Tomotherapy Machine QA

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Unique aspects of the Tomotherapy

- 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^2 static field).
- Displayed Dose rate is average dose rate.
- All MLC leaves are closed for the initial 10 s.

Mechanichal Allignment

- 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.

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).

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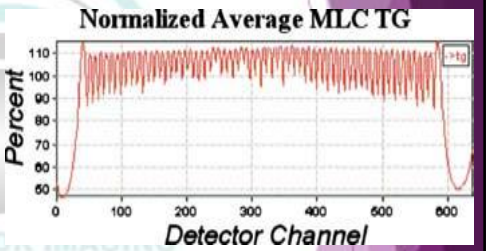
x-alignment of source (T&G)

- 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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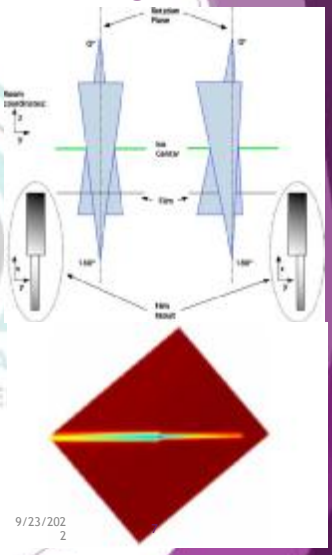
y-jaw divergence/beam centering

- 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 ×[85 cm/2 × *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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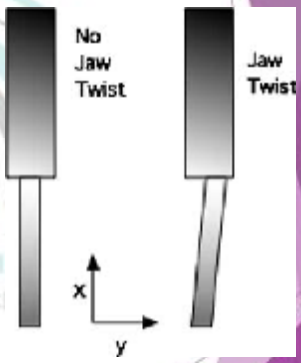
y-jaw/gantry rotation plane alignment

- 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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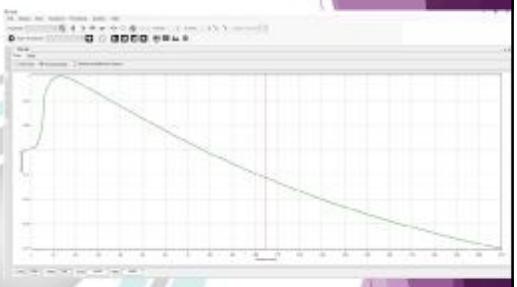
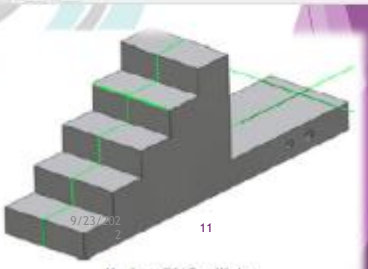
Beam quality

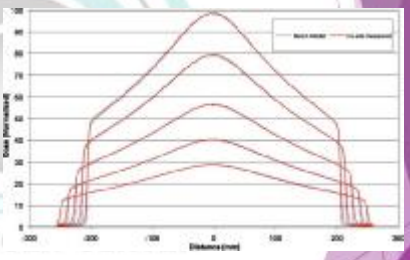
- Adjustments are performed by the field service engineer (FSE) and verified by the local medical physicist.
- Standard tomotherapy PDD_{10} is reduced compared to typical 6 MV linac (shorter SSD and lower inherent energy [4F design]).
- Tolerance for beam quality variations is 1% for the PDD_{10}
- 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.





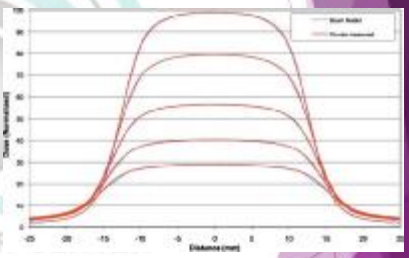
Cone (transverse) beam profiles

- 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.

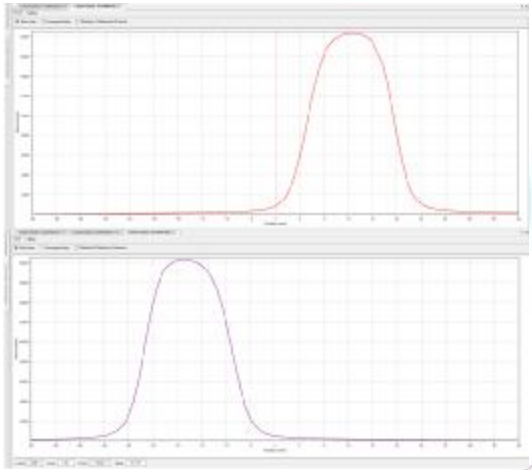


Longitudinal beam profiles

- 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).



Assymetric Profile



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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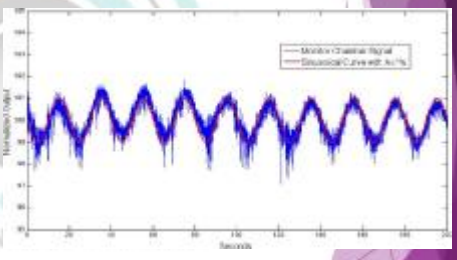
Output constancy (cont.)

- 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*

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 that 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.

Couch speed uniformity

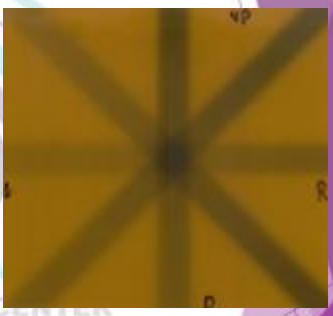
- Recommended to test this quarterly.
- A film with 1.5 cm buildup is taped to the tabletop.
- An irradiation is done with a static gantry in the 0° position.
- The collimation set to 1 cm, all MLC leaves are open
- A couch travel distance of 20 cm (0.3–0.5 mm/s)
- The film is scanned and a profile is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

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 12th 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.

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°).

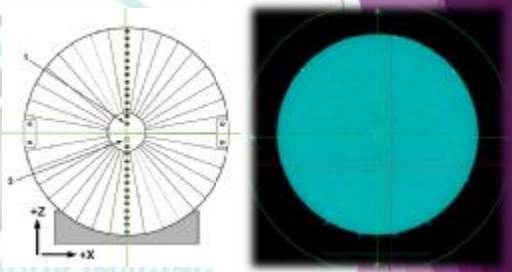


Laser localization

- 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.

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.



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.

Calibration

- The helical tomotherapy physical limitations do not permit a 10×10 cm^2 field size at 100 cm SSD. However, a 5cm×10cm 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 512×512 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.

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

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).

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.

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.

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)

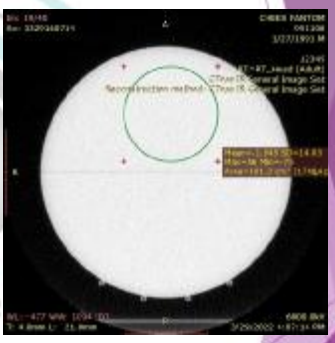
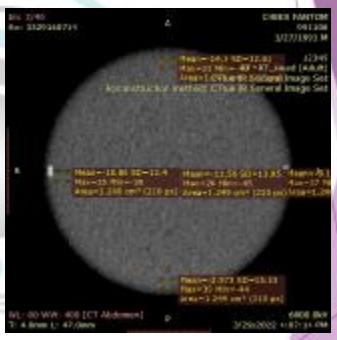


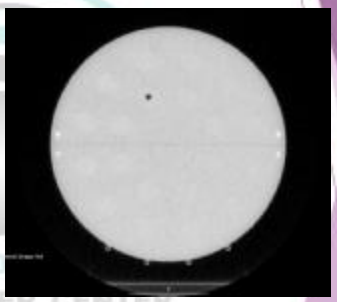
Image uniformity

- The uniformity can be assessed by measuring the average HU in smaller ROIs (5 mm in radius) located in the center and periphery of the phantom.
- The largest difference between any peripheral HU and the central HU is determined.
- It is recommended to monitor the image uniformity on a monthly basis.
- The largest HU difference between the peripheral and the central ROIs should be less than 25 HU.
  - 2.5% variation in the calculated density of water.



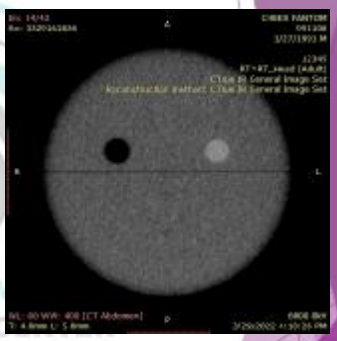
Spatial resolution

- Cheese phantom
- The spatial resolution can be measured with a high contrast hole pair test pattern
- Tomotherapy provides a resolution plug that can be used for this test.
- A monthly check of the MVCT image resolution should be performed.



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.

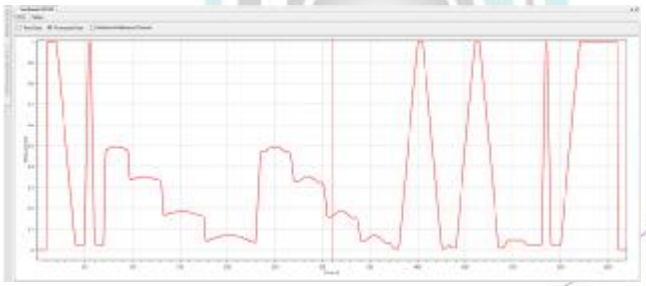


CT number to density calibration

- 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

Jaw Sweep-Dynamic Jaws

- Allignment of linac relative to jaws
- Movement function of dynamic jaws



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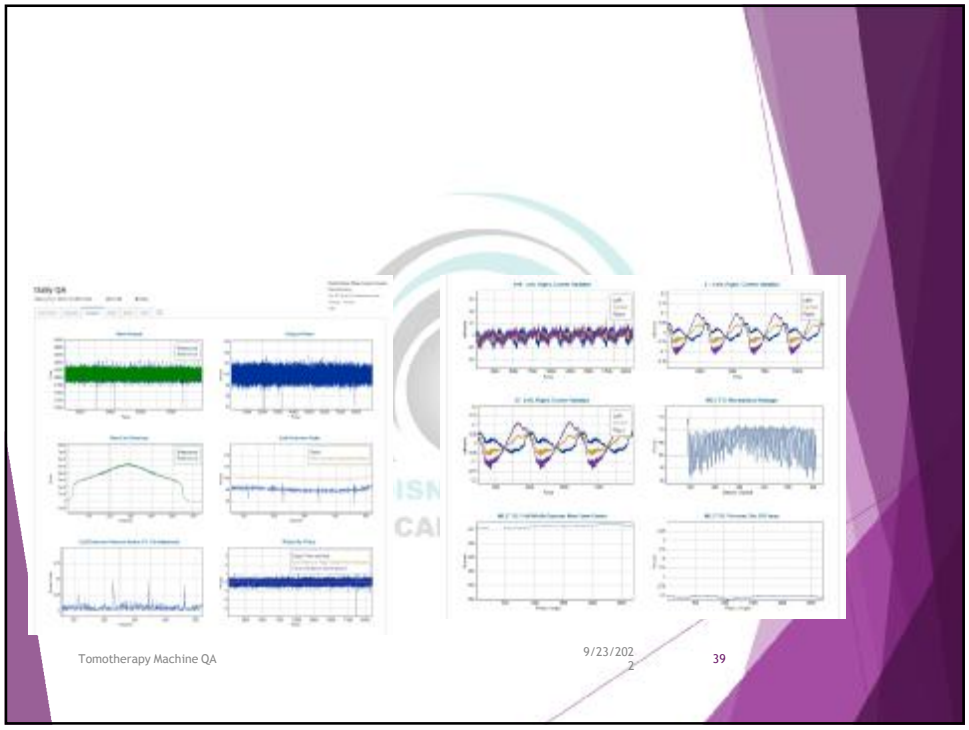
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