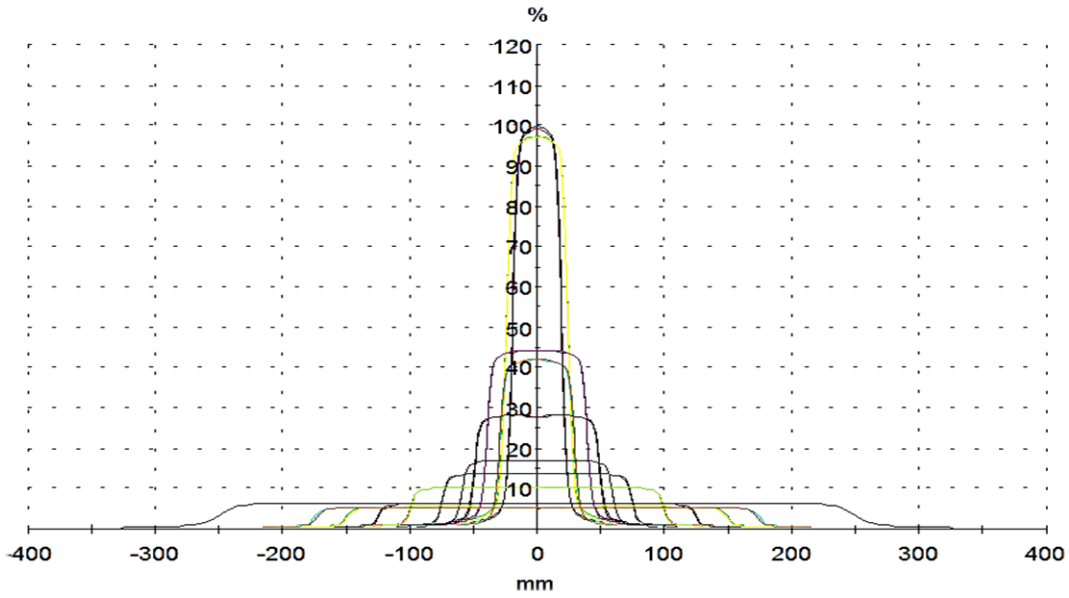

Figure 4.2: 6 MV photon open beam profiles for all square fields from 4x4 to 40x40 cm^2.

the other profiles were measured for all square fields were measured according to IAEA 398 for 6 MV Photon with wedges in all inserting directions, 95 SSD, At depth 5 cm with 0.0 ° Gantry, for example let's take the profiles for 45° wedge in (In) direction for all fields sizes start from 4x4 to 40x40 cm^2 which shown in *figure 4.3*.

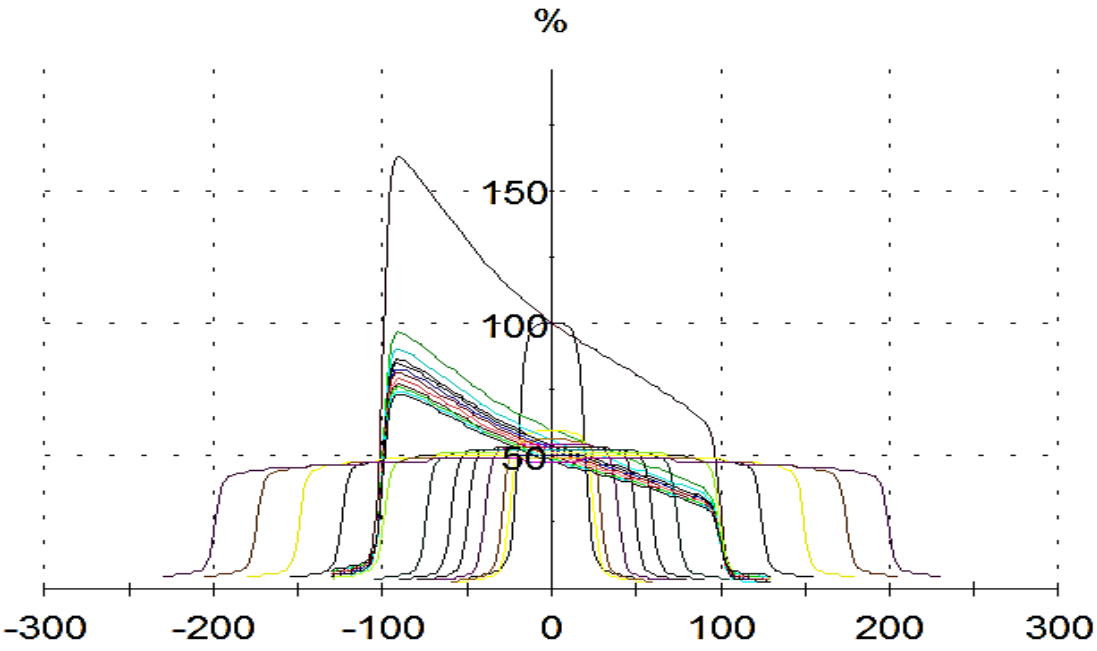

Figure 4.3: example for the 6 MV photon beam profiles for 45° wedge in (In) direction for all fields sizes start from 4x4 to 40x40 cm^2.

4.1.4 Wedge Factors:

Table 4.1 shows an example for the wedge factors measured for different field sizes and different wedge angles in the (IN) wedge direction.

Table 4.1: Wedge factors for square different field sizes and different wedge angles:

Wedge Angles	field size (cm^2)						
	4×4	**5×5**	**10×10**	**15×15**	**20×20**	**25×20**	**26.7×26.7**
15˚	0.783	0.783	0.781	0.783	0.789	0.795	0.797
30˚	0.636	0.636	0.633	0.639	0.646	0.656	0.660
45˚	0.487	0.486	0.483	0.486	0.499	0.499	0.502

4.1.5 Spectral distribution Data:

Table 4.2 shows an example for The data which was collected from the Varian MDX 2100 linear accelerator with/without the wedge as shown in *figure 3.10* this data was measured for 6 MV photon beam, SSD=100, at (D_{max} depth=1.6 cm) and (dose at 15 cm depth, for 200 MU.

Table 4.2: Spectral distribution data for the wedges with different angles:

Wedge Angles	Off axis distance (cm)						
	-8.0	-5.0	-2.0	0.0	2.0	5.0	8.0
15˚	0.535	0.555	0.565	0.567	0.562	0.553	0.525
30˚	0.557	0.577	0.588	0.590	0.5585	0.568	0.530
45˚	0.577	0.591	0.595	0.595	0.592	0.574	0.537

4.1.6 Back scatter Factor (BSF):

Table 4.3 Show the back scatter factor which was calculated with the treatment planning system for different square field sizes from 0x0 to 40X40 cm^2 taking to consideration the buildup depth or the Dmax for 6 MV which is 1.6 cm and the linear attenuation coefficient which equal to 0.480 cm^{-1} .

Table 4.3: Back scatter factor for Square field sizes .

Field Size (cm^2)	0×0	4×4	6×6	8×8	10×10	15×15	20×20	30×30	40×40
BSF	1.000	1.049	1.060	1.067	1.070	1.082	1.087	1.093	1.097

4.1.7 Output Factor:

Table 4.4 Shows the output factors for different square field sizes from 0x0 to 40X40 cm^2, for a square field sizes, normalized to the 10×10 cm^2 field size.

Table 4.4: Output factors for different square fields.

Field Size (cm^2)	4×4	6×6	8×8	10×10	12×12	15×15	20×20	30×30	40×40
4×4	0.895								
6×6		0.941							
8×8			0.974						
10×10				1.000					
12×12					1.019				
15×15						1.041			
20×20							1.066		
30×30								1.105	
40×40									1.130

4.2 Verification Tests:

4.2.1 Dose Pointsverification:

Tables 4.5, 4.6, 4.7, 4.8, 4.9, 4.10, 4.11, 4.12, 4.13, 4.14, 4.15, 4.16, 4.17, 4.18, 4.19, 4.20, and *4.21* show theDose Points Measurement along the central axis at depths (2, 5, 10, and 18 cm) and the calculated dose for the same depths from the (PlanW2000) and show the deviation as an error .

These tables followed by *figures 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, 4.10, 4.11, 4.12, 4.13, 4.14, 4.15, 4.16, 4.17, 4.18, 4.19,* and *4.20,* which show the curve deviation according to the depth (cm) and the dose (Gy).

For the Dose Points Measurement in the off axis at 10 cm depths, in the off axis distances(-3,0,+3), and the calculated dose for the same off axis distances at 10 cm depth from the (PlanW2000) and show the deviation as an error .

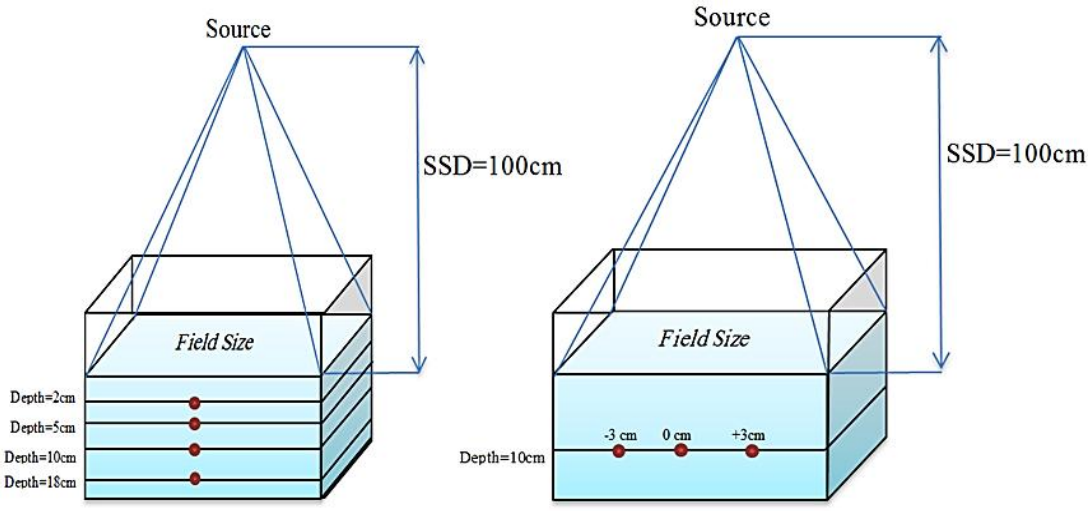

Figure 4.4: the Dose point verification for the central axis and the off axis dose Points setup.

Table 4.5: Calculated and measured dose along central axis points for 6 MV photon beam energy, 207 Monitor Unit (MU), and open field:

Depth (cm)	Calculated (PlanW2000) (Gy)	Measured (PTW Phantom) (Gy)	Error (%)
2	2.290	2.300	0.43%
5	2.000	1.996	-0.20%
10	1.530	1.540	0.65%
18	0.980	0.985	0.51%

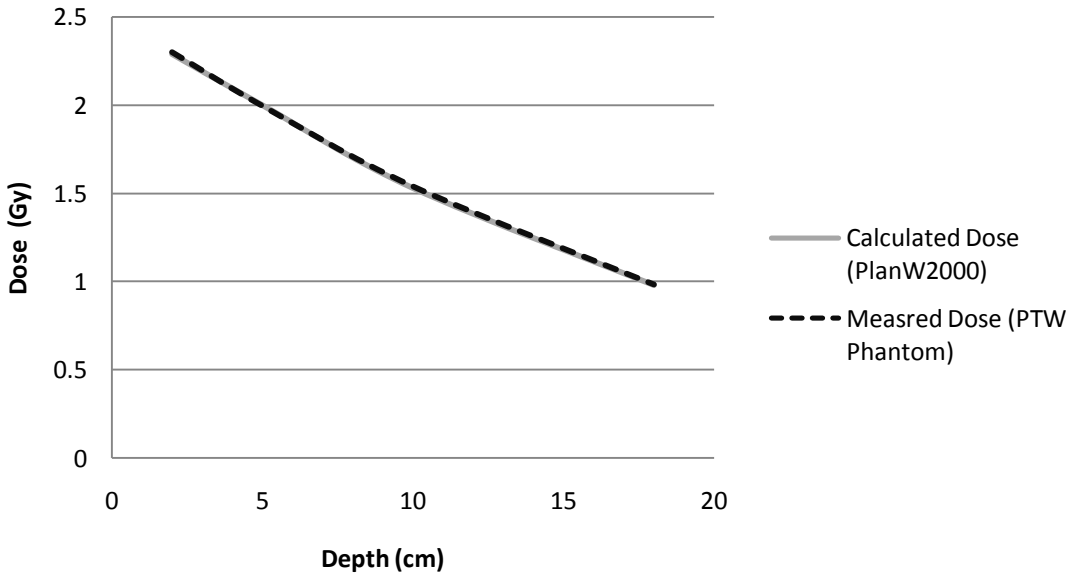

Figure 4.5:Calculated and measured Dose Points at central axis for 6MV Photon Energy, 207 MU, and open field.

As shown in (*figure4.5)* above there is a good agreementbetween the measured to dose points and the calculated points with an average difference of±0.4475 %; this good agreement is due to the accuracy of the pencil beam algorithm in the PlanW2000 TPS.

Table 4.6: Calculated and measured dose at central axis points for 6 MV photon beam energy, 265 Monitor Unit (MU), and 15° wedge-In:

Depth (cm)	Calculated (PlanW2000) (Gy)	Measured (PTW Phantom) (Gy)	Error (%)
2	2.280	2.226	-2.43%
5	2.000	1.997	-0.15%
10	1.550	1.541	-0.58%
18	1.000	0.995	-0.50%

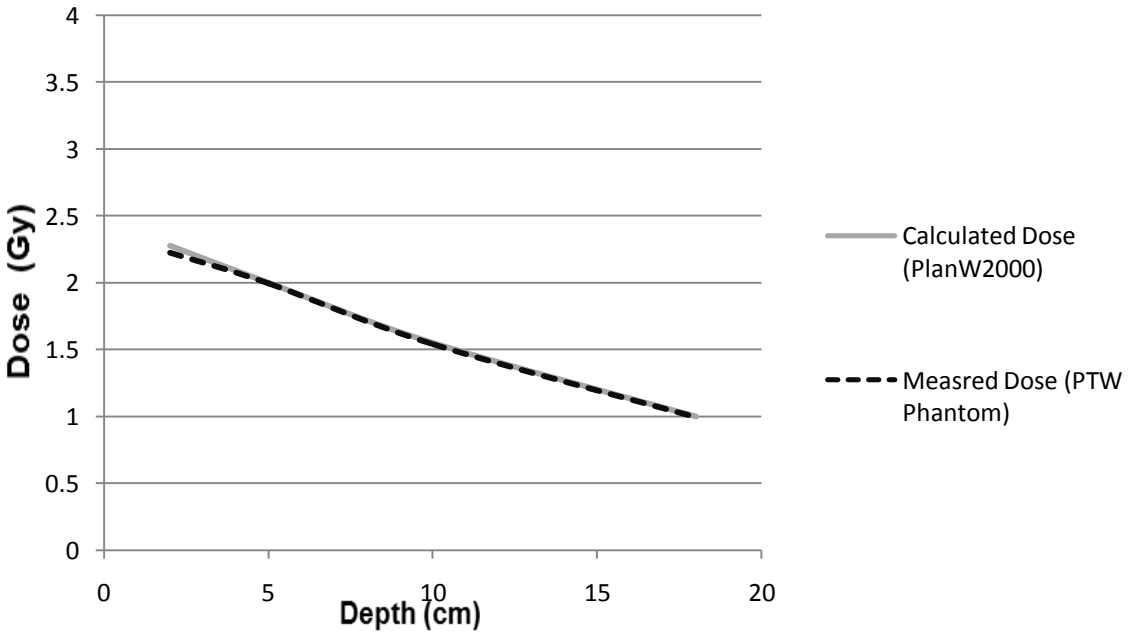

Figure 4.6: Calculated and measured Dose Points at the central axis for6MV Photon Energy, 265 MU,and 15˚ wedge –In.

As shown in (*figure4.6)* above there are small deviation betwixt the measured and calculated dose at depth of 2 cm; this deviation is due to the difficulties of the Adjustment of the effective point in the ionization chamber for small depths. When the depth increased there isa good agreement between the measured dose pointswhich is within the acceptable limit with a difference value of ±0.9150 %.

Table 4.7:Calculated and measured dose at central axis points for 6 MV photon beam energy, 265 MU,and 15° wedge-out:

Depth (cm)	Calculated (PlanW2000) (Gy)	Measured (PTW Phantom) (Gy)	Error (%)
2	2.280	2.280	0.00%
5	2.000	1.993	-0.35%
10	1.550	1.538	-0.78%
18	1.000	0.973	-2.77%

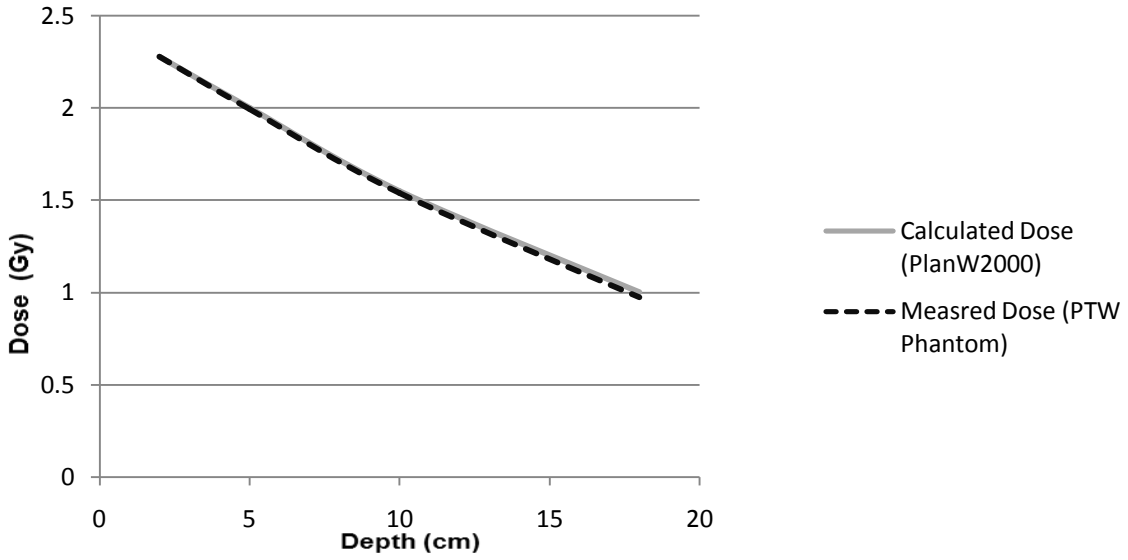

Figure 4.7: Calculated and measured Dose Points at central axis for6MV Photon Energy, 265MU,and 15˚ wedge –Out.

As shown in (*figure4.7)*above there is a good agreementbetween the measured to dose points and the calculated points with an average difference of ±0.9750 %; this good agreement is due to the accuracy of the pencil beam algorithm in the PlanW2000 TPS.

Table 4.8: Calculated and measured dose at central axis points for 6 MV photon beam energy, 265 MU, and 15° wedge-right:

Depth (cm)	Calculated (PlanW2000) (Gy)	Measured (PTW Phantom) (Gy)	Error (%)
2	2.310	2.299	-0.48%
5	2.000	1.997	-0.15%
10	1.540	1.549	0.58%
18	0.980	0.998	1.80%

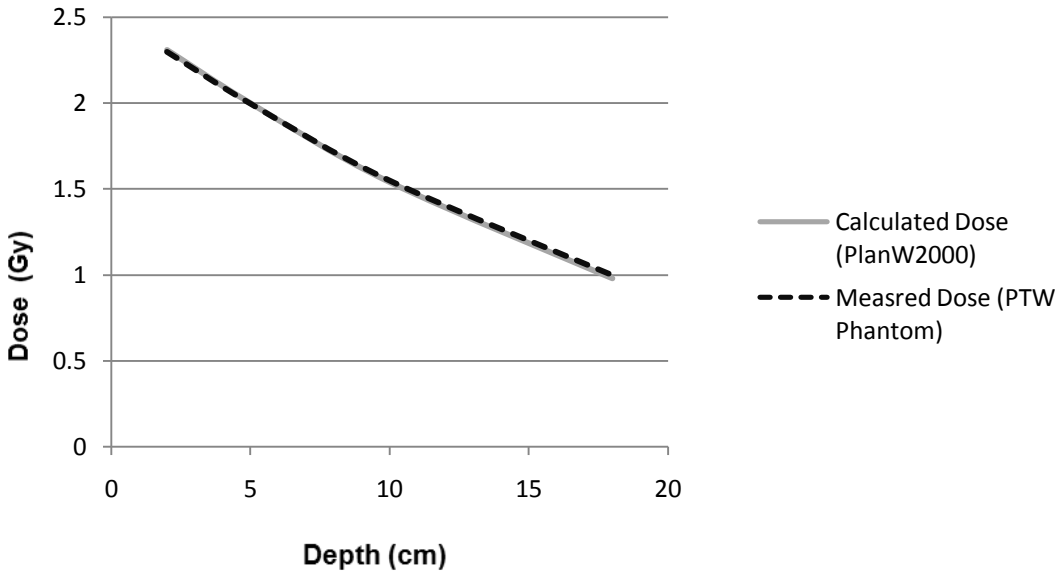

Figure 4.8: Calculated and measured Dose Points at the central axis for 6MV Photon Energy, 266 MU, and 15 ˚ wedge–Right.

As shown in *(figure4.8)*above there is a good agreementbetween the measured to dose points and the calculated points with an average difference of ±0.7525%; this good agreement is due to the accuracy of the pencil beam algorithm in the PlanW2000 TPS.

Table 4.9: Calculated and measured dose at central axis points for 6 MV photon beam energy, 265 M), and 15° wedge-left:

Depth (cm)	Calculated (PlanW2000) (Gy)	Measured (PTW Phantom) (Gy)	Error (%)
2	2.320	2.334	0.60%
5	2.000	2.031	1.53%
10	1.550	1.570	1.27%
18	0.990	1.011	2.08%

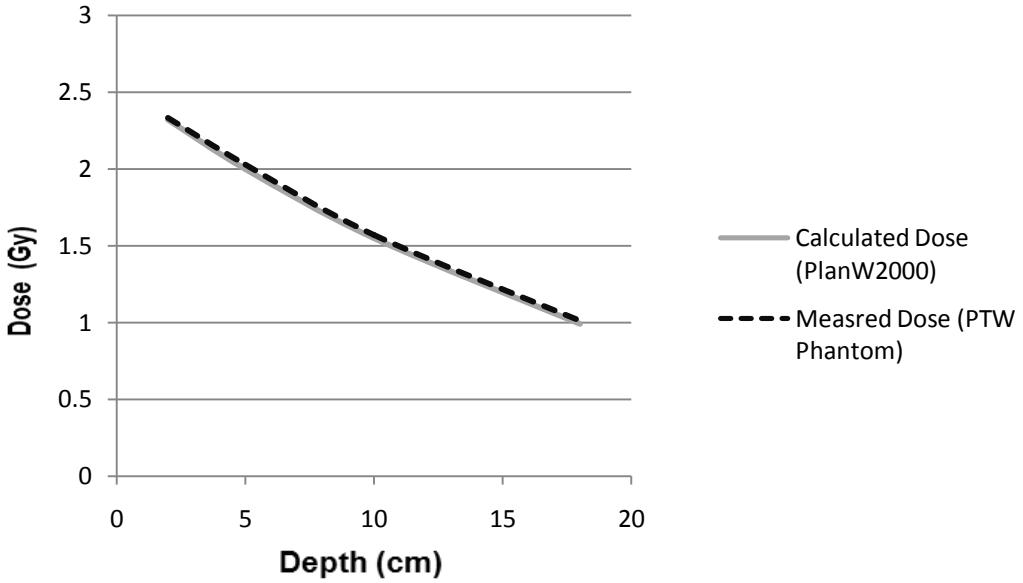

Figure 4.9:Calculated and measured Dose Points at central axisfor 6MV Photon Energy, 327 MU, 269 MU, and 15˚ wedge –Left.

As shown in (figure4.9) above there is a good agreement between the measured dose points and the calculated Dose points with an average difference value of ±1.370 %; the deviation increased with greater depths, which is within the acceptable limit.

Table 4.10: Calculated and measured dose at central axis points for 6 MV photon beam energy, 327 MU, and 30˚ wedge –In:

Depth (cm)	Calculated (PlanW2000) (Gy)	Measured (PTW Phantom) (Gy)	Error (%)
2	2.270	2.287	0.74%
5	2.000	2.003	0.15%
10	1.550	1.556	0.39%
18	1.010	1.012	0.20%

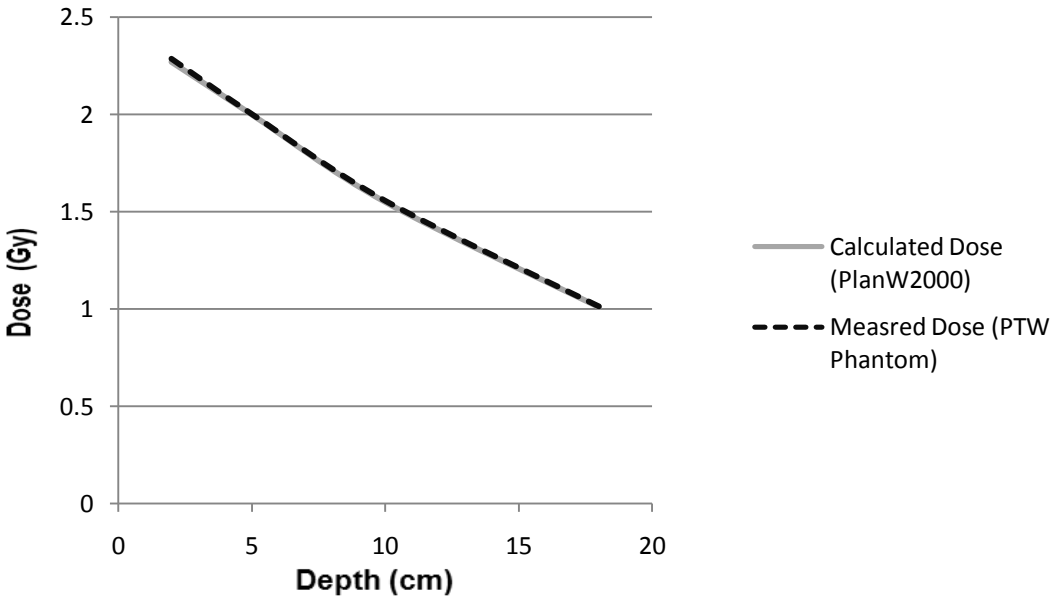

Figure 4.10:Calculated and measured Dose Points at central axis for6MV Photon Energy, 327 MU, and 30˚ wedge –In.

As shown in (*figure4.10)*above there is a good agreementbetween the measured to dose points and the calculated points with an average difference of ±0.0.370%; this good agreement is due to the accuracy of the pencil beam algorithm in the PlanW2000 TPS.

Table 4.11: Calculated and measured dose at central axis points for 6 MV photon beam energy, 327MU, 30˚ wedge –Out:

Depth (cm)	Calculated (PlanW2000) (Gy)	Measured (PTW Phantom) (Gy)	Error (%)
2	2.270	2.287	0.74%
5	2.000	2.003	0.15%
10	1.550	1.556	0.39%
18	1.010	1.012	0.20%

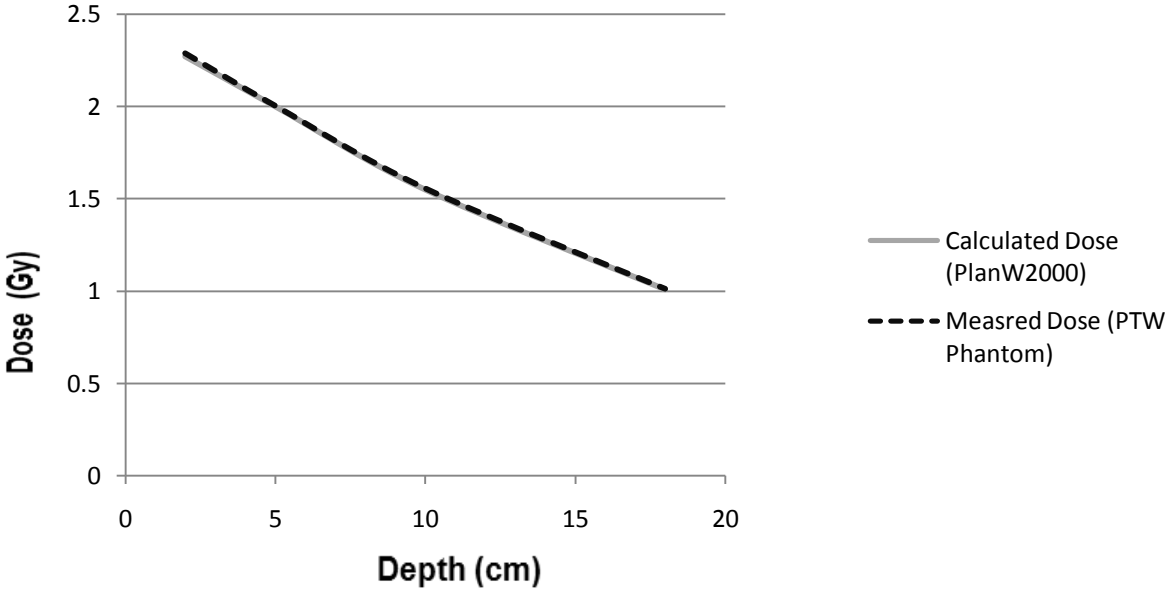

Figure 4.11: Calculated and measured Dose Points at central axis for6MV Photon Energy, 327 MU, and 30˚ wedge –Out.

As shown in (*figure4.11)*above there is a good agreementbetween the measured to dose points and the calculated points with an average difference of ±0.0.370%; this good agreement is due to the accuracy of the pencil beam algorithm in the PlanW2000 TPS.

Table 4.12: Calculated and measured dose at central axis points for 6 MV photon beam energy, 327 MU, 30˚ wedge –Right:

Depth (cm)	Calculated (PlanW2000) (Gy)	Measured (PTW Phantom) (Gy)	Error (%)
2	2.229	2.293	2.79%
5	2.000	2.005	0.25%
10	1.530	1.553	1.48%
18	0.980	1.006	2.58%

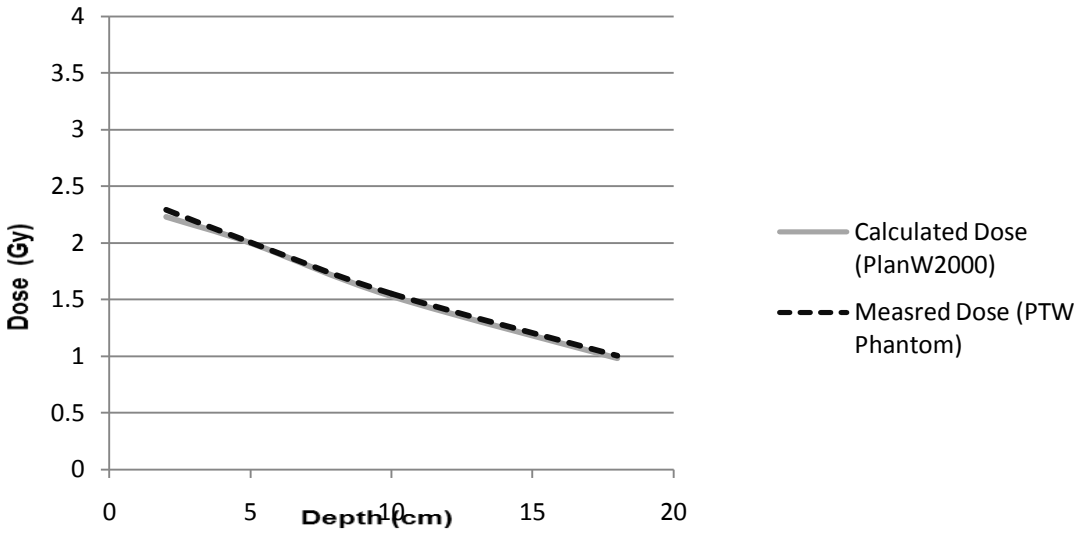

Figure 4.12: Calculated and measured Dose Points at central axis for 6MV Photon Energy, 327MU,and 30˚ wedge –Right.

As shown in (*figure4.12)* above there are small deviation betwixt the measured and calculated dose at depth of 2 cm; this deviation is caused by the experimental error due to the difficulties of measuring at reference effective point at small depth. The deviations betwixt measured dose points and calculated Dose points were within the acceptable limit with an average difference value of ±1.775 %.

Table 4.13**:** Calculated and measured dose at central axis points for 6 MV photon beam energy, 429 MU, 30˚ wedge –Left:

Depth (cm)	Calculated (PlanW2000) (Gy)	Measured (PTW Phantom) (Gy)	Error (%)
2	2.310	2.287	-1.01%
5	2.000	2.011	0.55%
10	1.540	1.561	1.35%
18	0.980	1.014	3.35%

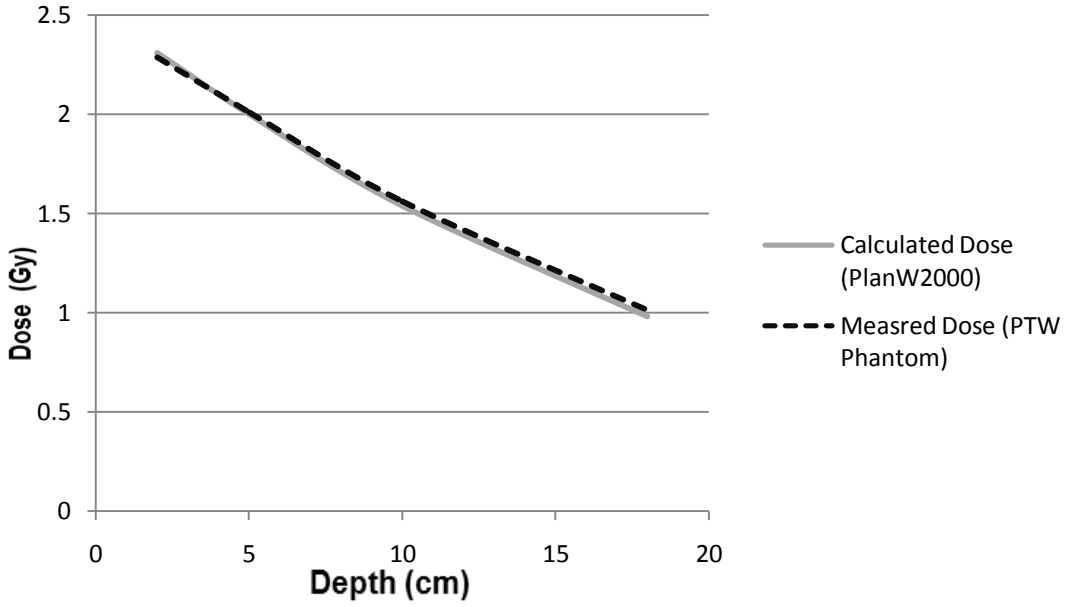

Figure 4.13:Calculated and measured Dose Points at central axis for 6MV Photon Energy, 327MU,and 30˚ wedge –Left.

As shown in (*figure4.13)*above there are small deviation betwixt the measured and calculated dose at depth of 2 cm; this deviation is caused by the experimental error due to the difficulties of measuring at reference effective point at small depth. The deviations betwixt measured dose points and calculated Dose points were within the acceptable limit with an average difference value of ±1.5650 %.

Table 4.14: Calculated and measured dose at central axis points for 6 MV photon beam energy, 429 MU, 45˚ wedge –In:

Depth (cm)	Calculated (PlanW2000) (Gy)	Measured (PTW Phantom) (Gy)	Error (%)
2	2.260	2.268	0.35%
5	2.000	2.010	0.50%
10	1.560	1.579	1.20%
18	1.020	1.035	1.45%

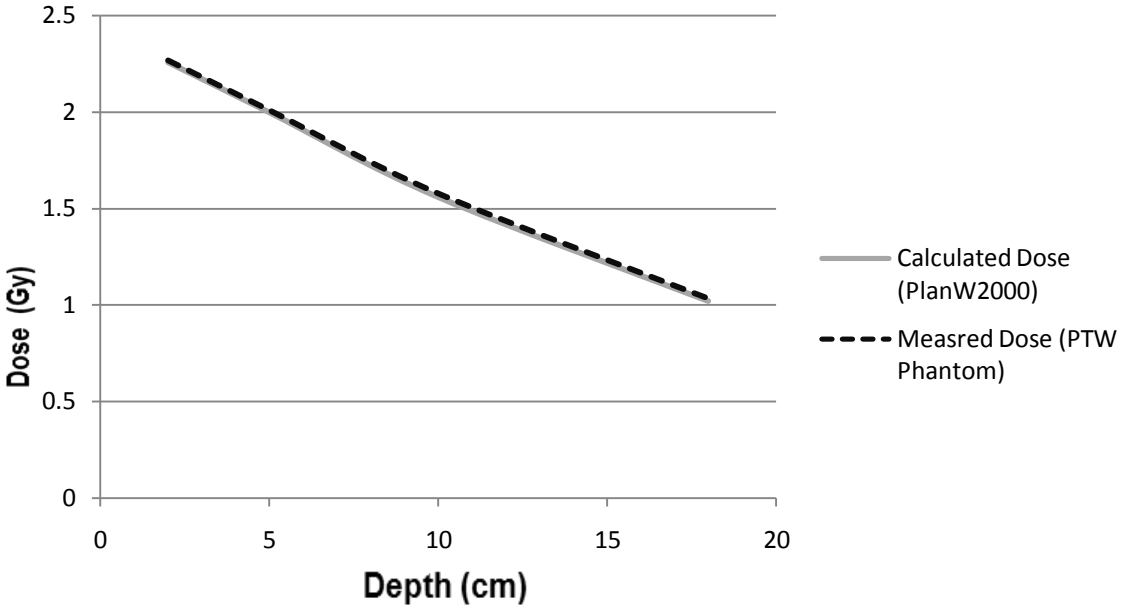

Figure 4.14: Calculated and measured Dose Points at central axis for6MV Photon Energy, 429 MU, And 45˚ wedge –In.

As shown in (*figure4.14)*above there is a good agreementbetween the measured to dose points and the calculated points with an average difference of ±0.875%; this good agreement is due to the accuracy of the pencil beam algorithm in the PlanW2000 TPS.

Table 4.15: Calculated and measured dose at central axis points for 6 MV photon beam energy, 429 MU, 45˚ wedge –Out:

Depth (cm)	Calculated (PlanW2000) (Gy)	Measured (PTW Phantom) (Gy)	Error (%)
2	2.260	2.298	1.65%
5	2.000	1.991	-0.45%
10	1.560	1.570	0.64%
18	1.020	1.026	0.58%

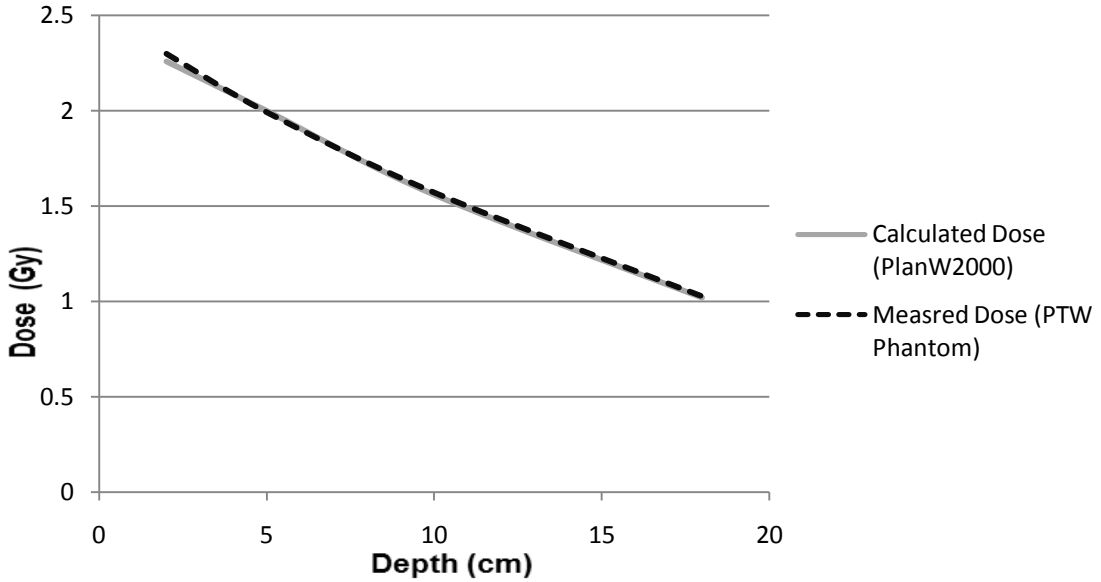

Figure 4.15: Calculated and measured Dose Points at central axis for 6MV Photon Energy, 429MU,and 45˚ wedge –Out.

As shown in (*figure4.15)*above there are small deviation betwixt the measured and calculated dose at depth of 2 cm; this deviation is caused by the experimental error due to the difficulties of measuring at reference effective point at small depth. The deviations betwixt measured dose points and calculated Dose points were within the acceptable limit with an average difference value of ±0.830%.

Table 4.16 Calculated and measured dose at central axis points for 6 MV photon beam energy, 429 MU, 45˚ wedge –Right:

Depth (cm)	Calculated (PlanW2000) (Gy)	Measured (PTW Phantom) (Gy)	Error (%)
2	2.290	2.274	-0.70%
5	2.000	2.000	0.00%
10	1.530	1.527	-0.20%
18	0.980	1.030	4.854%

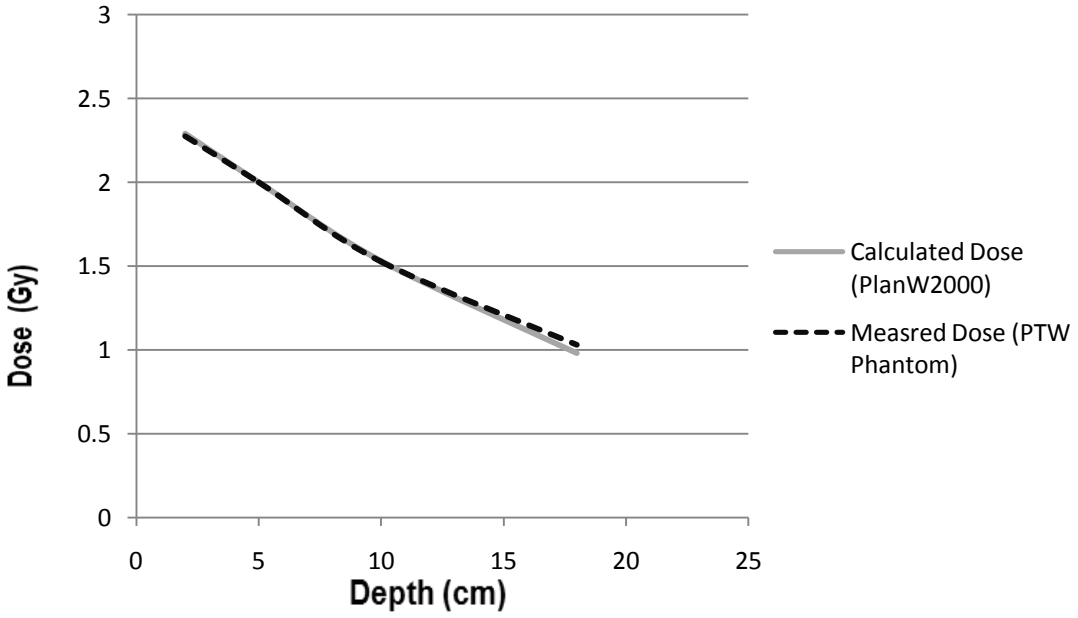

Figure 4.16: *Calculated and measured Dose Points at central axis for* 6MV Photon Energy, 429 MU, and 45˚ wedge -Right.

As shown in (*figure4.16)*above there is a good agreementbetween the measured to dose points and the calculated points with an average difference of ±1.4385%; this good agreement is due to the accuracy of the pencil beam algorithm in the PlanW2000 TPS. The difference increase when the depth increases but still within the acceptable limit.

Table 4.17: Calculated and measured dose at central axis points for 6 MV photon beam energy, 429 MU, 45˚ wedge –Left:

Depth (cm)	Calculated (PlanW2000) (Gy)	Measured (PTW Phantom) (Gy)	Error (%)
2	2.290	2.274	-0.70%
5	2.000	2.002	0.10%
10	1.530	1.550	1.29%
18	0.980	1.021	4.016%

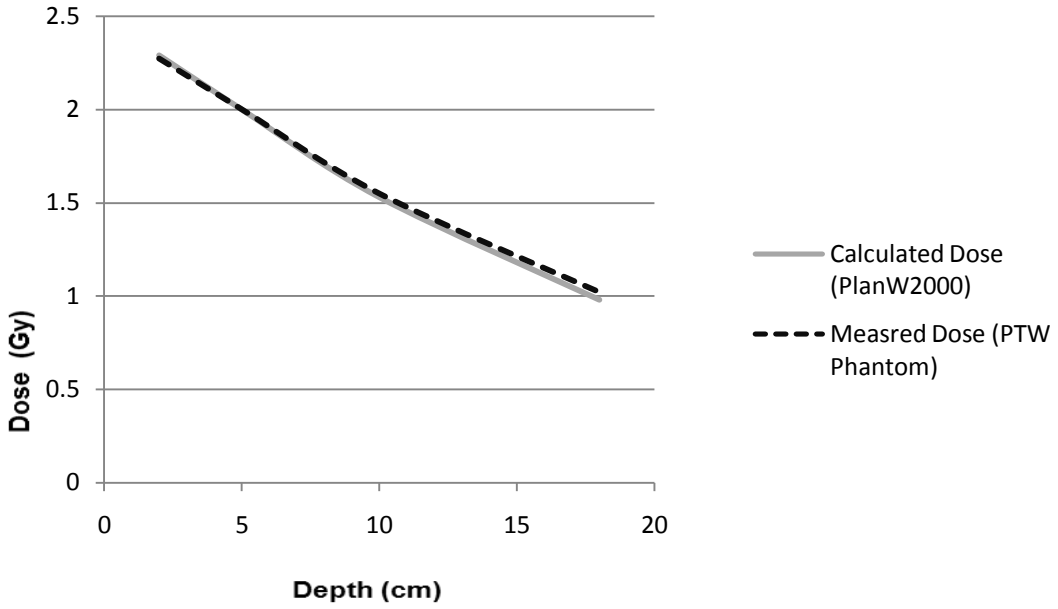

Figure 4.17: Calculated and measured Dose Points at central axis for 6MV Photon Energy, 429 MU, and 45˚ wedge -Left

As shown in (figure4.17) above there is a good agreement between the measured to dose points and the calculated points with an average difference of ±1.5265%; this good agreement is due to the accuracy of the pencil beam algorithm in the PlanW2000 TPS.

Table 4.18: Calculated and measured dose at the off axis points for 6 MV photon beam energy, 266 MU, 15˚ wedge –Right:

Off axis distance (cm)	Calculated (PlanW2000) (Gy)	Measured (PTW Phantom) (Gy)	Error (%)
+3	1.479	1.47	-0.61%
0	1.549	1.54	-0.58%
-3	1.583	1.59	0.44%

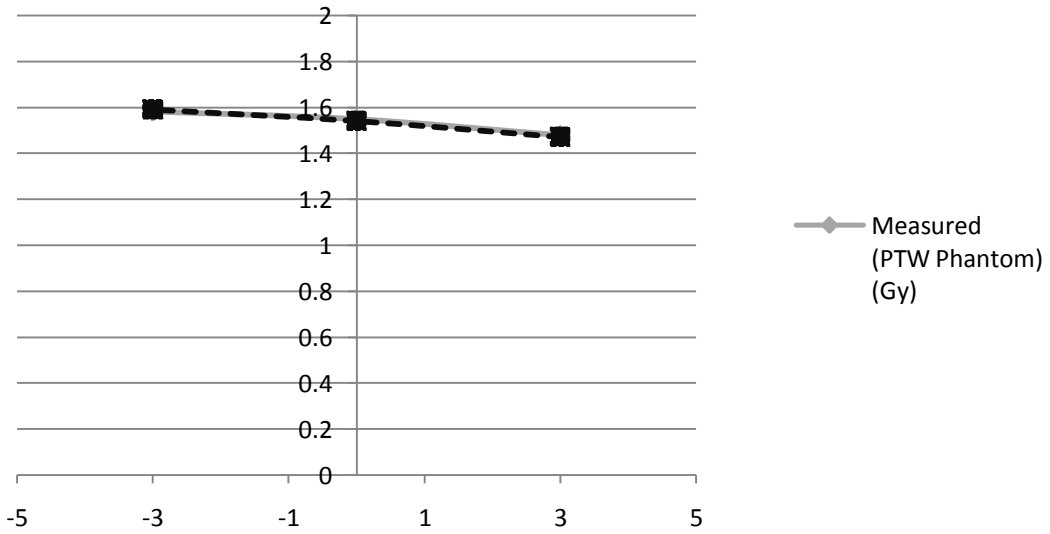

Figure 4.18: Calculated and measured Dose Points for 10 cm depth at the off axis distances(+3.0, 0.0.-3.0 cm) for 6MV Photon Energy, 266 MU, and 15˚ wedge –Right.

As shown in *(figure4.18)* above there is a good agreement between the measured to dose points and the calculated points at the off axis distances with an average difference of ±0.25%; this good agreement is due to the accuracy of the pencil beam algorithm in the PlanW2000 TPS, even when the point is not on the central axis.

Table 4.19: Calculated and measured dose at the off axis points for 6 MV photon beam energy, 327 MU, 30˚ wedge –Right:

Off axis distance (cm)	Calculated (PlanW2000) (Gy)	Measured (PTW Phantom) (Gy)	Error (%)
+3	1.41	1.42	0.70%
0	1.53	1.553	1.48%
-3	1.65	1.664	0.84%

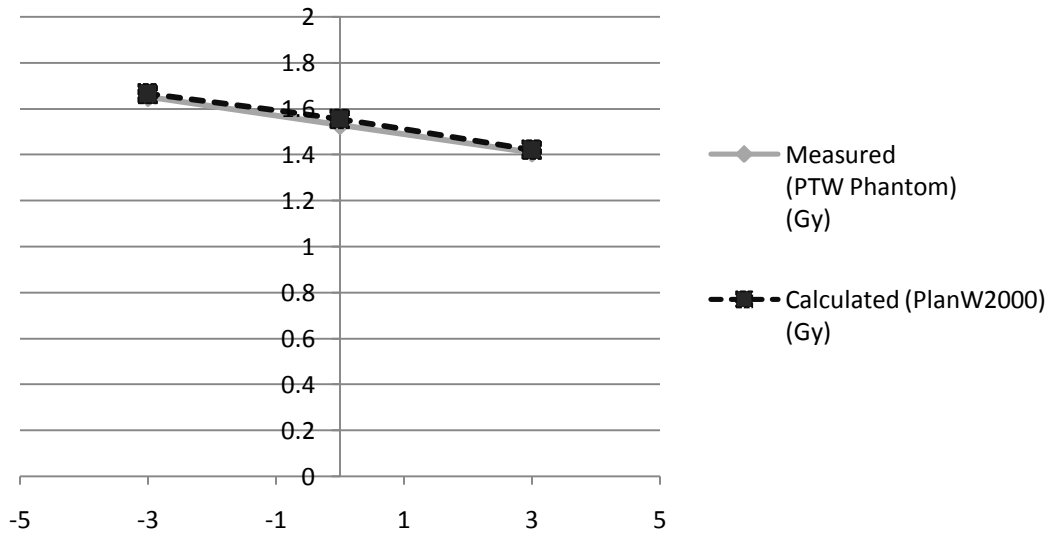

Figure 4.19:Calculated and measured Dose Points for 10 cm depth at the off axis distances(+3.0, 0.0.-3.0 cm) for 6MV Photon Energy, 327 MU, and 30˚ wedge –Right.

As shown in *(figure4.19)* above there is a good agreement between the measured to dose points and the calculated points at the off axis distances with an average difference of ±1.01%; this good agreement is due to the accuracy of the pencil beam algorithm in the PlanW2000 TPS, even when the point is not on the central axis.

Table 4.20: Calculated and measured dose at the off axis points for 6 MV photon beam energy, 429 MU, 45˚ wedge –Right:

Off axis distance (cm)	Calculated (PlanW2000) (Gy)	Measured (PTW Phantom) (Gy)	Error (%)
+3	1.34	1.374	2.47%
0	1.53	1.572	2.67%
-3	1.73	1.751	1.20%

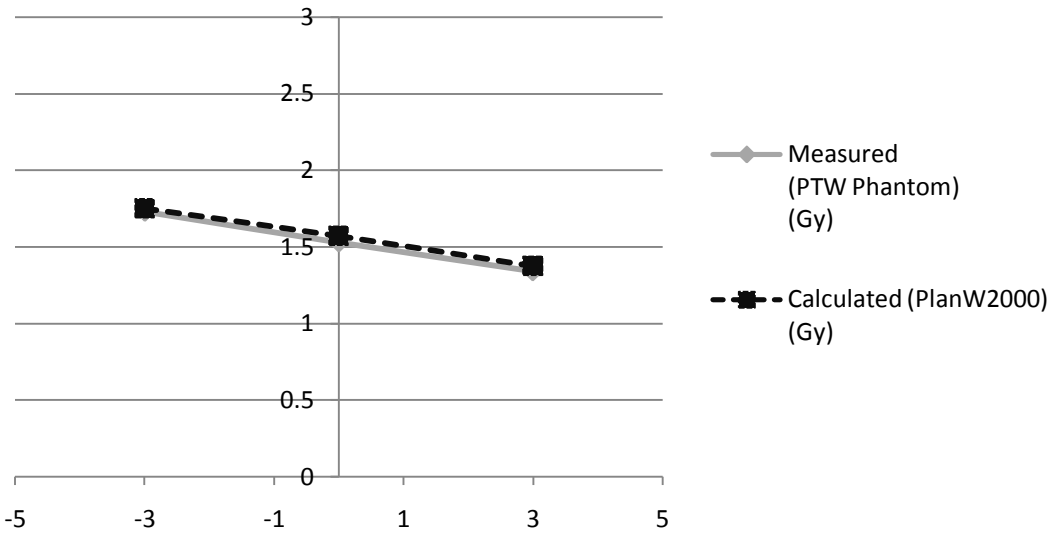

Figure 4.20:Calculated and measured Dose Points for 10 cm depth at the off axis distances(+3.0, 0.0.-3.0 cm) for 6MV Photon Energy, 429 MU, and 45˚ wedge –Right.

As shown in *(figure4.20)* above there is a good agreement between the measured to dose points and the calculated points at the off axis distances with an average difference of 2.11%; this good agreement is due to the accuracy of the pencil beam algorithm in the PlanW2000 TPS, even when the point is not on the central axis.

4.2.2 Percentage Depth Dose verification:

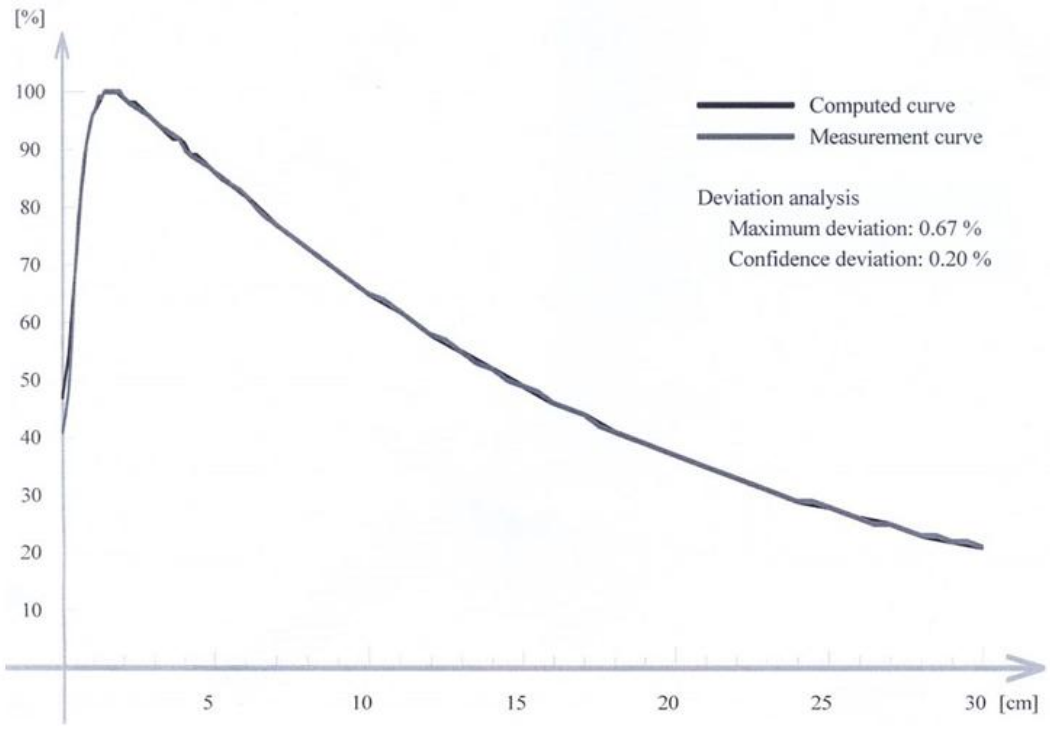

Figure 4.21: A comparison between measured and calculated depth dose data of 6 MV photons generated by Varian MDX linear accelerator at 100 cm SSD with 7×7 cm^2. The depth doses divided by monitor unit are normalized at 2 cm depth. The dark line represents calculated data and bright line represents measured data.

As shown in *(figure 4.21)* the computed PDD curve (Calculated PDD curve by the TPS) and the measured PDD curve (Measured form the PTW Phantom) show a good agreement within the acceptable value for the maximum deviation of (0.67 %), and Confidence deviation of (0.20 %).

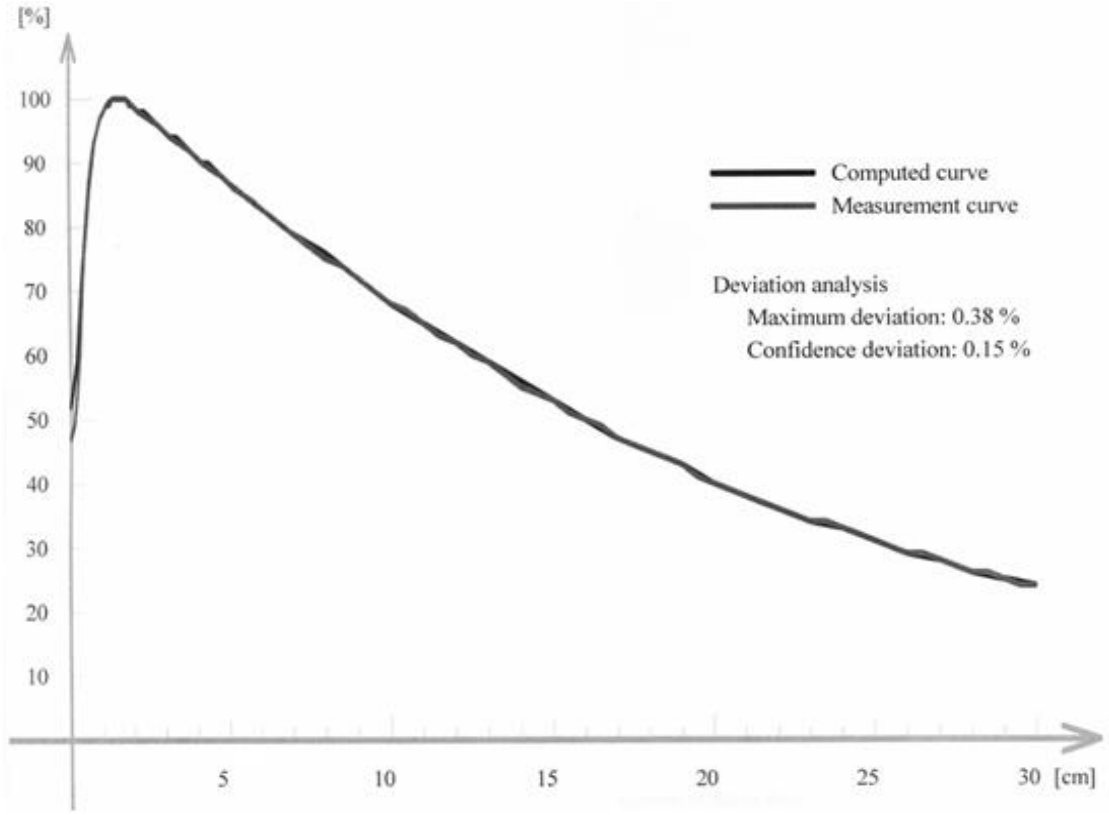

Figure 4.22: A comparison between measured and calculated depth dose data of 6 MV photons generated by Varian MDX linear accelerator at 100 cm SSD with 13×13 cm^2. The depth doses divided by monitor unit are normalized at 2 cm depth. The dark line represents calculated data and bright line represents measured data.

As shown in *(figure 4.22)* the computed PDD curve (Calculated PDD curve by the TPS) and the measured PDD curve (Measured form the PTW Phantom) show a good agreement within the acceptable value for the maximum deviation of (0.38 %), and Confidence deviation of (0.15 %).

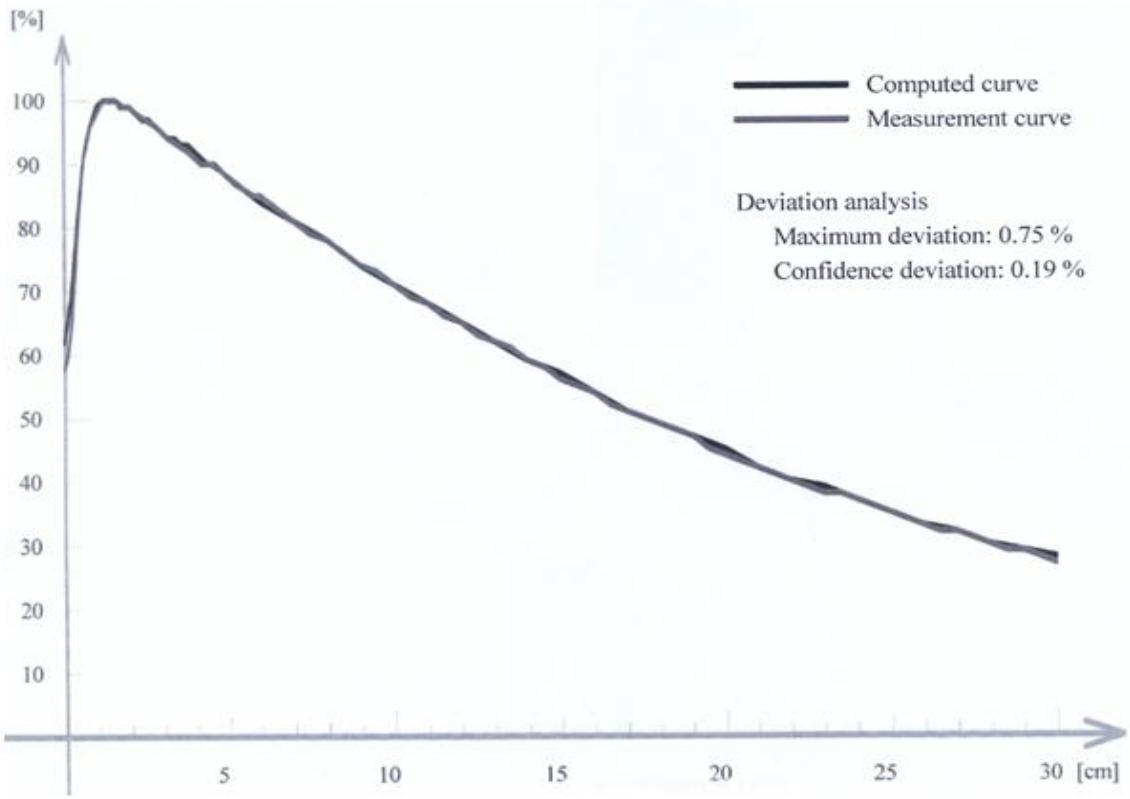

Figure 4.23: A comparison between measured and calculated depth dose data of 6 MV photons generated by Varian MDX linear accelerator at 100 cm SSD with 27×27 cm^2. The depth doses divided by monitor unit are normalized at 2 cm depth. The dark line represents calculated data and bright line represents measured data.

As shown in *(figure 4.23)* the computed PDD curve (Calculated PDD curve by the TPS) and the measured PDD curve (Measured form the PTW Phantom) show a good agreement within the acceptable value for the maximum deviation of (0.75 %), and Confidence deviation of (0.19 %).

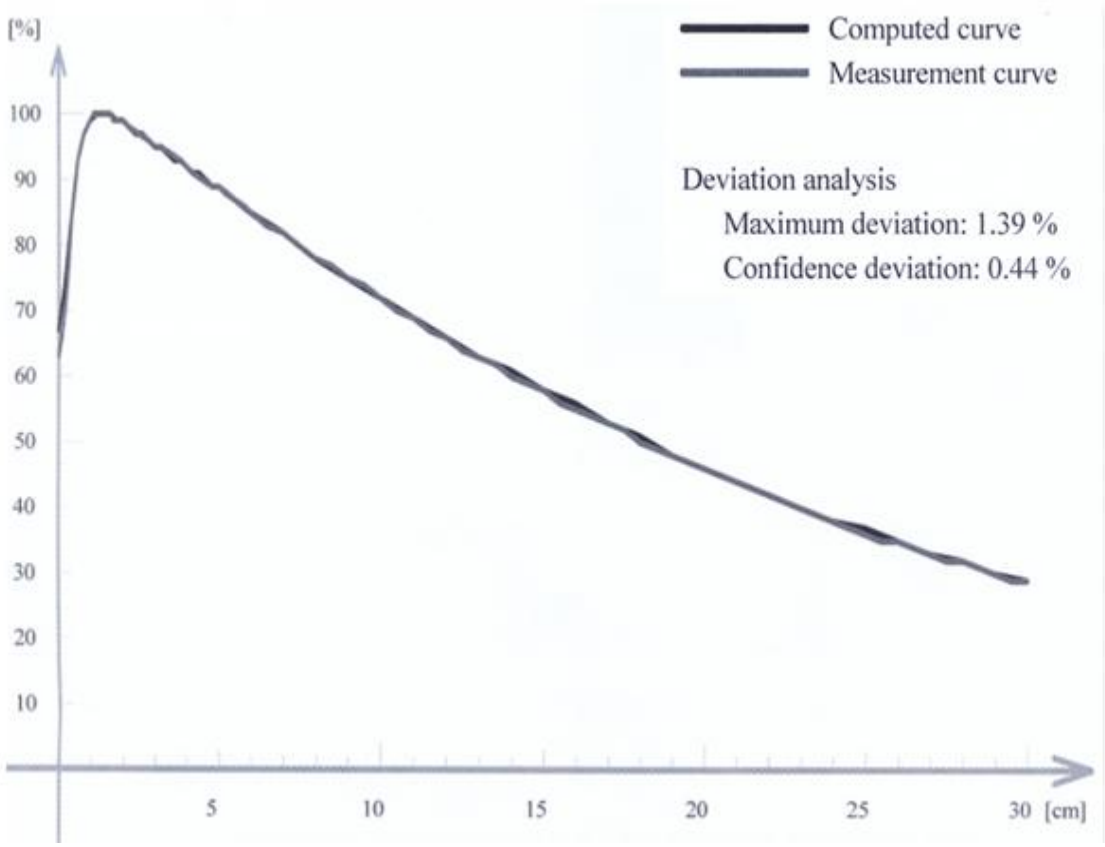

Figure 4.24: A comparison between measured and calculated depth dose data of 6 MV photons generated by Varian MDX linear accelerator at 100 cm SSD with 37×37 cm^2. The depth doses divided by monitor unit are normalized at 2 cm depth. The dark line represents calculated data and bright line represents measured data.

As shown in *(figure 4.24)* the computed PDD curve (Calculated PDD curve by the TPS) and the measured PDD curve (Measured form the PTW Phantom) show a good agreement within the acceptable value for the maximum deviation of (1.39 %), and Confidence deviation of (0.44 %).

4.2.3 Photon Beam Profiles verification :

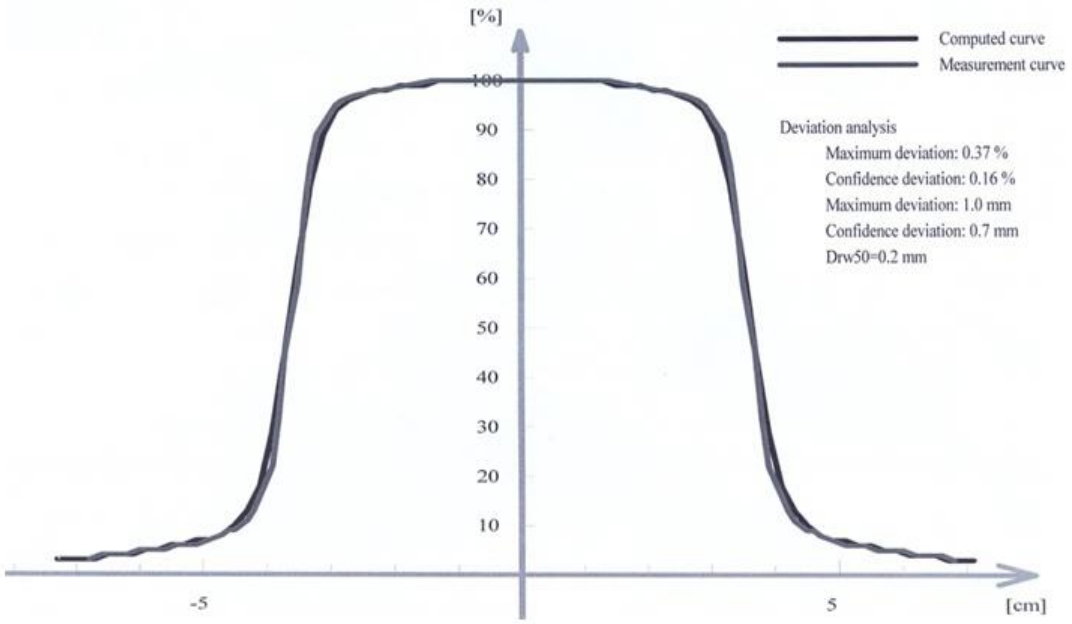

Figure 4.25: A comparison between measured and calculated beam profiles of 6 MV photons generated by Varian MDX linear accelerator at 100 cm SSD with 7x7 cm^2 field size, open field, and in the In-plane direction .The doses divided by monitor unit are normalized at 10 cm depth . The dark lines represent calculated data and bright lines represent measured data.

As shown in *(figure 4.25)* the computed Profile curve (Calculated profile curve by the PlanW2000 TPS) and the measured Profile curve (Measured form the PTW Phantom) show a good agreement within the acceptable value for the maximum deviation of (0.37 %), and Confidence deviation of (0.16%), in the 7x7 cm^2 field size the value of the maximum deviation is 1.0 mm, and the confidence deviation is 0.7 mm. all the value above shows the accuracy of the PlanW2000 TPS.

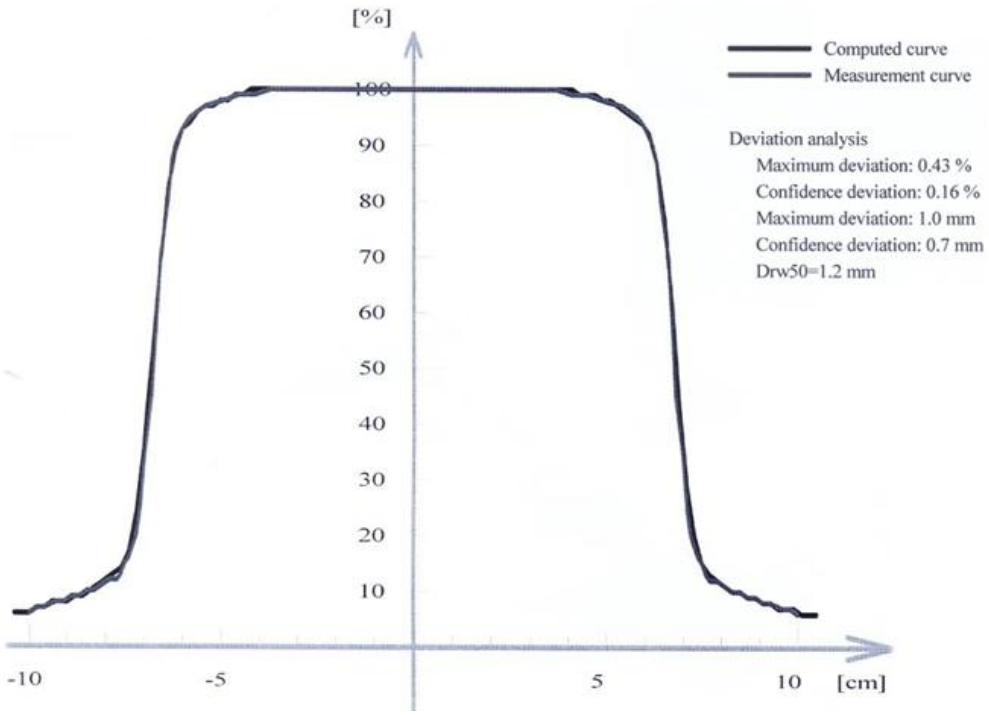

Figure 4.26: A comparison between measured and calculated beam profiles of 6 MV photons generated by Varian MDX linear accelerator at 100 cm SSD with 13×13 cm^2 field size, open field, and in the In-plane direction .The doses divided by monitor unit are normalized at 10cm depth . The dark lines represent calculated data and bright lines represent measured data.

As shown in *(figure 4.26)* the computed Profile curve (Calculated profile curve by the PlanW2000 TPS) and the measured Profile curve (Measured form the PTW Phantom) show a good agreement within the acceptable value for the maximum deviation of (0.43 %), and Confidence deviation of (0.16%), in the 13×13 cm^2 field size the value of the maximum deviation is 1.0 mm, and the confidence deviation is 0.7 mm. all the value above shows the accuracy of the PlanW2000 TPS.

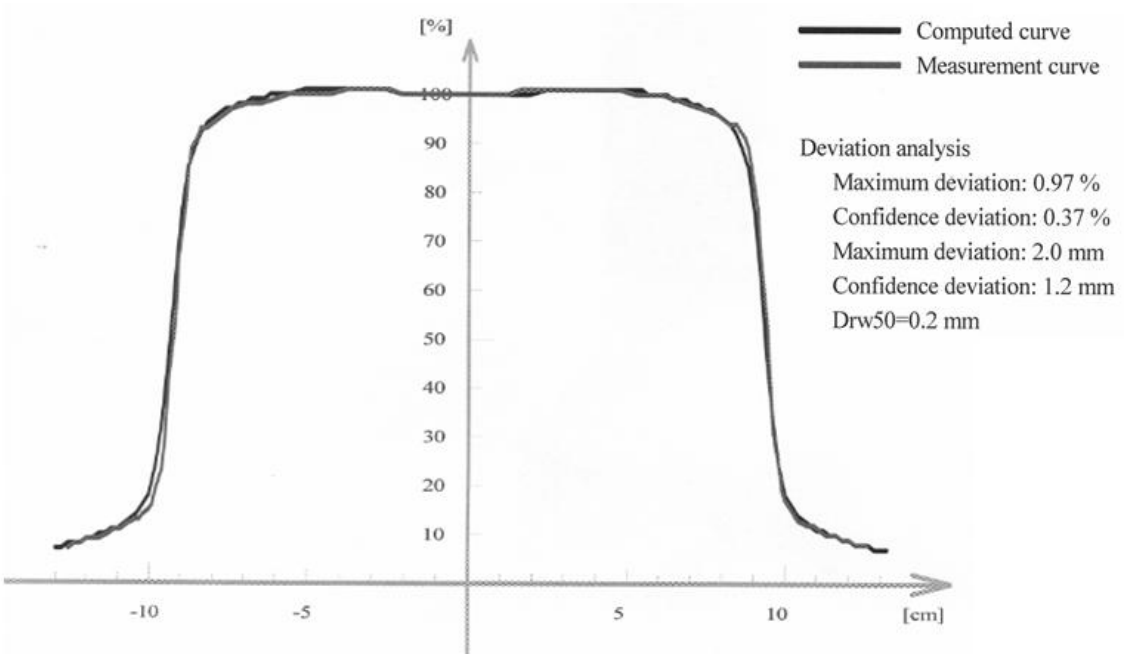

Figure 4.27: A comparison between measured and calculated beam profiles of 6 MV photons generated by Varian MDX linear accelerator at 100 cm SSD with 17×17 cm^2 field size, open field, Diagonal in the In-plain direction .The doses divided by monitor unit are normalized at 10 cm depth . The dark lines represent calculated data and bright lines represent measured data.

As shown in *(figure 4.27)* the computed Profile curve (Calculated profile curve by the PlanW2000 TPS) and the measured Profile curve (Measured form the PTW Phantom) show a good agreement within the acceptable value for the maximum deviation of (0.97 %), and Confidence deviation of (0.37%), in the 17×17 cm^2 field size the value of the maximum deviation is 2.0 mm, and the confidence deviation is 1.2 mm. all the value above shows the accuracy of the PlanW2000 TPS in the diagonal calculation compare with the in-plain and cross-plain.

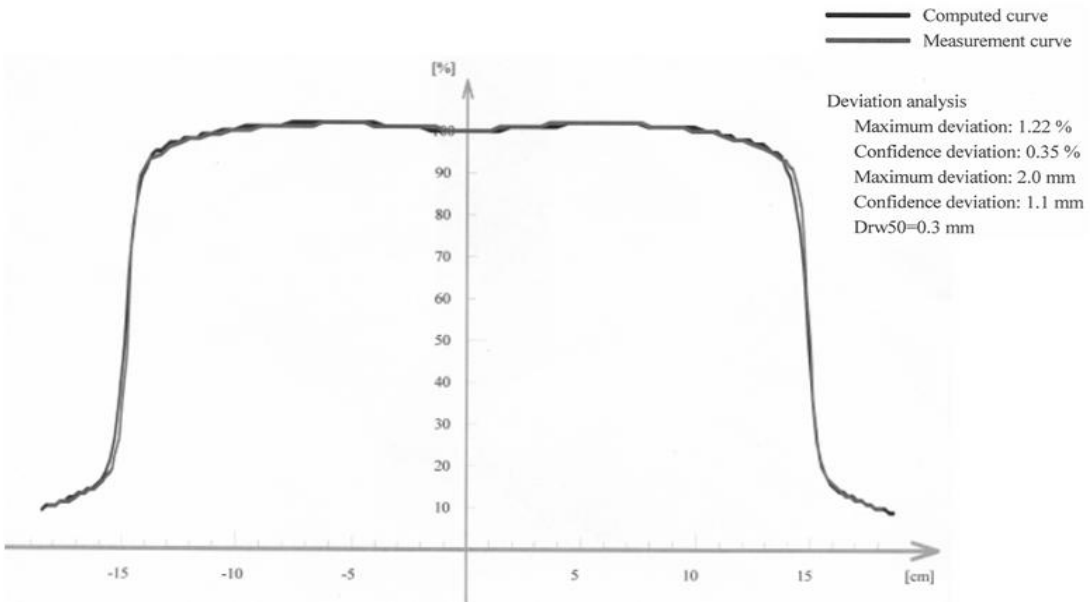

Figure 4.28: A comparison between measured and calculated beam profiles of 6 MV photons generated by Varian MDX linear accelerator at 100 cm SSD with 27×27 cm^2 field size, open field, Diagonal in the In-plain direction .The doses divided by monitor unit are normalized at 10 cm depth . The dark lines represent calculated data and bright lines represent measured data.

As shown in *(figure 4.28)* the computed Profile curve (Calculated profile curve by the PlanW2000 TPS) and the measured Profile curve (Measured form the PTW Phantom) show a good agreement within the acceptable value for the maximum deviation of (1.22 %), and Confidence deviation of (0.35%), in the 27×27 cm^2 field size the value of the maximum deviation is 2.0 mm, and the confidence deviation is 1.1 mm. all the value above shows the accuracy of the PlanW2000 TPS in the diagonal calculation compare with the in-plain and cross-plain.