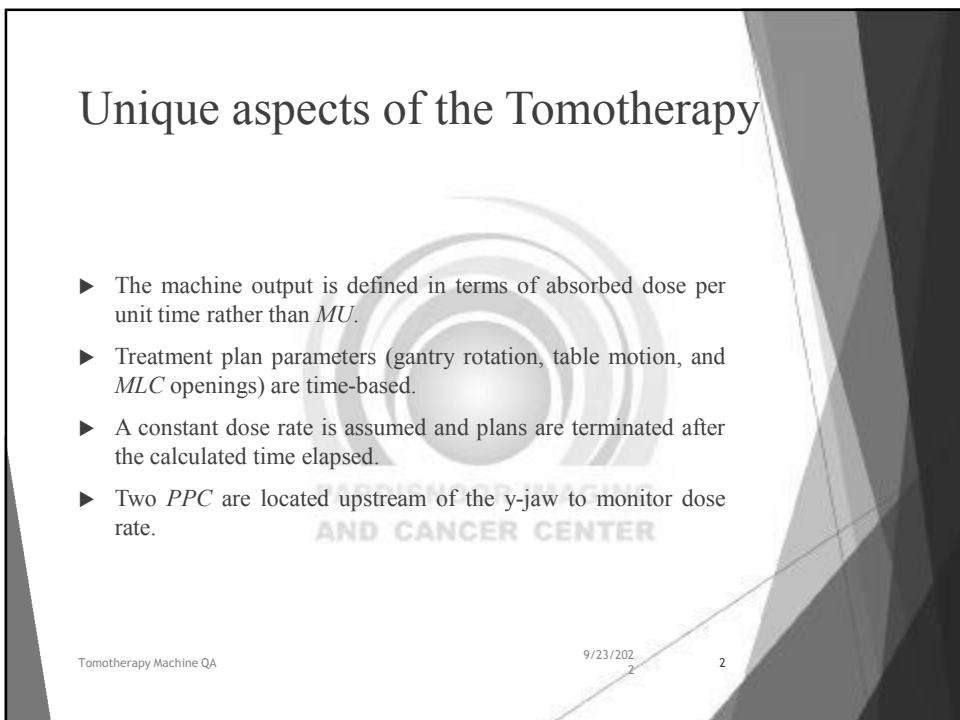


The slide features a logo in the top left corner consisting of concentric circles with the text "PARDISNOOR IMAGING AND CANCER CENTER" below it. The main title "Tomotherapy Machine QA" is centered in a large, serif font. Below the title, the author's name "Hadi Hasanzadeh" and affiliation "PNICC Assistant Prof. of Medical Physics" are listed. At the bottom, there is a footer with "Tomotherapy Machine QA" on the left, "9/23/2022" in the center, and a page number "1" on the right.



The slide has a title "Unique aspects of the Tomotherapy" at the top. Below the title is a list of four bullet points, each starting with a right-pointing triangle. The background features a faint version of the center's logo. At the bottom, the footer contains "Tomotherapy Machine QA" on the left, "9/23/2022" in the center, and a page number "2" on the right.

- ▶ The machine output is defined in terms of absorbed dose per unit time rather than *MU*.
- ▶ Treatment plan parameters (gantry rotation, table motion, and *MLC* openings) are time-based.
- ▶ A constant dose rate is assumed and plans are terminated after the calculated time elapsed.
- ▶ Two *PPC* are located upstream of the y-jaw to monitor dose rate.

## Unique aspects of the Tomotherapy (Cont.)

The treatment will be terminated if:

- ▶ The monitor chamber readings differ by more than 50% from their nominal rate for more than 3 s.
- ▶ The monitor chamber readings differ by more than 5% from their nominal rate for more than three consecutive rolling 10 s windows.
- ▶ The monitor chamber signals are expressed in  $cGy/min$  ( $d=1.5$  cm,  $SAD=85$  cm,  $5X40$  cm<sup>2</sup> static field).
- ▶ Displayed Dose rate is average dose rate.
- ▶ All MLC leaves are closed for the initial 10 s.

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## Mechanical Alignment

- ▶ Several mechanical alignments must be tested annually and whenever the alignment could be compromised.
- ▶ Most tests use film dosimetry.
- ▶ The first set of tests check the alignment of the linac against the y-jaw, *MLC*, and rotation plane.
- ▶ The second set of tests check the alignment of the y-jaw and *MLC* with the rotation plane as well as the centering of each treatment slice.

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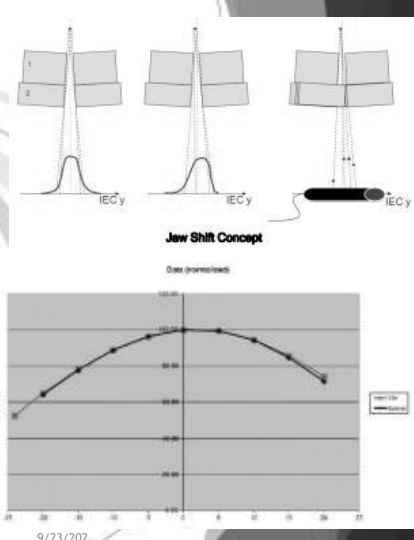
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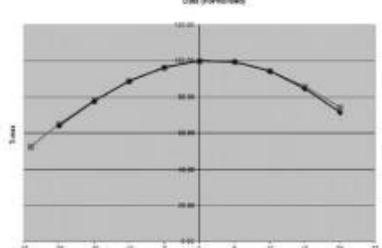
## y-jaw centering

- ▶ Check that the linac is centered in the collimated field.
- ▶ This alignment needs to be checked if any component is replaced or moved that can affect this alignment.
- ▶ It is recommended to check the y-jaw centering annually.
- ▶ The procedure uses a 2 mm y-jaw opening that is moved in 11 steps along the y-direction (24 to-24 mm).
- ▶ A stationary long active volume ion chamber located at isocenter (Exradin A17, 1.5cc, 8cm).
- ▶ Output is plotted as a function of axial jaw shift.
- ▶ The linac position should agree with its nominal position (commissioning) within 0.3 mm (0.2 mm for dynamic jaw).



**Jaw Shift Concept**

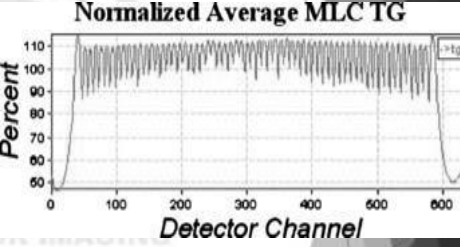
Data (normalized)



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## x-alignment of source (T&G)

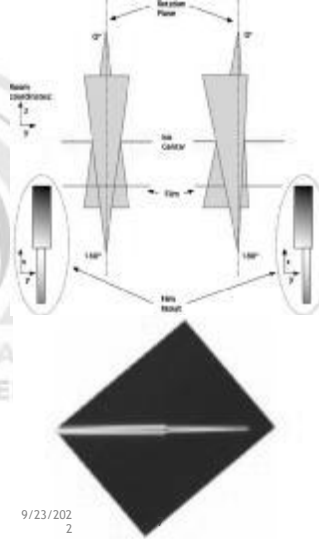
- ▶ The position of the source in the x-direction is checked against the MLC position.
- ▶ The T&G effect is minimized if the MLC is focused on the source.
- ▶ Uses the MVCT detector array to collect output profiles with all even-numbered MLC leaves opened and then with all odd-numbered MLC leaves opened (maximize T&G).
- ▶ Normalized T&G profile should be symmetric about the center.
- ▶ Maximum out-of-focus tolerance of 2% (0.34 mm lateral offset).



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### y-jaw divergence/beam centering

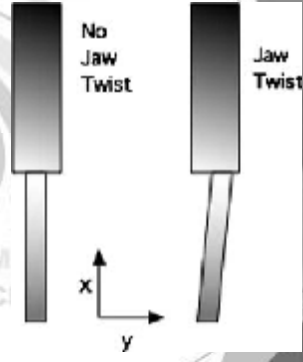
- ▶ A film is positioned horizontally between solid water plates (2 cm) below isocenter (23-25 cm).
- ▶ The MLC field is defined so that only leaves on one side of the central axis are open during exposure (0 & 180).
- ▶ Divergence at isocenter
  - ▶ Difference between fields  $\times [85 \text{ cm}/2 \times d]$ .
- ▶ This alignment needs to be checked if any component is replaced or moved that can affect this alignment (Annually).
- ▶ Should be 0.5 mm or less.



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### y-jaw/gantry rotation plane alignment

- ▶ Check that if the y-jaw is parallel to the plane of rotation.
- ▶ This needs to be checked on an annual basis and anytime that this alignment can be compromised.




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## Treatment field centering


- ▶ All clinical treatment fields must share a common center.
- ▶ This alignment should be checked if any component is replaced or moved.
- ▶ It is recommended to check the field centering annually.
- ▶ A film can be placed perpendicularly to the beam axis at an 85 cm distance (1-2 cm slab)
- ▶ MLC leaves 11-18, 29-36, and 47-54 remain open (y-jaws 2.5 cm).
- ▶ MLC leaves 2-9, 20-28, 38-45, and 56-63 (y-jaws 5 cm).
- ▶ Agreement of the field centers within 0.5 mm at isocenter.



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## MLC alignment test

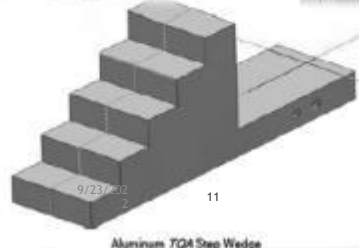
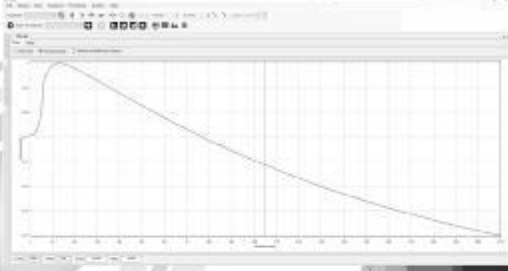
- ▶ A film is positioned at isocenter and two central MLC leaves (32 & 33) are opened in addition to two off-center leaves (27 & 28).
- ▶ The film is exposed with the gantry at 0°.
- ▶ The gantry is moved to 180° and only the two off-center leaves are opened.
- ▶ The MLC offset should be less than 1.5 mm at the isocenter and the MLC twist should be less than 0.5°.



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## Beam quality

- ▶ Adjustments are performed by the field service engineer (FSE) and verified by the local medical physicist.
- ▶ Standard tomotherapy PDD<sub>10</sub> is reduced compared to typical 6 MV linac (shorter SSD and lower inherent energy [4F design]).
- ▶ Tolerance for beam quality variations is 1% for the PDD<sub>10</sub>
- ▶ The consistency of the beam quality should be tested on a monthly basis.
- ▶ On an annual basis water tank data needs to be acquired for comparison with the beam data.
- ▶ The step wedge is 270 mm long, 97.5 mm high, and 69.7 mm wide. Each step is 19.5 mm high.

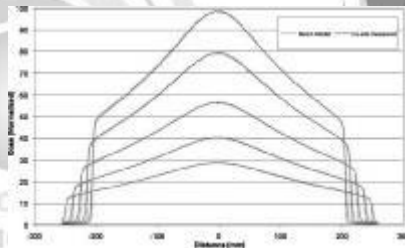


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Aluminum TQM Step Wedge

## Cone (transverse) beam profiles

- ▶ Tomotherapy units do not use a flattening filter.
- ▶ Transverse beam profiles are cone shaped.
- ▶ The intensity at the beam edge falls to 50% of the central axis value.
- ▶ Transverse beam profile size should be monitored monthly and be compared to the beam model on an annual basis.
- ▶ Beam profile consistency tolerance of 1% is specified monthly.



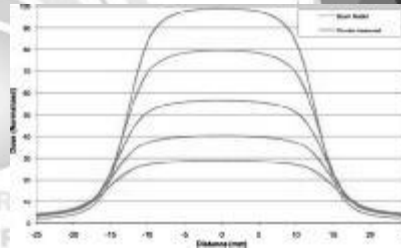
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## Longitudinal beam profiles

- ▶ The consistency of the longitudinal profiles should be monitored monthly for all commissioned slice widths.
- ▶ This test procedure relies on uniform couch motion.
- ▶ The profile's *FWHM* should not vary by more than 1%.
  - ▶ The absolute tolerance on *FWHM* changes is treatment slice width specific, 0.5, 0.25, and 0.1 mm, for the 5.0, 2.5, and 1.0 cm treatment slice widths.
- ▶ Agreement of the measured profiles with the beam model should be verified annually (water tank data).

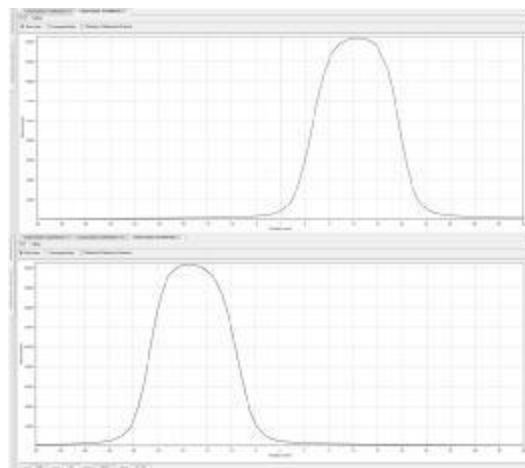


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## Assymmetric Profile



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## Output constancy

- ▶ The consistency of the output should be monitored on a daily basis.
- ▶ It is recommended that the output is monitored using a stationary and/or rotational procedure.
- ▶ The output of the Tomotherapy unit is sensitive to the machine's operating temperature (within 2 °C of its nominal operating temperature).
- ▶ If the static output is monitored on a daily basis the rotational output should be monitored on a weekly basis and vice versa (Two IC).
- ▶ The daily output checks should be consistent within a 3% window.
- ▶ Monthly output checks should be consistent within a 2% window.

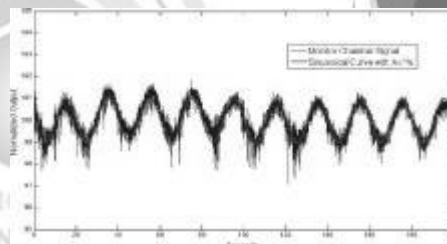
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## Output constancy (cont.)

- ▶ The rotational output on a tomotherapy unit is measured while the gantry continuously rotates.
- ▶ The increased test frequency is recommended based on the fact that the time-based output is sensitive to dose rate fluctuations with gantry angle.
- ▶ The rotational output variations are typically reproducible over several rotations with random variations (1SD) of the order of 1%–2%.



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## Synchrony tests

- ▶ The delivery of a helical tomotherapy plan requires synchronization between the gantry rotation and table movement.
- ▶ The defined tests assume standard treatment scenarios
  - ▶ *Gantry angle consistency*
  - ▶ *Couch speed uniformity*
  - ▶ *Couch translation/gantry rotation*

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## Interrupted treatment procedures

- ▶ If a treatment is interrupted, the helical tomotherapy system can be used to generate a procedure to complete the treatment.
- ▶ The correct generation of this completion procedure should be tested monthly.
- ▶ Based on the developed films, the interrupted treatment should differ from the completed procedure by no more than 3% in its delivered dose
- ▶ The overall length (FWHM) of the dose distribution in the y-direction should differ by no more than 1 mm.

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## Couch speed uniformity

- ▶ Recommended to test this quarterly.
- ▶ A film with 1.5 cm buildup is taped to the tabletop.
- ▶ An irradiation is done with a static gantry in the 0° position.
- ▶ The collimation set to 1 cm, all MLC leaves are open
- ▶ A couch travel distance of 20 cm (0.3–0.5 mm/s)
- ▶ The film is scanned and a profile is generated along the axis of couch travel.
- ▶ The relative optical density along this line should vary by less than 2%.

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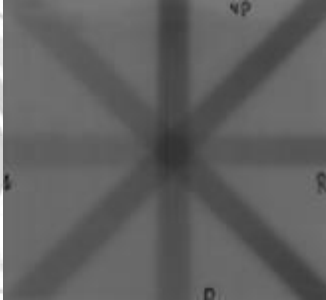
## Couch translation/gantry rotation

- ▶ A film with 1.5 cm buildup is placed on the couch.
- ▶ A rotational irradiation is used with the nominal 1.0 cm beam and a pitch of 1 for 13 rotations.
- ▶ Open all the leaves for half a rotation on the second, seventh, and 12<sup>th</sup> rotation. The resulting film is scanned and a profile is produced along the direction of table travel.
- ▶ The resulting profile should show maxima 5 cm apart to within 1 mm.

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## Gantry angle consistency

- ▶ Correctly identify gantry angles (quarterly).
- ▶ Two films parallel to the rotation plane and separated on either side of the virtual isocenter by 3 cm.
- ▶ A delivery sequence is defined that specifies a slice width of 2.5 cm and a pitch of 0.1 for a minimum of 40 rotations (middle two leaves 32 and 33) at projections centered at 0°, 120°, and 240°.
- ▶ Using a horizontal line marked on the films during setup, the resulting star pattern can be checked for the correct initial angles (tolerance of 1°).



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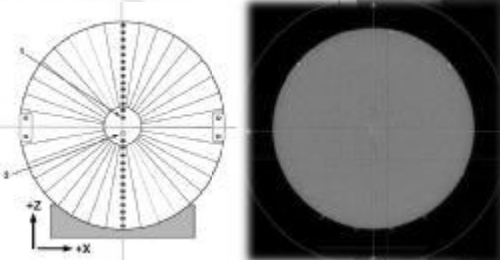
## Laser localization

- ▶ The accurate longitudinal spacing between the stationary (green) laser plane and the treatment isocenter should be tested annually.
- ▶ The center of the radiation field should agree with the laser position to within 1 mm.
- ▶ The treatment field should be parallel to the laser to within 0.3°.
- ▶ The accurate movement of the movable laser with respect to the stationary laser should be tested monthly (within 1mm)
- ▶ The green and red lasers should coincide within 1.5 mm for non-SBRT/SRS and within 1 mm for SBRT/SRS treatments.

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## Coincidence of laser and radiation isocenter

- ▶ Tomo phantom centered on green lasers, as viewed from behind the gantry.
- ▶ Label 1 is the dowel 10 mm above isocenter.
- ▶ Label 2 is the empty cavity at -5mm.



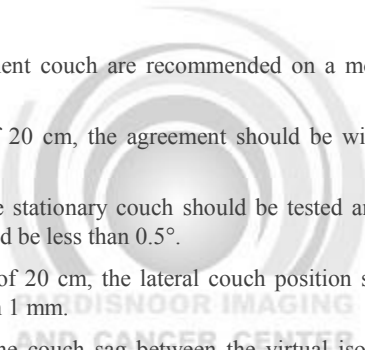
The diagram shows a circular Tomo phantom with a central isocenter. A coordinate system is overlaid with the X-axis pointing right and the Z-axis pointing up. Labels 1 and 2 are positioned relative to the isocenter. To the right of the diagram is a square image showing the phantom's appearance from behind the gantry, with a central circular area.

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## Treatment couch

- ▶ Tests of the treatment couch are recommended on a monthly basis.
- ▶ Over a distance of 20 cm, the agreement should be within 1 mm.
- ▶ The leveling of the stationary couch should be tested and the pitch and roll should be less than 0.5°.
- ▶ Over the distance of 20 cm, the lateral couch position should deviate by less than 1 mm.
- ▶ At the isocenter, the couch sag between the virtual isocenter and the treatment plane should be less than 5 mm for an unloaded couch.



The diagram shows a circular treatment couch with a central isocenter. A coordinate system is overlaid with the X-axis pointing right and the Z-axis pointing up.

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## Calibration

- ▶ The helical tomotherapy physical limitations do not permit a  $10 \times 10 \text{ cm}^2$  field size at 100 cm SSD. However, a  $5 \text{ cm} \times 10 \text{ cm}$  field size can be set at 85 cm SSD.
- ▶ This field is called a *machine-specific reference (msr)* field.
- ▶ In addition to static-field dosimetry it allows a second calibration route that is based on the delivery of composite fields.
- ▶ The formalism suggests that the physicist will develop a *plan-class specific reference (pcsr)* field and perform the measurements within this field to determine the output of the machine as it rotates about the calibration phantom.

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## Megavoltage CT imaging

- ▶ Nominal energy of the incident electron beam is 3.5 MeV
- ▶ Matrix size is  $512 \times 512$  pixels
- ▶ Field-of-view has a diameter of 40 cm
- ▶ Three pitch values 1 (Fine), 2 (Normal), and 3 (Coarse)
  - ▶ Nominal slice thickness of 2, 4, and 6 mm
- ▶ Rotational period during the image acquisition is fixed at 10 s
- ▶ The imaging dose depends on the selected pitch and the thickness of the imaged anatomy (1–3 cGy)

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## Geometric distortions

- ▶ Cheese Phantom
- ▶ Distances between embedded objects in the x, y, and z directions, and the orientation of the phantom (in MVCT image Vs. physical distances).
- ▶ Fine scan (nominal slice thickness of 2 mm)
- ▶ Minimum scan length of 20 cm
- ▶ The dimension of the embedded objects or distances should be within 2 (non-SRS/SBRT) and 1 mm (SRS/SBRT).
- ▶ Test frequency is monthly.

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## Imaging/treatment/laser coordinate coincidence

- ▶ On an annual basis and after software upgrades, a phantom-based end-to-end test of the image registration and treatment chain
  - ▶ The phantom is imaged
  - ▶ A plan is generated in the TPS
  - ▶ MVCT imaging is used to check the phantom alignment
  - ▶ The phantom is treated
  - ▶ Dose distribution within the phantom is tested for accuracy to establish image and treatment coordinate coincidence.
    - ▶ film-based or IC based (A1SL, 0.053 cc)
- ▶ Within 2 (non-SRS/SBRT) and 1 mm (SRS/SBRT).
- ▶ Accurate location of the reconstructed image with respect to the green laser (Daily)
- ▶ Phantom with a high contrast object, is aligned (red or green laser), scanned

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## Image registration and alignment (position/repositioning)

- ▶ Cheese phantom
  - ▶ Intentionally and reproducibly misaligned prior to MVCT imaging can be scanned and registered to monitor the functionality and consistency of the image guidance process.
- ▶ The image registration process should be reproducible to within 1 mm (for phantoms that contain a high contrast object).

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## Image quality tests


- ▶ Image degradation indicate
  - ▶ Suboptimal performance of the beam collimation,
  - ▶ MVCT detector system
  - ▶ Variations in the MVCT beam with target wear.
- ▶ The accuracy of the primary y-jaws in defining the MVCT slice width
- ▶ Fan beam is wider than intended (patient dose).
- ▶ The appearance of ring artifacts in the image points (Malfunction in the detector system).
- ▶ The HU to electron density conversion can also vary with target wear.

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## Image quality tests

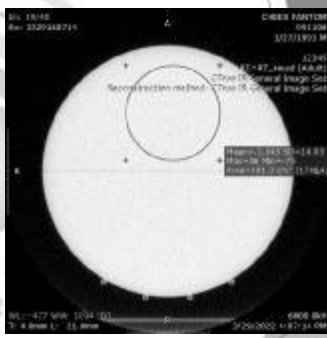
- ▶ Image noise
- ▶ Uniformity
- ▶ Spatial resolution
- ▶ Contrast
- ▶ MVCT dose
- ▶ The CT number reproducibility and image uniformity are essential if the MVCT images are used for dose calculations
- ▶ Monthly MVCT QA protocol will vary with the intended MVCT use.



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## Image noise

- ▶ An image of a water or water-equivalent uniform phantom can be used.
- ▶ The noise can be assessed by calculating the standard deviation of the HUs in a ROI.
- ▶ Noise values of 3.7–3.8 have been published for MVCT images (35–36 HU in a homogeneous water bath)
- ▶ Cylindrical uniform phantom with a diameter of at least 20 cm
- ▶ Monitor the noise level on a monthly basis.
- ▶ Typical noise levels
  - ▶ Central region of the MVCT image (50–70 HU)
  - ▶ In the periphery (25–35 HU)



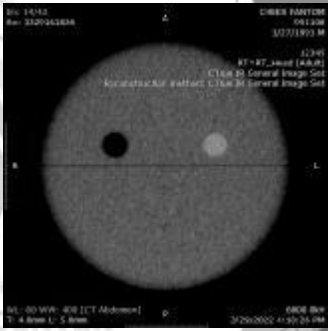
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## Contrast

- ▶ Cheese phantom
- ▶ The low contrast visibility can be measured by inserting various density test plugs supplied by the vendor in the phantom.
- ▶ On a monthly basis, the visibility of the identical test plugs can be checked.
- ▶ This test relies on the operator and is subjective in nature.



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## CT number to density calibration

- ▶ The relationship of MVCT number to electron or mass density is different from that observed in kVCT scanners.
- ▶ This is due to the difference in physical interaction probabilities in the two beams.
- ▶ Consequently, the MVCT number to physical density calibration table is expected to reflect a linear relationship.
- ▶ If MVCT images are used for dose calculations, the reproducibility of this calibration curve should be monitored on a monthly basis

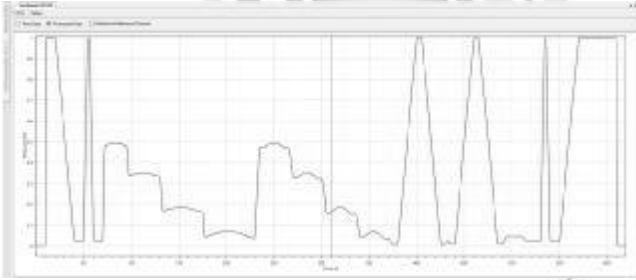
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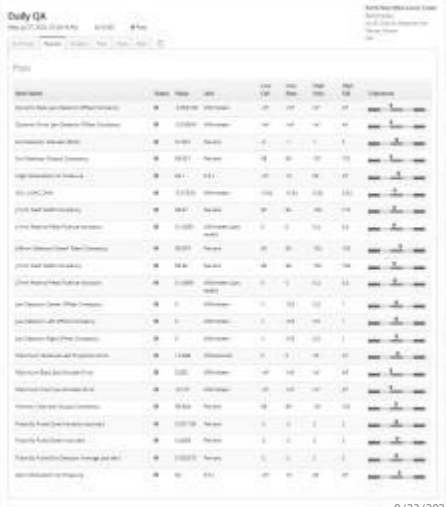
## Jaw Sweep-Dynamic Jaws

- ▶ Alignment of linac relative to jaws
- ▶ Movement function of dynamic jaws



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## TQA



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