CHAPTER 2

MATERIALS AND METHODS

2.1 COMPARISON OF BEAM DATA REQUIREMENTS FOR MLC COMMISSIONING ON A TREATMENT PLANNING SYSTEM

Radiation treatment planning consists of many steps including patient diagnosis, tumor staging, imaging acquisition for treatment planning, the localization of tumor and normal tissue volumes, optimal beam or source placement, treatment simulation and optimization (Jacob Van Dyk pg232 1999). Commissioning is the process of preparing the product for clinical treatment or clinical service. Treatment Planning System (TPS) commissioning require input radiation data in particular form depends upon the algorithm. The accuracy and quality of the input data are dependent on the measured and calculated by the user in particular reference conditions. Various parameters like Percentage Depth Dose (PDD), Beam Profiles, Output Factors, Transmission Factors and Scatter Factors are being measured and calculated during commissioning of the radiotherapy machine. In this study beam data like PDD, cross beam profiles and output factors were acquired in two different sets using jaws and MLC separately as a beam definer.

Varian Clinac Trilogy (Figure 2.1) was used for the beam data collection for 23 MV photons. Figure 2.2 shows the jaws and MLC of Varian Clinac Trilogy Linear Accelerator which can independently move the MLC or Jaws for beam shaping. The required beam data like PDD, Output factors and
beam profiles were measured using Trilogy Linear in required reference conditions and also with the reference conditions given by the treatment planning system.

![Clinac Trilogy Linear Accelerator](image1)

**Figure 2.1 Clinac Trilogy Linear Accelerator**

![Varian Jaw and 120 Millennium MLC](image2)

**Figure 2.2 Varian Jaw and 120 Millennium MLC**

On Varian Clinac-iX linear accelerator (Figure 2.3) the beam data like pdd, beam profiles and output factors were measured for 6 and 10 MV photon beams using the jaws and MLC. In this measurement also the jaws and MLC were used separately as a beam definer for the comparison in reference and required setup conditions. Using the above mentioned linear accelerators the required beam data for 6 MV, 10 MV and 23 MV photon beam were measured which covers choice of modern linear accelerators.
Figure 2.3 Varian Clinac iX Linear Accelerator

Varian 600 C (Figure 2.4) have been used in this study with BrianLab’s 52 leaf microMLC to cover another corner of radiotherapy which included SRS and SRT. Figure 2.5 shows the BrainLab’s micro MLC and Figure 2.6 shows secondary jaws of Varian Clinac 600C. The jaws and microMLC defined square fields on Clinac-600C linear accelerator for 6 MV photon beam were used to the collect the data like PDD, Beam Profiles and Output Factors.

Figure 2.4 Varian 600 c Linear Accelerator
Percentage depth dose and cross beam profiles were acquired with (Scanditronix Wellhofer radiation field analyzer RFA-200 (Figure 2.7) with CC13-S ion chambers (Figure 2.8) and OmniPro-Accept software (Scanditronix Wellhofer) (Figure 2.9).
Figure 2.8 Scanditronix CC13S ion chamber with cap

Figure 2.9 Omni Pro RFA Software screen shot

Figure 2.10 MedTec TG-51 Water Tank and Max 4000 Standard Imaging Electrometer
A Medtec-TG51 water tank (Figure 2.10) with Max-4000 electrometer (Standard Imaging) and 0.6 cc PTW ionization chamber (Figure 2.11) and a mini phantom (Standard Imaging) (Figure 2.12) was utilized for output measurements for millennium-120 MLC.

Figure 2.11 PTW 0.6 cc Farmer Type water proof ion chamber

Figure 2.12 Standard Imaging mini-phantoms

Figure 2.13 Scanditronix SFD diode detector
SRS diode detectors (Scanditronix Wellhofer) (Figure 2.13 for micro-MLC). All the measurements were done with SSD setup keeping 100 cm on the surface of the water phantom and the detector at 10 cm depth from the surface of the water. Varian Medical Systems beam shaper software was used for MLC square field shaping. The programmed MLC files were transferred using the floppy disks and executed from MLC workstation.

2.2 THE EFFECT OF DETECTOR SIZE ON BEAM DATA MEASUREMENTS FOR NARROW PHOTON BEAMS

In this study we used m3 micro multileaf collimator (BrainLAB GmbH, Germany) (Figure 2.5) and Clinac 600 C Linear Accelerator (Varian Medical Systems, Palo Alto, CA USA) (Figure 2.4). The micro multileaf collimator is a detachably structure mounted on Varian Clinac 600 C accelerator delivering 6 MV X-rays.

![Figure 2.14 Keithley 35040 Therapy Dosimeter](image)
The micro MLC has 52 tungsten leaves (26 pairs) which moves perpendicular
to the beam central axis and it has variable lead widths. The finer 14 pairs
with 3 mm width located in the centre of the field area helps to improve
shaping around the smaller targets, 6 pairs of 4.5 mm leaf width and another 6
pairs of 5.5 mm leaf width are arranged in such a way that the smaller width
starts from the center of the field area to the larger width leaf at the periphery
of the field area. All the leaves are 12 cm in length, 6 cm of height and give
the maximum field area of 10x10 cm$^2$ at isocenter. Med-Tec TG-51 water
tank (Figure 2.10) and Standard Imaging Max 4000 electrometer was used for
all the measurements. All the measurements were done with 100 cm SSD at
dmax. TG-51 protocol was followed to establish the absolute dosimetry using
PTW 0.6 cc chamber (Figure 2.11) and Keithley 35040 electrometer
(Figure 2.17). Using CC13S (volume 0.13 cm$^3$ and inner radius s 3 mm)
(Figure 2.8) and SFD Diode detector (diameter of the active area 0.6 mm and
thickness of active volume is 0.3 mm) (Figure 2.13) with RFA 200 radiation
field analyzer (Figure 2.7) the required PDD, scatter factors, diagonal profiles,
mlc leakage and transmission factors were measured and compared.

PDD was measured with RFA-200 (IBA Dosimetry) with Omni Pro
software (Figure 2.9). The measurement was made with SSD setup for the
field sizes from 6x6 mm$^2$ to 100x100 mm$^2$. The diagonal profile for the largest
field size with out mMLC was also measured with both detectors and values
were tabulated. The cross and inline profiles with mMLC are not a required
measurement for this since we do have the measurement with maximum jaw
field. Scatter factors were measured at the same setup as for the nominal linac
output measurement. It was measured as matrix combinations of square
mMLC fields times square jaw setting field sizes. Square field sizes from 6x6
mm sq to 100x100 mm sq. the measured values were tabulated. It is important
to note and measure all scatter factors where mMLC size is smaller or equal
to the jaw field size. It is recommended to copy the value of equal mMLC and jaw field size when the mMLC field size is bigger than the jaw field size.

Dynamic leaf leakage was measured using the pre-planned test files. It describes an effective leaf shift to the round leaf end design of the mMLC. It can be determined by measuring the isocenter doses for sliding gaps with different widths using pre-planned mMLC files. With the detector in position at dmax with SSD 100 cm, field size jaws opened to 10x10 cm² execute the mlc plan and measured the reading. mMLC leakage was measured using the same setup with mMLC closed asymmetrically 50 mm off the isocenter. Open field measurement was done setting the mlc to 10x10 cm² field with the same measurement conditions. The measured dose D can be approximately calculated as a linear function described in BrainLab user manual

\[ D - D_{\text{leak}} = b(gap + 2\delta) = b\cdot gap + a \]  

(2.1)

where gap is the nominal gap width i.e. 1, 5, 10, ……, 10 mm, \( D_{\text{leak}} \) is the measured mMLC leakage and \( \delta \) is the effective dynamic leaf shift per leaf. The values a and b are determined by linear regression, then, \( \delta \) is calculated by \( \delta = a / 2b \). All the values were tabulated.

2.3 INFLUENCE OF PHOTON BEAM ENERGY ON IMRT PLAN QUALITY FOR RADIOTHERAPY OF PROSTATE CANCER

A cohort of 20 prostate cases was selected for our study. The patient characteristics are given in Table 2.1. The mean anterior-posterior (AP) separation of these patients was 23.3 cm (range 18 - 30 cm, SD 3.1) and the mean lateral separation was 37.7 cm (range 34 - 40 cm, SD 2.00). The prostate volume varied from 16.8 to 181.9 cc (mean 69.2 cc, SD 41.4).
The planning target volume (PTV) was defined as the entire prostate without seminal vesicles and includes 3mm margin around the prostate for set up error. The average PTV for these patients was 123.7 cc (range 38.9 – 270.9 cc, SD 57.5). The rectum and bladder volumes varied from 34.2 to 267.2 cc and 89.9 to 441.9 cc respectively (mean 89.7, SD 49.2 and mean 228.3, SD 114.7).

All patients received full-course IMRT treatments to a dose of 79.2 Gy to PTV in 44 fractions. For inverse IMRT treatment planning, we used a 6-coplanar non opposed beam arrangement at 225,270,0,75,105 and 135 degree angles. Fields were selected so that all entrance and exit beams were spaced about the patient. The plan was generated on a commercial Corvos treatment planning system (Nomos Radiation Oncology, A division of North American Scientific, PA, USA). For all plans we defined dose volume constraints as given in Table 2.2. Deliveries were modeled using actual beam data for delivery with a Clinac-iX linear accelerator using millennium 120 multileaf collimator in dynamic mode (Varian Medical Systems, Palo Alto, CA, USA). For all of the cases we developed treatment plans using 6 MV and 10 MV intensity modulated beams with identical dose volume constraints. The dose volume histograms (DVHs) for the 6-MV and 10-MV plans were compared for PTV and for critical structures such as the rectum, bladder, femoral heads, small intestine and urethra. We also defined the conformal index to compare the treatment plans. The conformal index was defined as the ratio of the 95% isodose volume divided by the PTV volume that is enclosed by the 95% isodose line since we selected 95 % isodose line as our reference. From this definition the closer the conformal index approaches 1.0, the more conformal is the treatment plan. We also calculated the integral dose surrounding normal tissue by integrating the dose over all voxels within the volume. All the values were tabulated for evaluation and analysis.
Table 2.1 Patient characteristics for the cohort

<table>
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<tr>
<th>Patient Number</th>
<th>AP (cm)</th>
<th>Lat (cm)</th>
<th>Prostate Volume (cc)</th>
<th>PTV Volume (cc)</th>
<th>Rectum Volume (cc)</th>
<th>Bladder Volume (cc)</th>
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Table 2.2 The optimization constraints used for all IMRT plans

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<th>Structure</th>
<th>Goal (Gy)</th>
<th>Volume below goal in %</th>
<th>Minimum (Gy)</th>
<th>Maximum (Gy)</th>
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<td>Prostate target</td>
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<td>76</td>
<td>83</td>
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<td>Seminal vesicles target</td>
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<td>79</td>
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<td>Tissue</td>
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<td>0</td>
<td>0</td>
<td>79</td>
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<td>65</td>
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<td>1</td>
<td>50</td>
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<td>Rectum</td>
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<td>1</td>
<td>65</td>
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<td>Urethra</td>
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2.4 QUALITY ASSURANCE OF VARIAN ON-BOARD IMAGER

Accurate and reproducible setup of patients is an important part in radiotherapy and it results. In recent development the IGRT with On Board Imaging System helps to achieve this goal and series of QA test needs to be performed to achieve the aim. There are many types of equipment and tools are being used for this purpose, in this study we have used the following tools. PTW 0.6cc Ion chamber (model No. N300020) Aluminum plates of 1.5 mm and 2.7 mm thickness, 50cm metal ruler (in accurate increments of 1mm), Graph Paper (in accurate increments of 1mm).

Keithley kVp Divider model No.35080 with W-R Filter pack No.37617 and Mobile Filter Pack No.37946, Two (2) 50ft RG-58 coaxial
cables (for Keithley mA meter and the Keithley model 35080 kVp divider), Digital Multimeter with a minimum 0-20 mA scale, 0.1 resolution, Digital mAs meter that will read in tenths, 0.1 resolution, High Contrast Resolution: Nuclear Associates 07-523 Converging line pair tool or Huttner tool imbedded within the TOR 18FG tool, Linearity: Leeds GS2 test tool or aluminum step wedge 07-456, X-ray Field Checking Plate (Varian Part No. TM51202000) or equivalent, Precision Level, Couch Support Bracket Varian Part No. (B300815R01), Isocenter Cube (Varian Part No. TM55150000), Blade Calibration Plate (Varian Part No. B300852R01), OBI Geometric Phantom (Marker Seed Phantom with Exact Couch Lok-bar), RPM-Gating Phantom (Breathing Phantom), Low Contrast Sensitivity: Leeds TOR 18FG, 1mm Copper Filter (included with Leeds TOR 18FG tool).

2.4.1 Mechanical QA Procedures

The Door Interlock QA prevents the production of X-Rays and this interlock stating “the door to the treatment room is open” will occur on the OBI workstation and prevent beam-on. The QA test was carried out clearing all OBI interlocks and successfully beamed-on in the Pulsed Fluoro mode. Then open the treatment room door and attempted to beam-on again and verified that the treatment room door interlock will prevent beam-on or not. And the indication was recorded in the in the table give below.

2.4.2 Warning Lights and Sound Indications

The OBI system shall provide the circuitry required to illuminate a warning light when the fluoroscopic foot switch is depressed and while X-Rays are being generated the warning light will illuminate. Also when power is applied to the X-ray generator and an audible warning shall be present at the OBI Console when X-Rays are being generated. This test was carried out with the beam-on in the Pulsed Fluoro mode and verified that the
warning light was illuminated and an audible beeping sound was present at the OBI console throughout the duration of a Pulsed Fluoro mode exposure. Recorded the condition in the below table.

2.4.3 Collision Detection

A series of collision detection switches are built into the touch guard assemblies on the KVS Collimator and KVD imager panel housing. Collision paddles are also located on both OBI arms. If any of these switches are activated, a collision shall be detected and all major motor motions will stop and require a manual reset at the Clinac. An interlock message shall appear on the OBI workstation within the Faults and Interlocks window stating “Supervisor detected that the Clinac touch guard is pressed.” This QA test was carried out in three steps as follows

2.4.4 KVS Collimator

While rotating the Gantry, firmly press the KVS Collimator touch guard frame or cover and verify that a collision is detected and motor motions stop. Reset the collision by manually depressing the Clinac Collimator touch guard button.

2.4.5 Imager Cover

While rotating the Gantry, firmly press the KVD Imager housing touchguard frame or cover and verify that a collision is detected and motor motions stop. Reset the collision by manually depressing the Clinac Collimator touchguard button.
2.4.6 **KV Source and Detector Arm Paddles**

While rotating the Gantry, sequentially press each paddle on both arms and verify that a collision is detected and motor motions stop. Reset the collision by manually depressing the Clinac Collimator touchguard button and recorded the indication in the below given table.

2.4.7 **Motion Enable Button/Bars**

All Arm motions on the OBI are controlled through a combination of motion enable buttons, or bars, and a speed control and directional input from a thumbwheel or computer (auto move). Arm motion shall not be permitted without the activation of a motion enable. Blades, being enclosed in the Collimator, do not require a secondary motion enable circuit. Motion enable bars are located on the IR Hand Pendant (2 bars, both necessary for Motion Enable) and Motion enable buttons are located on the OBI Console. This test was carried out and demonstrated that both motion enable bars on the pendant to allow a manual motion to occur.

2.4.8 **Collimator Rotational Isocenter**

This test was carried out to ensure the specification of the rotational excursions of the Collimator shall be confined within a sphere of \( \leq 1.0 \text{mm} \) radius. The steps followed are

1. Installed the front pointer and accurately adjusted the pointer tip to 100cm TSD. This was verified by referencing the tip to a stationary 2mm drill bit (or another front pointer tip) extended over the front edge of the couch while rotating the Gantry between 90° to 270°.
2. With the front pointer distance accurately set to 100cm TSD, leveled the Gantry at 180° (0° IEC). Aligned a piece of graph paper on the couch top (slightly under the front pointer) and rotated the Collimator from 90° to 270°. And adjusted the front pointer for minimal run-out. Recorded the final result.

2.4.9 Gantry Rotational Isocenter

This test was carried out to ensure the specification of the rotational excursions of the Gantry shall be confined within a sphere of ≤1.0mm radius throughout the entire 360° of rotation. The steps followed are, with the front pointer aligned per the previous test and a 2mm drill bit (or second front pointer tip) extended over the front edge of the couch, rotated the Gantry throughout its full rotation and measured the maximum amount of run-out and recorded results for analysis.

2.5 POSITIONAL ACCURACY DEMONSTRATION

2.5.1 kV Source Mechanical Positioning Tests

The Vertical range of motion for the kV Source shall be from 80 to 100cm from isocenter. The Source vertical position readouts shall be accurate to within ±2.0mm with a reproducibility of ±2.0mm. The Source is also capable of Preset auto positions, Retract, and out position. Positioned the Gantry to 270°, and using the hand pendant Preset positions, sequentially positioned the KVS arm to the vertical positions listed in the table and recorded the required vertical position measurements. All measurements for the Source vertical position were measured from the Source collimator faceplate to the Clinac crosshairs. The distance between the faceplate and the Source focal point was 14.8 cm. This value was added when recording the measurements. For example, If actual measured distance between Clinac
crosshairs and Source Collimator faceplate is 85.2 cm, add the 14.8 cm offset and record the final value in the table (85.2 + 14.8 = 100.0 cm).

2.5.2 kV Imager Mechanical Positioning Tests

The Imager position readouts shall be accurate to ±2.0 mm with a reproducibility of ±2.0 mm. The Imager is capable of Retract and Out (Park) positions as well as Preset auto positions. The Vertical range of motion shall be ≥80.0 cm (From isocenter to ≥80.0 cm below isocenter). The Longitudinal and Lateral travel ranges are dependent upon the vertical position and the specifications.

Positioned the Gantry to 90° and using the hand pendant Preset positions, sequentially positioned the KVD imager to the vertical positions listed in the table. At each position, measured the actual vertical position using a tape measure or measuring stick, referenced to the projected Clinac crosshair. The effective surface of the PaxScan imaging panel is approximately 1.6 cm below the top surface of the black carbon panel or 1.8 cm below the top surface of the 2 mm grid. When recording the actual measured vertical position in the following table, added the effective surface offset distance as mentioned in the previous example. Vertically drive the KVD arm to each travel limit and note the readout display on the pendant and calculated the total vertical travel range and recorded the results. With the vertical position measurements completed, setup the Crosslaser tool on the “tennis racket” couch panel so that the projected laser is accurately representing the Clinac isocenter on the imager panel. An overhead laser can be used in place of the Crosslaser tool if it is accurately calibrated.

Using the hand pendant Preset positions, positioned the KVD imager to the vertical positions listed in the table and recorded the required
Longitudinal and Lateral position measurements. And finally checked retract and out (park) positions.

2.6 APPLICATION TOOLS DEMONSTRATION

2.6.1 Measurement of Distance, Area, and Angle

This test was done to ensure that the imaging software measurement tools shall be accurate to within ±2mm or 1% whichever is greater on the measurement being made. The Distance, Area and Angle tools are being demonstrated to provide assurances that images produced with OBI are not only clinical but precise measurements can be performed on the images. The test was carried out in steps, Leveled the Gantry at the 12 o’clock position, setup and aligned the Blade Calibration Plate to the Clinac crosshairs at isocenter and rotated the Gantry to 90°. Set the KVD arm to –40cm (P3 Preset position) and set the KVS arm to 100cm and fully open blades to 50cm2. In Maintenance mode, setup a Pulse Fluoro technique of 45 kVp / 25 mA / 4 mSec / ABC off and acquired an image of the plate and measured the distance, area and angle like the following steps

2.6.2 Distance

With the image displayed, selected the Measure Distance icon tool button and measured the distance between the 10 x 10cm pairs of lines as shown in the following figure. Recorded the values in the provided boxes Using the zoom tool for more accurate alignment

2.6.3 Angle

Selected the Measure Angle icon tool button and draw a straight line between any two corners of the 10 x 10cm field and then drew a diagonal line between the corners of the 10 x 10 cm field as shown in the following
figure. The apex of the angle is a junction of the two measurement lines and the angle should be $45^\circ \pm 1.15^\circ$ using the zoom tool for more accurate alignment.

2.6.4 Area

Selected the Area Profile icon tool button and draw a 10 x 10cm box that aligns to the center of the Blade Calibration plate as shown in the following figure (use cursor to align box). When the box is accurately aligned to the 10 x 10cm square, recorded the Width and Height values that are displayed in the Area Profile information box using the zoom tool to aid accurate alignment.

Figure 2.15 kV Imager Panel Virtual Alignment Demonstration
This test was carried out to ensure the center of the PaxScan imager panel shall be aligned to the beam isocenter path to an accuracy of ±2.0mm.

Set up the Blade Calibration plate on the couch top so that it is accurately aligned to the Clinac isocenter, leveled the Gantry at 90° and positioned the KVD arm to –50 / 0 / 0 (P2 Preset) and the KVS arm to 100 / 0 (P1 Preset).

Set up a High Quality – Single Pulse Full Resolution image technique and acquired an image of the plate. Adjusted the technique parameters until a good image was acquired. Then, OBI application was closed and opened the IAS Monitor application and acquired an image of the plate again.

Zoomed out on the image until the center circle on the plate is visible, dragged the green zoom box in the upper left hand corner until it is aligned with the center circle on the plate and zoom in until individual pixels are clearly visible. It may be necessary to adjust the Window and Level values in the upper left toolbar to see the individual pixels more clearly.

Using the cursor, locate the central pixel that is aligned to the center of the circle on the Blade calibration plate. The X and Y pixel values will be displayed near the lower right hand corner of the image. Verified that the central pixel position is 1024 x 768 ±10 pixels in either axis (pixel size is 0.194mm).

2.7 OPTICAL ISOCENTER DEMONSTRATION

2.7.1 kV Detector and kV Source Axes Coincident with Gantry Rotation Axis

This test was carried out to ensure the kVD and kVS arm axes shall be coincident (isocentric) to the gantry rotational axis and shall be confined
within a sphere of \( \leq 1.5 \text{mm} \) radius throughout the entire 360° of gantry rotation.

Accurately positioned the Isocenter Cube tool on the couch top at isocenter using the projected clinac crosshairs, leveled the gantry at 180° (0° IEC) and 90° when positioning the cube. Approximately centered and taped the X-Ray Checking plate on the top of the imager panel and positioned the Gantry to 0° (180° IEC) and the KVD arm to \(-50 / 0 / 0\) (P2 Preset). Acquired a Pulsed Fluoro image of the isocenter cube and moved the imager until the checking plate crosshair is aligned to the center of the ball within the image. Rotated the Gantry to 90° and acquire another image. Using the distance tool, measure and note any positional deviation of the imaged ball from the checking plate crosshair. Repeated this procedure for Gantry angles of 180° (0° IEC) and 270° and to keep a note the results of this test are dependent on the accuracy of the Clinac crosshairs and Gantry leveling, therefore, based on the test results, It may be necessary to more accurately re-position the cube to isocenter using a lateral image and an AP image to complete this test. Reviewed the test results for each Gantry angle to determine the radius and record the isocenter results.

### 2.7.2 X-Ray Measurements and Imaging System Quality Demonstration

#### 2.7.2.1 Definition / Technical Description / Specifications

Three imaging modes are available with OBI. Full field imaging used on OBI for pulsed mode is made up of an aSi flat panel with an imaging area of approximately 40 cm x 30 cm. The panel is operated in either a half-resolution 2 x 2 binned mode that provides 1024 x 768 resolution at 15 frames per second (fps) or a 1 x 1 binned high-resolution mode that provides a 2048 x 1536 resolution at 7.5 fps.
The modes and specifications are shown in the table below.

<table>
<thead>
<tr>
<th>IMAGING MODES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital Radiography – High Quality – Single Pulse Full Resolution</td>
</tr>
<tr>
<td>Digital Radiography – Single Standard – Single Pulse Half Resolution</td>
</tr>
<tr>
<td>Digital Fluoroscopy – Pulsed Fluoro</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>VARIAN 100 KHZ SPECIFICATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode</td>
</tr>
<tr>
<td>Digital Radiography</td>
</tr>
<tr>
<td>Digital Fluoroscopy (Pulsed Fluoro mode)</td>
</tr>
</tbody>
</table>

Figure 2.16 Imagining mode and 100 KHz Specification Table

### 2.8 X-RAY MEASUREMENTS

#### 2.8.1 Digital Fluoroscopy, Pulsed Mode kVp, mA and mS Method

1. Placed the Keithley 35080 kVp Divider (using W-R Filter Pack No.37617) within 20 inches or 50cm of the X-ray tube target. Aligned the sensor pack perpendicular to the long axis of the X-ray tube. To avoid the heel effect, did not place the sensor pack towards the anode side of the X-ray tube.

2. Removed the jumper plug from the mA test jack. Install a dc mAs meter.
3. Set up the Keithley 35050 or a storage oscilloscope to measure kVp.

4. Set up the storage oscilloscope to measure mA. Place the o’scope probe on the input jacks of the DC mA meter (200 range). The mA meter does NOT need to be turned on, as it is ONLY being used as a terminating resistor for this test setup.

5. Beam-on for each of the techniques listed in the Digital Fluoroscopy table that follows and record the kVp, mA and mS values. Verified the recorded values fall within the specifications listed in the VARIAN 100 KHZ SPECIFICATIONS table.

2.8.2 Digital Radiography, Single Pulse Half Resolution Mode kVp, mA and mS Specification Method

1. Placed the Keithley 35080 kVp Divider (using W-R Filter Pack No.37617) to within 20 inches of the X-ray tube target. Aligned the sensor pack perpendicular to the long axis of the X-ray tube. To avoid the heel effect, did not place the sensor pack towards the anode side of the X-ray tube.

2. Ensured the jumper plug from the mA test jack on the HT tank is removed, and a DC mA/mAs meter is installed.

3. Placed the DC mAs meter near the control console and storage Oscilloscope

4. Set up the storage oscilloscope to measure mA. Placed the o’scope probe on the input jacks of the DC mA meter (200 range). Noted that the mA meter does NOT need to be
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turned on, as it is ONLY being used as a terminating resistor for this test setup.

5. Beam-on for each of the techniques listed in the Digital Radiography table that follows and record the kVp, mA and mS values. Verify the recorded values fall within the specifications listed in the VARIAN 100 KHZ specifications table.

2.9 HALF VALUE LAYER (HVL) USING DIGITAL FLUOROSCOPY PULSED MODE (FOR CANADA AND USA)

The Half Value Layer (HVL) is a function of tube potential and the total filtration for diagnostic X-ray units are published in CFR, volume 21, 1020.30, paragraph ‘M’. For 100 kVp, the HVL is equivalent to a minimum of 2.7mm of Aluminium (AL). For 70 kVp, the HVL is equivalent to a minimum of 1.5mm of AL.

1. Placed the 150cm² ion chamber from the Keithley/ Innovision 35050 dosimeter or an equivalent dosimetry system at isocenter in air with at least 50 cm to the next scattering surface.

2. Setup a Pulsed Fluoro technique of 70 kVp /, 50 mA, 6 ms. Took three 20 second exposures and recorded the average of the unfiltered exposures.

3. Placed the minimum of 1.5 mm of AL in the X-ray beam path. Repeated the exposures using the same technique and increased the thickness of AL until the filtered readings are
reduced by half of the unfiltered readings. Recorded the final amount of AL required and the final filtered mR value.

4. Repeated the above process for 100 kVp using 2.7 mm of AL as a minimum starting point to reduce the output by half. Past test results have indicated that significantly thicker filtration is required to achieve the half value layer. If there is not enough aluminum plates to achieve the half value layer, recorded the final filtered value with the maximum filtration. The purpose of this test is only to verify that the half value layer will require a minimum of 1.5mm for 70kVp and 2.7mm for 100kVp.

2.10 IMAGING SYSTEM QUALITY DEMONSTRATION

2.10.1 High Contrast Resolution

The Imaging system shall be capable of resolving 1.29 (1.2887) line pairs (lp) in a 2x2 binned mode over the aSi panel without any obstructions to the X-ray beam.

1. Placed the high contrast resolution test tool (Nuclear Associates model No. 07-523, or Huttner type 18) at a diagonal angle on the center of the Imager panel cover.

2. Set the KVD arm to -50 cm and the KVS arm to 100cm. Made sure the beam path is clear of any objects or filtration.

3. Fully opened the blades (do not collimate onto the test tool for this test).

4. Acquired a Pulsed Fluoro image using the following starting technique and fine tuned the technique to resolve the highest lp/mm 50 kVp / 50 mA / 6 mSec / ABC OFF.
5. Selected the zoom function from the toolbar and draw an area around the test tool to magnify the test tool. Adjusted the window and level scroll bars for the sharpest display and record the results in the box provided. It may be easier to distinguish the line pairs with the room lights off.

The PaxScan is able to resolve only 1.25 lp/mm when using the Huttner tool, which is part of the supplied TOR 18FG test tool (or can be a separate tool) because of the limited graduations in number of line pair groupings within the test tool. The groupings jump between 1.25 lp/mm and 1.40 lp/mm in the Huttner tool.

The PaxScan is able to resolve a higher value when using the Nuclear Associates xray test pattern because this tool uses a continuous tapered line pair rule. The spatial resolution is enhanced slightly due to placement of the x-ray test pattern on the top of the imager cover that results in a magnification factor slightly >1 (1.04). The PaxScan can resolve 1.3 lp/mm when using the Nuclear Associates x-ray test pattern, which is slightly more than the PaxScan’s published specification. The inherent magnification factor of 1.04 is based on the physical position of the test tool relative to the imager. The result of this test was 1.35 lp/mm which is 0.5 lp/mm higher than the specification.

2.10.2 Gray Scale Linearity

The imaging system shall be capable of displaying eleven uniform shades of gray (from black to white) using the Nuclear Associates 07-456, or a Leeds GS2 step wedge penetrometer.
1. Using the same positional setup as the previous demonstration, placed one of the step wedge penetrometer test tools described above on the face of the aSi Imaging panel.

2. Taped 1 mm of copper filtration onto the KVS Collimator faceplate.

3. Setup a Pulsed Fluoro technique of 75 kVp / 50 mA / 6 mSec and beam-on. Collimate down on the test tool and maintain kVp while fine-tuning the pulsed technique to maximize the number of gray levels visible on the image. Recorded the results and the result of this was found to be 11 gray levels.

2.11 **AUTOMATIC BRIGHTNESS CONTROL (ABC)**

ABC controls kVp only in Fluoroscopic modes. The ABC will maintain a constant dose rate to the Imager while imaging the variable-density phantom using Pulsed Fluoro mode. While in ABC mode, kVp reproducibility shall be within ± 2 kVp when approached from either maximum or minimum kVp using the step wedge penetrometer as a variable density phantom. The response time for kVp stabilization on an image is ≤ 3 seconds.

1. Used the identical set-up and technique from the gray scale linearity procedure and used the step wedge. Beam-on and turn ABC mode on and verify the kVp does not drive excessively high or low.

2. Beam off and raise the kVp to maximum. Beam back on with ABC ON and verify that the kVp returns to the previous kVp value (± 2 kVp) within ≤ 3 seconds. Repeated this procedure again with the kVp set to minimum and the result of this test of found to be ok.
2.12 LOW CONTRAST SENSITIVITY

Using the Leeds test object type TOR [18FG] The imaging system shall be capable of resolving a minimum of 2.33% sensitivity in a Pulsed Live image (2x2 binned mode).

1. Used the arrow indicator on the test tool and place the tool on the face of the Imaging panel.

2. Taped a 1 mm copper filter on the Source face (Collimator faceplate). Verified the collimation does not exceed the edges of the copper filtration.

3. Setup for a Pulsed Fluoro technique of 75 kVp / 25 mA / 4 mSec / ABC off. Beam-on and fine tuned the technique for the best image.

4. Turned off the Console area lights and view the captured image. The image is best viewed at a distance approximately four times the diameter of the displayed field. Adjust the window levels until a small white circle is visible within the white square and the small black circle is visible within the black square.

5. For the Leeds TOR[18FG] tool there are 18 low-density disks embedded in the phantom in a 9 disk arc at the top of the image and a 9 disk arc at the bottom. Starting with the darkest disc (disk 1 at roughly 10 o’clock) count to the lowest density disc that can be resolved. Refer to the table of contrast sensitivity on the following page to determine the disk sensitivity and the result of this test give disk number 12.
corresponds 2.33\% of contrast sensitivity with the specification of ≥12 disk corresponds 2.33\% contrast sensitivity.

2.13 DENSITY RESOLUTION (HOUNSFIELD UNIT/ CT NO.)

This test was carried out to verify the accuracy of the HU calibration using the histogram tool to calculate the HU numbers of the Catphan phantom (Figure 2.17). The Values were recorded in the following Table 2.3 and the procedure was carried out in steps with 504 model catphan phantom. The correct image slice that displays the Density Resolution (Hounsfield / CTNo.) module was selected and verified the HU measurements to match those on the given parameter sheet for example, Head Scan With Bow Tie, For Air must have a HU of -1000 ± 40. Using the TOOLS-MEASURE-HISTOGRAM function to drew a square in each homogenous substance and Ensuring the square does not protrude the edge of the substance being measured determined the HU Mean value results and recorded the values in given Parameter Sheet for CBCT and the same type of experiment was repeated for all Verification modes.

Table 2.3 Accuracy of HU values

<table>
<thead>
<tr>
<th>Material</th>
<th>Measured CT-No</th>
<th>Ideal Mean CT-No.</th>
<th>Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>980</td>
<td>-1000</td>
<td>± 40</td>
</tr>
<tr>
<td>Acrylic</td>
<td>100</td>
<td>120</td>
<td>± 40</td>
</tr>
<tr>
<td>LDPE</td>
<td>90</td>
<td>-100</td>
<td>± 40</td>
</tr>
</tbody>
</table>
This procedure was done to verify the distance measurement using the distance measuring tool to measure the distance between 4 holes (3 air and 1 Teflon) spaced 50mm apart on the Catphan phantom and the values were checked. The test was carried by selecting the correct image slice that displays Spatial Linearity module, using the Page Up / Down keys and verified the DISTANCE, by measuring the distances between the verification holes located on the Catphan phantom, using the MEASURE-DISTANCE function. Measurements must fall within an accuracy of 1% of the actual distance. And found the values are within 1% of the expected value.
2.15 IMAGE UNIFORMITY MEASUREMENTS

This procedure was done to verify the Image Uniformity of the scanned image. This must conform to a value measured at the Image Uniformity Module of the Catphan phantom (Figure 3.22). Selected the correct image slice that displays the Image Uniformity module, using the Page Up / Down keys. And using the TOOLS-MEASURE-HISTOGRAM function to draw an approximate 20 x 20 (DX and DY = 20) pixels square in each selected Region of Interest (ROI) and verified the maximum difference between the mean HU value of the Center ROI No.5 (reference value) and the mean HU values for each of the peripheral ROIs (Figure 3.21) (No.1 - No.4) is less than or equal to +/- 40 HU. Use either the minimum (less than the reference) or maximum (greater than the reference) HU value difference (max difference), whichever is greater. i.e. +/- tolerance with respect to the reference ROI No.5.

Example: No.1 = -32, No.2 = -37, No.3 = -30, No.4 = -39 and No.5 = -60. The maximum difference is therefore 30 HU greater than the reference.

![Figure 2.18 ROI areas for the Uniformity measurements](image)
This procedure was done to verify the Spatial Resolution of the scanned image using the High Resolution Module in the Catphan Phantom. Selected the correct image slice that displays the High Resolution module, using the Page Up/ Down keys and Switch off the Control room lights, if required. Then, using the Window Level and zoom function, verified the Line pair / cm (Figure 2.20, 2.21) measurements are greater than 7 (Inclusive) for Head Scans (full fan) and greater than 6 (Inclusive) for Body Scans (half fan). Repeated the above steps for all Verification modes.
<table>
<thead>
<tr>
<th>Line Pair/cm</th>
<th>Gap Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.500 cm</td>
</tr>
<tr>
<td>2</td>
<td>0.250 cm</td>
</tr>
<tr>
<td>3</td>
<td>0.167 cm</td>
</tr>
<tr>
<td>4</td>
<td>0.125 cm</td>
</tr>
<tr>
<td>5</td>
<td>0.100 cm</td>
</tr>
<tr>
<td>6</td>
<td>0.083 cm</td>
</tr>
<tr>
<td>7</td>
<td>0.071 cm</td>
</tr>
<tr>
<td>8</td>
<td>0.063 cm</td>
</tr>
<tr>
<td>9</td>
<td>0.056 cm</td>
</tr>
<tr>
<td>10</td>
<td>0.050 cm</td>
</tr>
<tr>
<td>11</td>
<td>0.045 cm</td>
</tr>
<tr>
<td>12</td>
<td>0.042 cm</td>
</tr>
<tr>
<td>13</td>
<td>0.038 cm</td>
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<td>14</td>
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<td>15</td>
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</tr>
<tr>
<td>16</td>
<td>0.031 cm</td>
</tr>
<tr>
<td>17</td>
<td>0.029 cm</td>
</tr>
<tr>
<td>18</td>
<td>0.028 cm</td>
</tr>
<tr>
<td>19</td>
<td>0.026 cm</td>
</tr>
<tr>
<td>20</td>
<td>0.025 cm</td>
</tr>
<tr>
<td>21</td>
<td>0.024 cm</td>
</tr>
</tbody>
</table>

Figure 2.20 Line Pair/cm and gap size
Figure 2.21 Catphan module for High resolution Measurements
2.17 LOW CONTRAST RESOLUTION

This procedure was done to verify the Low Contrast Resolution of the scanned image using the Low Contrast Sensitivity Module in the Catphan Phantom (Figure 2.22, 2.23). Selected the correct image slice that displays the Low Contrast Sensitivity module, using the Page Up / Down keys. Using the Window Level and zoom functions, verified the Low Contrast Targets meet the Minimum specification of the 15mm sphere on the 1% Supra-Slice targets taking the below refer Table as a reference. Repeated the above steps for all Verification modes. And the mean HU values for each of the peripheral ROIs (No.1 - No.4). Use either the minimum (less than the reference) or maximum (greater than the reference) HU value difference (max difference) to enter in the table, whichever is greater i.e. +/- tolerance with respect to the reference ROI No.5.

Example: No.1 = -32, No.2 = -37, No.3 = -30, No.4 = -39 and No.5 = -60. The maximum difference is therefore 30 HU greater than the reference.

<table>
<thead>
<tr>
<th>Supra-Slice Target Diameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0 mm</td>
</tr>
<tr>
<td>3.0 mm</td>
</tr>
<tr>
<td>4.0 mm</td>
</tr>
<tr>
<td>5.0 mm</td>
</tr>
<tr>
<td>6.0 mm</td>
</tr>
<tr>
<td>7.0 mm</td>
</tr>
<tr>
<td>8.0 mm</td>
</tr>
<tr>
<td>9.0 mm</td>
</tr>
<tr>
<td>15.0 mm</td>
</tr>
</tbody>
</table>

Figure 2.22 Supra Slice Target diameters
Figure 2.23 Catphan module for Low Contrast Resolution