Dosimetric Characteristics of Electronic Portal Imaging Device (EPID)

Ramesh Krishnan. S, G.Ramani
SRM Institute of Science & Technology Trichy-621105
Lakshmi Narayana Institute of medical sciences Puducherry-605502

Abstract: The modern days IMRT involves quality assurance before every treatment to check the accuracy of the treatment, it involves solid phantom and 0.6cc chamber simulated on the CT machine to minimize the time consuming work, the use of EPID play a major role in treatment quality assurance of IMRT treatment by gamma evaluation method, the procedure involves the commissioning of PDIP algorithm and to verify the characteristics of EPID such as linearity with dose, gravity effects, dose rate dependence.

Keywords: EPID, CU, MU

1. INTRODUCTION

A portal image is an image obtained from a radiotherapy treatment beam. It shows exactly the irradiated area, which is the reason why it is useful for treatment verification, in spite of the inherently lower quality of images obtained from megavoltage radiation, compared to kilovoltage x-ray images. Traditionally, the portal images have been acquired with film, but today it is increasingly common that they are acquired with EPIDs (Electronic Portal Imaging Devices). Advantages of using an EPID is that the images are immediately available without the need for film developing and that they are digital which facilitates image processing and image matching as well as allowing for easy access over a computer network.

The main use for portal images is patient set-up verification, where the EPID image of the patient is matched with a reference image in order to verify that the patient is positioned correctly. This matching can be done on bony structures or on radio-opaque markers, implanted prior to radiation therapy. The advantage of using markers implanted in the target organ is that it gives the position of the organ itself, which is not necessarily static relative to the bony structures.

An EPID has also the potential for use in measurements of various accelerator beam parameters, such as centre of collimator rotation and radiation vs. light field coincidence, or for design and QA of compensators.

There are different possible approaches to use portal dose information for verification,

- Comparison of the measured portal dose image to a predicted image. This in turn could be done either in vivo with a PDI of the patient in position, compared to a predicted image calculated using CT data of the patient.
- Back projection of the transmission dose information in order to calculate the dose in the patient and compare that with the dose distribution from the treatment plan.

It is more precisely the method without patient. It is a method of pre-treatment verification used to ascertain that the radiation fluence is delivered from the accelerator in accordance with the plan. This method would reveal errors in the movement and positioning of the MLC leaves, the correct transfer of the treatment plan and the mechanical and dosimetric performance of the accelerator. The need for pre-treatment verification of this kind mainly occurs in intensity modulated radiotherapy (IMRT) where the high complexity, with changing leaf patterns and non-homogenous dose distributions, increases the risk of errors as well as making the errors more difficult to detect.

This system is called Portal Dosimetry by the manufacturer (Varian Medical Systems). It consists of a set of capabilities which together provide the possibility to perform
• Acquisition of dosimetric images,
• Calculation of predicted dose images,
• Evaluation of acquired vs. predicted images.

The purpose of this study is,

- To calibrate and configure the imager.
- To configure the PDIP algorithm.
- To compare the dose distribution with gamma evaluation method.
- To analyze the characteristics of EPID such as Linearity with dose,

Gravity effects,
Dose rate dependence.

2. MATERIALS AND METHODS

2.1 DESCRIPTION OF EPID

The EPID studied in this work is a Varian aS500 (Varian medical system). It is mounted with a retractable robotic arm (the Exact Arm) on a Varian Clinac 2100C linear accelerator.

The accelerator is capable of delivering 6 MV and 15 MV. The Exact-Arm is used to position the image detector unit (IDU). It allows movement of the IDU vertically from 2.5cm above isocentre to 82 cm below isocentre, laterally ± 16 cm and longitudinally (depending on the vertical position) up to ±24 cm. The sensitive area (which is sometimes referred to as the active matrix) of the imager is 37.9x28.9 cm^2, the active matrix consists of 768 x 1024 pixels, so the size of each pixel is 0.39mmx0.39mm at the detector surface.

The aS500 is an amorphous silicon flat panel imager and it can be divided into four major parts

- A 1mm copper plate to provide build up and absorb scattered radiation.
- A scintillating phosphor screen made of terbium doped gadolinium oxysulphide (Gd_2O_2S: Tb) to convert the incident radiation to optical photons. The scintillating screen has a thickness of 0.34mm.
- A pixel matrix where each pixel is made up of a photodiode and a TFT.
- Electronics to read out the charge from transistors and translate it into image data

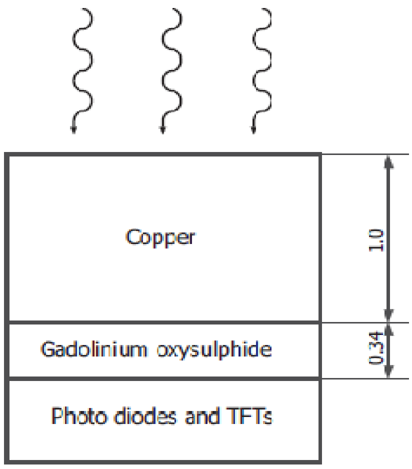

Figure 2

Figure 2 : Schematic view of the different layers of the aS500.

The curved arrows indicate direction of incident radiation. Units are in mm. The copper layer provides build-up. The gadolinium oxysulphide is a scintillator that converts the high energy radiation to optical photons. The photo diode detects the optical photons and the TFT's provide real read out signal.

The imager is enclosed by a protective plastic cover. There is a protective air gap between the protective cover and metal plate. The protective cover is about 4 cm above the effective point of measurement. The build up at the active matrix is equivalent to the 8mm of water so that the dose maximum has not been reached for either of energies used at this accelerator. The scintillating screen implies that the imager is of indirect type,as opposed to a direct type imager. A direct type imager does not have a metal plate or phosphor screen, and the incident radiation is directly sensed by the photo diodes. The advantage of the imager being indirect is it's higher sensitivity.

The indirect detector has higer DQE (Detective Quantum Efficiency) than the direct imager. DQE is a measure of the degradation of information caused by the imaging system relative to the information in the incident beam, DQE is the unity for an ideal detector and lower values mean more degradation. the direct imager has dosimetric properties resembling those of an ionization chamber. The higher average atomic number of the metal plate and gadolinium oxysulphide screen results in that it is more dependent on the energy of the interacting radiation. The indirect detector gives a higher response to lower-energy radiation compared to a direct detector.

In the photodiodes, the incoming light is transferred to electric charge, in the form of electron-pair hole pairs. The charge is temporarily stored in the pixels of the active matrix and later read out one row at a time by switching the TFTs. When a row is activated by the gate electronics all the TFTs of that row are accesible from the read out electronics. The read out is performedd by transferring the charge from the photodiodes to charge amplifiers in the read out electronics. The signal is subsequently converted to a digital signal. The read out electronics also have the role of providing bias voltage to the TFTs. When all the pixels of one row has been read out, the gate electronics switch to the next row. The image from reading out the entire matrix once is called a frame.
The pixels are activated row by row by the gate electronics, thereby enabling the signals to be read by the read-out electronics.

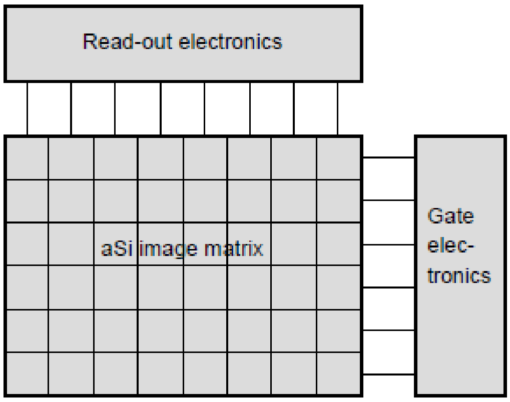

Figure 3

Figure 3 Schematic figure of the pixel matrix and surrounding electronics.

THE GAMMA EVALUATION METHOD

The gamma evaluation method is a means to quantitatively compare dose distributions. The relative dose difference between corresponding pixels is measured. The parts of the image where the dose difference is less than a certain value (ΔD) would pass in the sense and those parts where the difference is higher than the chosen level would fail. It is a suitable method in low gradient regions, but not suitable for high gradient regions of the image, where a small spatial displacement would give rise to large discrepancies in dose.

ΔD is a certain percentage of the dose, either the maximum dose or the local dose value of the reference image.

In regions with high dose gradients it would be more relevant to study the distance to-agreement (DTA). DTA is defined for a point in the reference image as the distance from that point to the closest point in the other image that has the same dose value. The images are not continuous, but made up of discrete pixels, it would include points that are interpolated between pixels. In order for a part of the image to pass it would have to have a DTA lower than the chosen criteria (Δd).

The DTA method is suitable in high gradient regions whereas the dose-difference method is suitable in low gradient regions. One way of comparing two images would be to use both methods with criteria for each method,
$\Delta D \leq 3\%$ and $\Delta d \leq 3$mm.

PREDICTION OF PORTAL DOSE IMAGES

The predicted portal dose image, the measured dose images are compared, and are calculated in the Eclipse treatment planning system (TPS). The calculation is done with an algorithm specifically for this purpose, the PDIP (Portal Dose Image Prediction) algorithm. The PDIP algorithm of Eclipse does not consider the patient and the treatment couch, so it is compared to a measured image without patient or couch. There also exist algorithms that use the planning CT data to calculate an image as obtained with the patient in the beam but this algorithm will focus on the algorithm without patient.

The portal dose image $I_{PD}(x, y)$ is calculated by convolution of the fluence (at the imager plane), ϕ_{EPID}, with a dose kernel, k:

$$I_{PD}(x, y) = \phi EPID(x, y)\ k$$

with x and y denoting position on the imaging plane. The kernel can be thought of as the dosimetric point spread function of the imager. It is radially symmetrical and it is made up of a sum of Gaussians:

$$k = \sum_{i=1}^{n} w_i \exp\left(-\frac{{r_k}^2}{2\sigma_i}\right)$$

where r_k is the distance from the centre of the kernel, n is the number of Gaussian components σ_i is the width of Gaussian i and w_i is the weighting factor for gaussian i with $\Sigma w_i = 1$. The parameters of the gaussians are obtained by a least-squares fit of a portal dose prediction to a portal dose measurement of a special test field.

CALIBRATION AND CONFIGURATION

The configuration of the system for dose verification consists of two parts: configuration of the imager and of the algorithm for predicting images, which is called the PDIP (Portal Dose Image Prediction) algorithm. The calibration and configuration are done in the product of eclipse and portal dosimetry.

PROCEDURE

Two images are required, a flood field image and a dark field image. These two images are also a part of the configuration process for standard imaging with the EPID. For dosimetry purposes, in addition to acquiring these images, a correction for the beam profile must be made, for absolute dosimetry, the dose needs to be normalized. All this information must be obtained separately for each combination of dose rate and energy, except the beam profile correction which only needs to be done for each energy.

The purpose of the dark field image is to correct for dark current in the pixels. The image is the average of several frames, acquired with the EPID in imaging position but without radiation.

The flood field image is acquired while irradiating the EPID with an open field. The field should be large enough to cover the entire sensitive area of the detector, but care should be taken so as not to irradiate the electronics around the sensitive area. The flood field is used to correct for sensitivity differences between the individual pixels. Like the dark field image, it is the average of several frames. The manufacturer recommends that at least 50 frames are acquired when performing the dark field and flood field calibration.

The flood field calibration does not take into account off-axis variations of the beam intensity. The beam profile at the Dmax depth of the active matrix usually exhibits characteristic "horns" as a result of complying with a flatness specification at greater depth. For ordinary imaging purposes, such as in patient set-up verification, it is not necessary to correct for this inhomogeneity. In dosimetry however, it gives rise to errors of up to 5%. The correction for beam profile shape is made with a beam profile measured at the largest field size possible (40×40 cm^2) diagonally from the central axis of the field. This method of correction assumes that the beam fluence is radially symmetrical around the central axis. For configuration, this profile was measured with an ion chamber at Dmax depth in an RFA water phantom

The unit in which the dose images are displayed is CU (calibrated unit), which is a unit that is specific to Varian's Portal Dosimetry. The calibration is performed so that 100 MU delivered with a 10×10 cm^2 field is normalized to a reading of 100 CU if the detector was positioned at isocenter distance (SSD = 100 cm). This choice of normalization makes 1 CU roughly correspond to 1cGy in reference conditions.

After these four steps –the dark field, the flood field, the beam profile and the normalization –the part of the configuration that is related to the IDU is complete.

CONFIGURING THE PDIP ALGORITHM

Three measurements are required for the configuration of the PDIP algorithm:

- A specific test field,
- Output factors and
- Intensity profile.

The measurement of the test field and the output factors are made with the EPID itself; the intensity profile can be taken from an existing intensity profile in the treatment planning system.

The test field is specially designed for the configuration of the PDIP. It is defined as an optimal fluence, i.e. a field with ideal modulation where the physical and mechanical limitations of the dynamic multi-leaf collimator (DMLC) have not been taken into account. From this optimal fluence the TPS calculates the motion of the DMLC to deliver a fluence as close to the optimal fluence as possible.

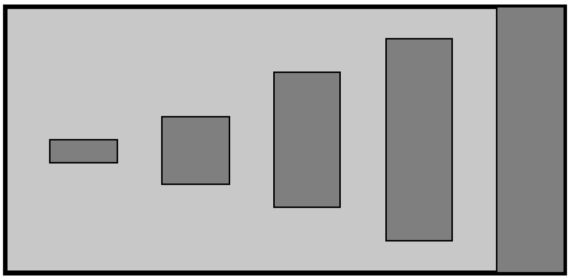

Figure 4

Figure 4: The optimal fluence for the test field.

The optimal fluence is unity in the dark grey areas and zero in the light grey areas. The outer edge indicates the position of the collimators. The field is 12×25 cm^2.

From this optimal fluence the TPS calculates the motion of the DMLC to deliver a fluence as close to the optimal fluence as possible. The shape of the test field, i.e. the optimal fluence of the test field, shown in fig 7. This field is delivered by the linac and measured by the EPID and the resulting image is used to calculate the kernels of the PDIP algorithm. The measurement is performed twice for each energy; once at SDD =100 cm and once at SDD =140 cm, 176 MU were used for 6 MV and 159 MU used for 15 MV as calculated by the TPS.

The output factors are measured for field sizes from 3×3cm^2 to 28×38cm^2. 28×38cm^2 is the largest field size that can be measured at SDD=100 cm since a larger field would irradiate the sensitive electronics of the imager. However, both X=28 cm, Y=38 cm and X=38 cm, Y=28 cm can be measured by turning the collimator 90^0, between those measurements. The values of the output factors are taken from the acquired dose images, by using the "dose profile tool" of Eclipse and taking the reading at the centre of the image.

LINEARITY WITH DOSE

The method of calibration for the aS500 is based on the idea that the reading of the EPID is linear to the dose it has received. To ascertain the linearity of the aS500, its response was measured for radiation fields with varying number of MUs. These measurements were done for both 6 MV and 15 MV. The MUs were in the range 50 MU to 500 MU. All the fields were measured at the same occasion. The field size was 10×10 cm^2, centred at the central axis. The collimator angle and the gantry angle were both 0°. The imager was positioned at SDD = 100cm. The measured dose was taken at the 10×10 cm^2 pixel area at the centre of the image.

GRAVITY EFFECTS

When irradiating the EPID at different gantry angles, errors may occur due to the effect of gravity on gantry and on the Exact Arm with the IDU. Possible reasons for these errors, if they occur, could be either changes in output, changes in the positions of the MLC leaves or changes in the position of the IDU. The ideal would of course be that there are no gravity effects, i.e. that there is no more difference between two images of identical fields at different gantry angles than when measured at the same gantry angle.

In order to study the effect of the gantry angle on the dose image for 15 MV Photon beam, the EPID was irradiated with an identical field at gantry angles of 0°–330°, with increments of 30°. The field used in this investigation is an intensity modulated field delivered with the sliding window method using the DMLC. The image acquired at 0° was used as a reference and the other images were compared to this reference by means of the gamma evaluation method. The average value was then plotted as a function of gantry angle. The gamma evaluation and calculation of the average was done, with acceptance criteria of $\Delta D \leq 1\%$ and $\Delta d \leq 1mm$.

DOSE RATE DEPENDENCE

The pixel values should be a function of dose only, and not on dose rate. In particular, the imager must be able to accurately measure the dose even at high dose rates, without being saturated, although mainly small errors except for the highest dose rates. In that case the saturation was caused by the read out of the frames; the dependence on dose rate was investigated in order to ascertain the independence of the imager on dose rate, or to describe the dependence if it exists. The dose rate dependence for 6 MV and 15 MV photon beam was studied by

- Changing the dose rate setting of the linac, while keeping the imager at a constant SDD of 100 cm. Dose rate settings from 100MU/min to 400MU/min were used, with increments of 100MU/min. A field size of 10×10 cm^2 was used.

3. RESULTS

- Acquired image of the test field for calculation of the kernels of the PDIP algorithm for 6 MV and 15 MV at SSD = 100 cm is shown.
- Acquired kernel shape for the 6 MV and 15 MV photon beam is shown in figure 7 and 8.
- Table1 shows the Gamma evaluation result for the optimal fluence for the 6 MV photon beam for the predicted and acquired image, it is shown in figure 9.
- Table 2 shows the gamma evaluation result for the optimal fluence for the 15 MV photon beam, it is shown in figure 10.
- Table 3 shows the measured output Vs monitor units of the EPID for 6 MV photon beam
- Table 4 shows the measured output Vs monitor units of the EPID for 15 MV photon beam
- Table 5 shows the gamma evaluation result for the fluence field for the EPID at different gantry angles for 15 MV photon beam
- Table 6 shows the measured output Vs dose rate of the EPID for the 6 MV photon beam and graphical representation is shown .
- Table 7 shows the measured output Vs dose rate of the EPID for the 15 MV photon beam and graphical representation is shown .

4. DISCUSSION

- The output of the EPID is measured for different field sizes and found to be increasing with the increase in the field size for both 6MV and 15 MV.
- The output factor is calculated for both 6 MV and 15 MV and it is also found increasing with the increase in the field size.
- The gamma evaluation result for 6 MV and 15 MV shows that the area gamma is less than 1%. Hence PDIP algorithm is successfully commissioned.

Area gamma for 6 MV is 0.841213%.
Area gamma for 15 MV is 0.532247%.

- The EPID shows the increase in the output when the monitor unit is increased. Thus the dose linearly increases with the linear increase in the monitor units.
- There must be no difference for the acquired fluence in the EPID for different gantry angles, it is found to be that the area gamma is less than 1% for 0^0 to 60^0 and 270^0 to 330^0 but area gamma is more than 1% for other gantry angles between 90^0 and 240^0 for 15 MV photon beam.
- The EPID output is same for all dose rate, it shows the EPID output is independent of dose rate for both 6 MV and 15 MV.

5. CONCLUSION

The characteristics of EPID was analysed and found that the response of detector is linear with dose and independent of dose rate and also found that gravity effect for gantry angle between 90^0-240^0 which is not clinically significant. The PDIP algorithm for both 6 MV and 15 MV photon beam has been commissioned successfully. Hence we conclude that EPID can be used as a quality assurance tool for pre treatment verification.

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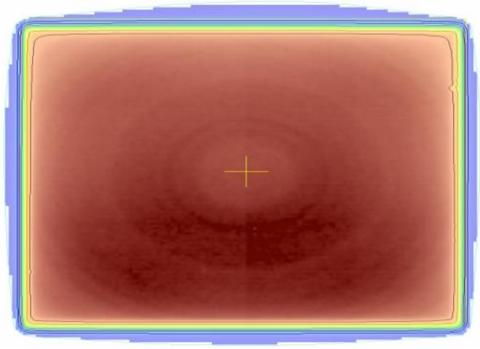

Figure 5 Acquired dose distribution of the imager for the 10x10 cm^2 for the 6 MV photon beam at the SDD = 100cm.

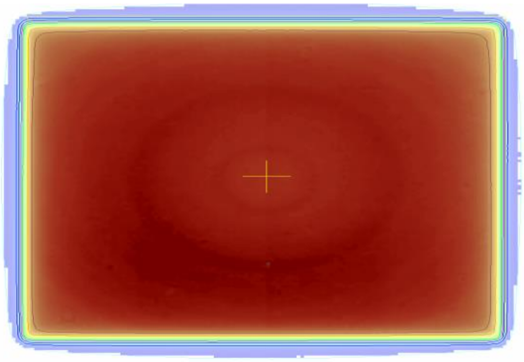

Figure 6 Acquired dose distribution of the imager for the 10x10 cm^2 for the 15 MV photon beam at the SDD = 100cm.

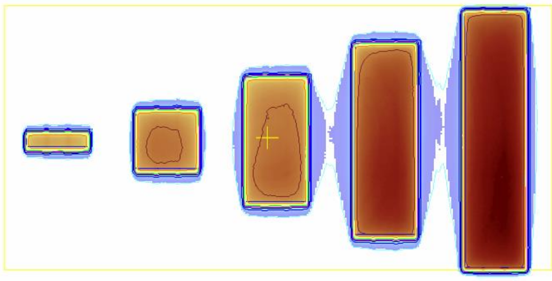

Figure 7: Acquired image of the test field for calculation of the kernels of the PDIP algorithm. This image is taken with 6 MV and SDD = 100 cm. The unit is CU.

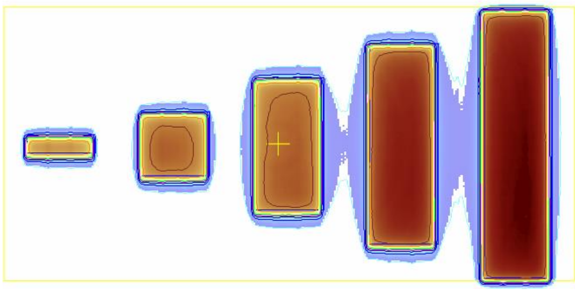

Figure 8: Acquired image of the test field for calculation of the kernels of the PDIP algorithm. This image is taken with 15 MV and SDD = 100 cm. The unit is CU.

TABLE 1
The gamma evaluation result for acquired and predicted image of the fluence for 6 MV photon beam,

S.NO	LABEL	VALUE
1	Dose difference criterion (%)	4.00000
2	DTA criterion (mm)	4.00000
3	Threshold (fraction of max. dose)	0.00000
4	Maximum gamma	2.67163
5	Average gamma	0.148322
6	Area gamma < 1.0 (%)	0.841213

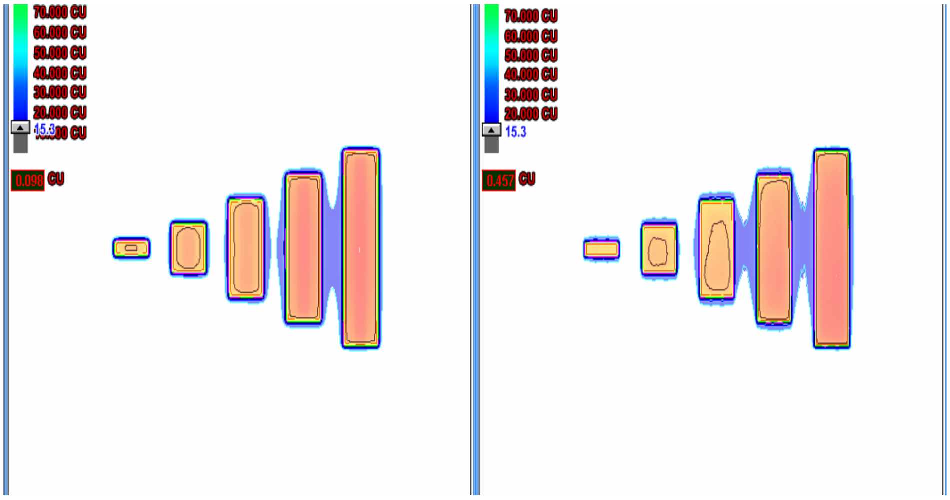

Figure 9 Predicted image and acquired image of the fluence field for 6 MV photon beam at SDD = 100 cm.

TABLE 2
The gamma evaluation result for acquired and predicted image of the fluence for 15 MV photon beam,

S.NO	LABEL	VALUE
1	Dose difference criterion (%)	4.00000
2	DTA criterion (mm)	4.00000
3	Threshold (fraction of max. dose)	0.00000
4	Maximum gamma	2.5444
5	Average gamma	0.127854
6	Area gamma < 1.0 (%)	0.532247

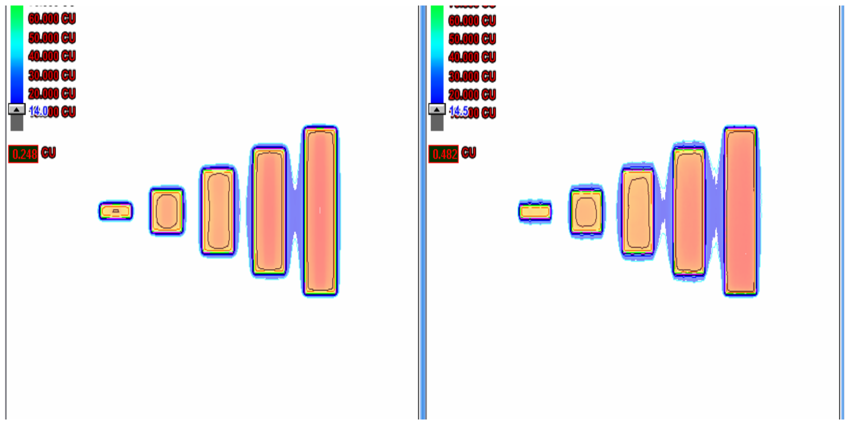

Figure 10 Predicted image and acquired image of the fluence field for 15 MV photon beam at SDD = 100 cm.
The images are not analysed manually in any way, instead they are imported in Eclipse as a part of a configuration of the PDIP algorthim and the Gamma evaluation is done by the eclipse.

LINEARITY WITH DOSE

The measured dose as a function of monitor units is shown in figure 24 & 25, which indicates that the dependence is linear as expected for both 6 MV and 15 MV. The CU is measured and tabulated for both 6 MV and 15 MV and their linearity is shown through graph.

TABLE 3. Measured Output Vs Monitor Units

6 MV DOSE LINEARITY		
S.NO	MU	OUTPUT (CU)
1	50	48.91
2	100	98.833
3	150	148.844
4	200	198.423
5	300	297.842
6	400	397.243
7	500	496.554

TABLE 4. Measured Output Vs Monitor Units

15 MV DOSE LINEARITY		
S. NO	MU	OUTPUT (CU)
1	50	49.574
2	100	100.604
3	150	150.881
4	200	201.871
5	300	302.008
6	400	402.695
7	500	504.694

GRAVITY EFFECTS

The area γ value from the comparison of the reference image (at gantry angle 0°) with the images acquired at the other angles and the graphical representation is shown in figure 26 for gantry angle Vs average gamma.

TABLE 5. The gamma evaluation values for different gantry angles for 15 MV photon beam.

S. NO	Angle	Dose difference criterion (%)	DTA criterion (mm)	Threshold (fraction of max. dose)	Maximum gamma	Average gamma	Area gamma < 1.0 (%)
1	0^0	4.00000	4.00000	0.00000	2.47710	0.13172	0.56198
2	30^0	4.00000	4.00000	0.00000	2.47574	0.13278	0.57861
3	60^0	4.00000	4.00000	0.00000	2.40676	0.13059	0.66681
4	90^0	4.00000	4.00000	0.00000	2.39501	0.13498	1.07541
5	110^0	4.00000	4.00000	0.00000	2.37154	0.14581	1.11693
6	150^0	4.00000	4.00000	0.00000	2.63233	0.15040	1.32401
7	180^0	4.00000	4.00000	0.00000	2.62633	0.14806	1.51996

8	210^0	4.00000	4.00000	0.00000	2.64751	0.14882	1.36300
9	240^0	4.00000	4.00000	0.00000	2.57335	0.14237	1.03592
10	270^0	4.00000	4.00000	0.00000	2.57030	0.13427	0.81263
11	300^0	4.00000	4.00000	0.00000	2.43672	0.12790	0.72909
12	330^0	4.00000	4.00000	0.00000	2.50901	0.12986	0.65018

DOSE RATE DEPENDENCE

The results from the measurements of dose rate dependence are shown in figures 27 and 28.

TABLE 6. Dose Rate vs. CU

6 MV PHOTON BEAM		
S.NO	DOSE RATE	CU
1	100	99.376
2	200	99.975
3	300	100.200
4	400	99.955

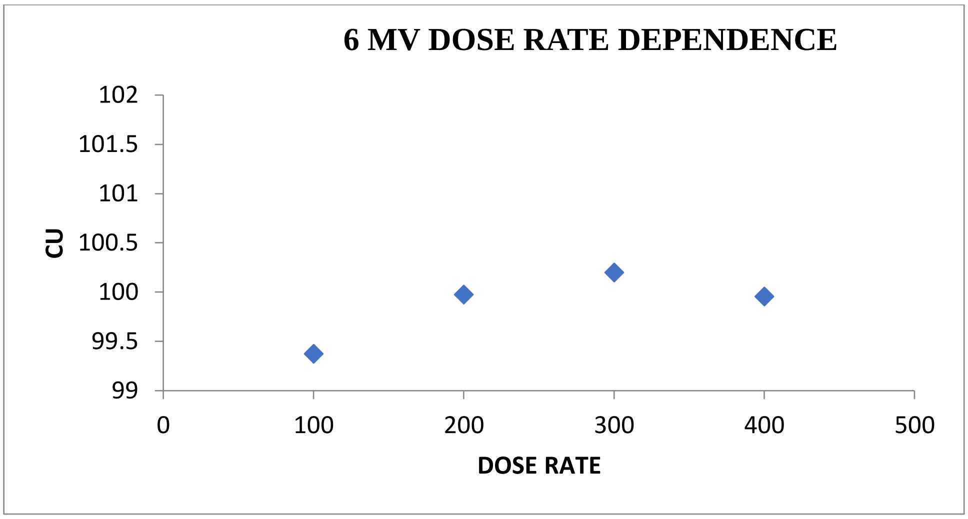

Figure 11 Variation of detector response with dose rate setting of the linac for 6 MV photon beam

TABLE 7

Dose Rate vs. CU

15 MV PHOTON BEAM		
S.NO	DOSE RATE	CU
1	100	99.376
2	200	99.999
3	300	100.577
4	400	99.171

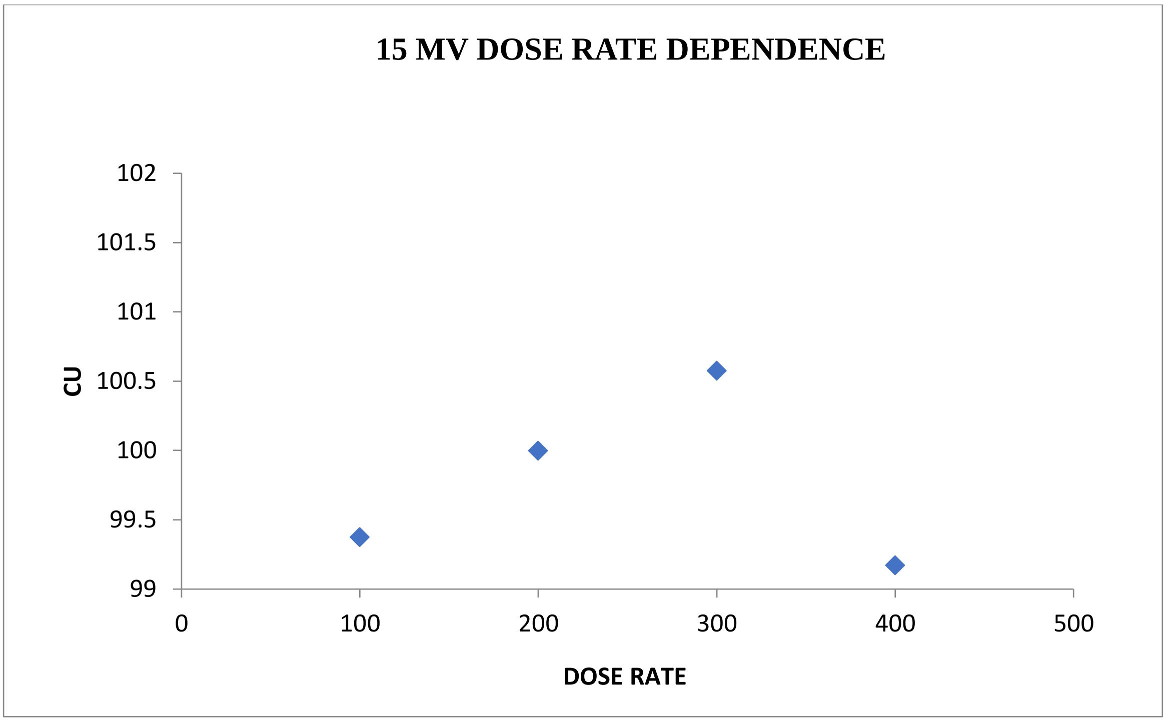

Figure 12 Variation of detector response with dose rate setting of the linac for 15 MV photon beam