AAPM 56th Annual Meeting - Austin, Texas
Image Quality for the Radiation Oncology Physicist: Review of the Fundamentals and Implementation

# *Image Quality Review II: Implementation of Image Quality Assurance*

TH-A-16A-3

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21st Century Oncology

# Funding Support, Disclosures, and Conflict of Interest:

None

# Implementation of Image Quality Assurance

- Image Guide Radiation Therapy (IGRT) has become the standard of care for patient setup and target localization for external beam therapy.

## Implementation of Image Quality Assurance

The expansion and integration of diagnostic imaging technologies such as On Board Imaging (OBI) and Cone Beam Computed Tomography (CBCT) into radiation oncology has required radiation oncology physicists to be responsible for and become familiar with assessing image quality.

# AAPM Reports

| | | |
|---|---|---|
| 2001 | TG-58 | Clinical Use of Electronic Portal Imaging |
| 2009 | TG-104 | The Role of In-Room kV X-Ray Imaging for Patient Setup and Target Localization |
| 2009 | TG-142 | Quality Assurance of Medical Accelerators |
| 2012 | TG-179 | Quality Assurance for Image-Guided Radiation Therapy Utilizing CT-based Technologies |
| 2014 | MPG 2.a | Commissioning and Quality Assurance of X-ray based Image-Guided Radiotherapy Systems |

# TG-142 Table VI Imaging QA

## Daily

**Planar kV and MV (EPID) imaging**

Collision interlocks
Positioning/repositioning
Imaging and treatment coordinate coincidence (single gantry angle)

**Cone-beam CT (kV and MV)**

Collision interlocks
Imaging and treatment coordinate coincidence
Positioning/repositioning

## Monthly

**Planar MV imaging (EPID)**

Imaging and treatment coordinate coincidence (four cardinal angles)
Scaling[b]
Spatial resolution
Contrast
Uniformity and noise

**Planar kV imaging[d]**

Imaging and treatment coordinate coincidence (four cardinal angles)
Scaling
Spatial resolution
Contrast
Uniformity and noise

**Cone-beam CT (kV and MV)**

Geometric distortion
Spatial resolution
Contrast
HU constancy
Uniformity and noise

## Annual

**Planar MV imaging (EPID)**

Full range of travel SDD
Imaging dose[e]

**Planar kV imaging**

Beam quality/energy (kVp / HVL)
Imaging dose (output - mR/mAs)

**Cone-beam CT (kV and MV)**

Imaging dose (CTDI or TG-111)

Daily QA – Therapist

Monthly QA – Physicist

Annual QA – Physicist

# Implementation of Image Quality Assurance

- TG-142 and other task group reports lists recommended QA tests but do not describe their implementation.
- Radiation oncology physicists may not be familiar or have experience with imaging QA tests and measures that are common for diagnostic physicists.

# Implementation of Image Quality Assurance

- The implementation of an image quality program in accordance with Task Group recommendations can be done relatively easily and simply with readily available phantoms.
- Automated image analysis software and phantoms may offer advantages and advanced capabilities, but come with caveats.

# EPID Monthly QA

## EPID Monthly QA

by : P. Imbergamo      Date: 09/27/11

Location: SNR - Woonsocket, RI
Unit: 21 EX      Serial # 2811

**I. Collision Interlocks** - alarm sounds & all motions disabled

| Location | Pass | Fail | Comments |
|---|---|---|---|
| Arms: | Pass | | |
| Detector: | Pass | | |

**II. MV Detector Positioning & Reproducibility**      cover to detector distance (cm): 2.5

- measure SSD to detector & shift at two different detector distances

| Detector Position | | | SSD (cm) | | Diff or Shift (<0.2 cm) | | | |
|---|---|---|---|---|---|---|---|---|
| Vertical | Long | Lat | expected | measured | diff. | (<0.2 cm) | Sup/Inf | Rt/Lt |
| 60.0 | 0.0 | 0.0 | 57.5 | 57.5 | 0.0 | Pass | P | P |
| 5.0 | 0.0 | 0.0 | 2.5 | 2.5 | 0.0 | Pass | P | P |

**III. EPID Imaging & Treatment Isocenter Coincidence**

- place isocenter Cube tool on couch top at isocenter using lasers & crosshairs
- load QA patient & take port films at four cardinal angles
- at each angle measured difference between center of steel ball & digital graticule

| Gantry Angle | difference (cm) | Pass/Fail (≤0.15cm) |
|---|---|---|
| 0 | 0.05 | Pass |
| 90 | 0.04 | Pass |
| 180 | 0.05 | Pass |
| 270 | 0.06 | Pass |

**IV. Scaling**

- measure isocenter Cube tool image in X & Y directions

| Direction | expected (cm) | measured (cm) | diff. (cm) | % diff | Pass/Fail (≤ 1%) |
|---|---|---|---|---|---|
| X | 5.0 | 4.99 | -0.01 | 0.20% | Pass |
| Y | 5.0 | 4.98 | -0.02 | 0.40% | Pass |

**V.EPID Calibration**      AM Maintenance

1. Dark & Flood Fields

a. Low Dose & High Quality Images

- Imager position: -50.0, 0.0, 0.0 (Auto)
- Jaw Settings: X = 28 Y =22

| Technique | Energy | Rep Rate | Dark | Flood |
|---|---|---|---|---|
| Low Dose | 6 | 300 | X | X |
| " | 6 | 400 | X | X |
| " | 18 | 400 | X | X |
| High Quality | 6 | 300 | X | X |
| " | 6 | 400 | X | X |
| " | 18 | 400 | X | X |



b. Integrated Image

- Imager position: -5.0, 0.0, 0.0 (P5)
- Jaw Settings: X = 38.1 Y = 28.6

| Technique | Energy | Rep Rate | Dark | Flood |
|---|---|---|---|---|
| Int. Image | 6 | 300 | X | X |
| " | 6 | 400 | X | X |
| " | 18 | 400 | X | X |

2. Dosimetry Calibration

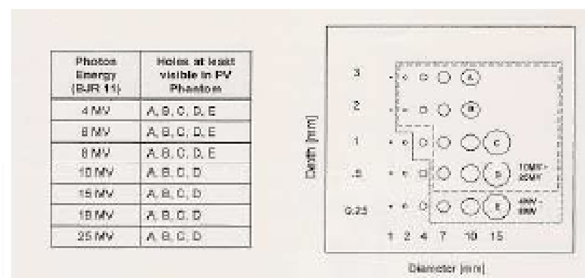
- Imager position: -5.0, 0.0, 0.0 (P5)
- Jaw Settings: X = 10.0 Y = 10.0

| | | Previous | | Current | |
|---|---|---|---|---|---|
| Energy | Rep Rate | Date | Value | Date | Value |
| 6 | 300 | 8/16/2011 | 0.097025 | 9/6/2011 | 0.0969912 |
| 6 | 400 | 8/16/2011 | 0.097217 | 9/6/2011 | 0.0974679 |
| 18 | 400 | 8/16/2011 | 0.110269 | 9/6/2011 | 0.110407 |

**VI. Image Quality (Resolution / Contrast & Noise)**

- Imager position: -40.0, 0.0, 0.0   Jaws: 20 X 20
- Acquisition Technique:High Quality Image, 6x/400, 18x/400
- Vegas phantom centered @ 100 cm SSD on couch
- identify smallest hole (column) with least contrast (row) visualized for both energies
- Enter the diameter corresponding to the smallest hole (column) visualized (see diagram below)
- Enter the letter of the row of the smallest hole with the least contrast visualized (see diagram below)
- Specification: see table & diagram below

| Energy | column dia. (mm) | row depth (mm) | % Object Contrast | Pass/Fail |
|---|---|---|---|---|
| 6 | 10.0 | E | 0.15 | Pass |
| 18 | 10.0 | D | 0.18 | Pass |



# EPID Monthly QA

I. Collision Interlocks
II. MV Detector Positioning & Reproducibility
III. EPID Imaging & Treatment Isocenter Coincidence
IV. Scaling
V. EPID Calibration
VI. Image Quality (Resolution/Contrast & Noise)

# EPID Monthly QA

**I. Collision Interlocks** - alarm sounds & all motions disabled

| Location | Pass | Fail | Comments |
|---|---|---|---|
| Arms: | **Pass** | | |
| Detector: | **Pass** | | |

**II. MV Detector Positioning & Reproducibility**

| cover to detector distance (cm): | 2.5 |
|---|---|

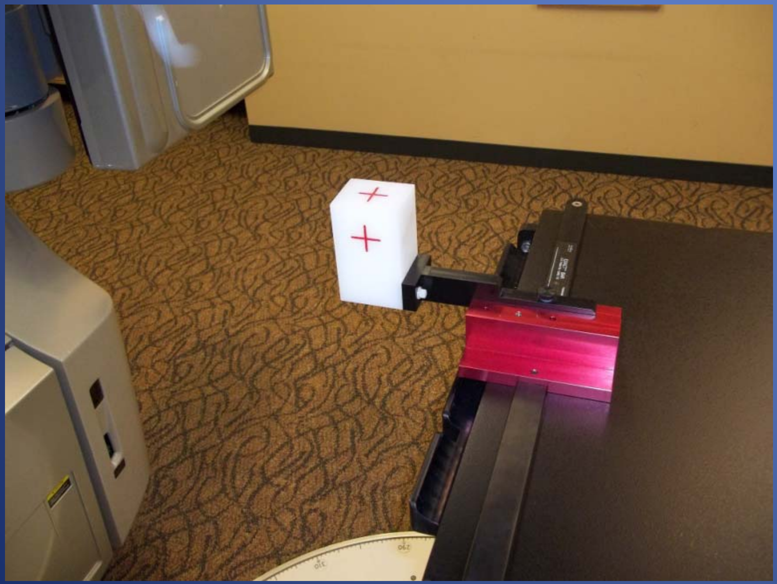
- measure SSD to detector & shift at two different detector distances

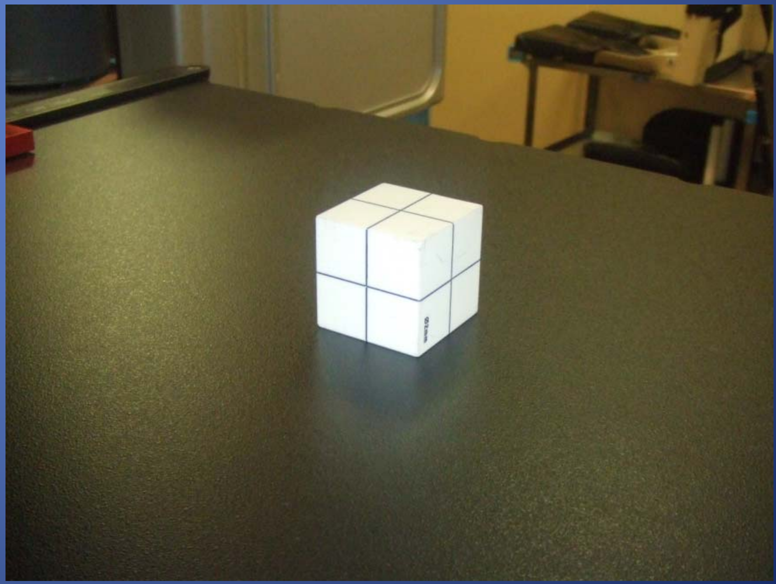
| Detector Position | | | SSD (cm) | | Diff or Shift ($\leq$0.2 cm) | | | |
|---|---|---|---|---|---|---|---|---|
| Vertical | Long | Lat | expected | measured | diff. | ($<$0.2 cm) | Sup/Inf | Rt/Lt |
| 60.0 | 0.0 | 0.0 | 57.5 | 57.5 | 0.0 | **Pass** | **P** | **P** |
| 5.0 | 0.0 | 0.0 | 2.5 | 2.5 | 0.0 | **Pass** | **P** | **P** |

## III. EPID Imaging & Treatment Isocenter Coincidence

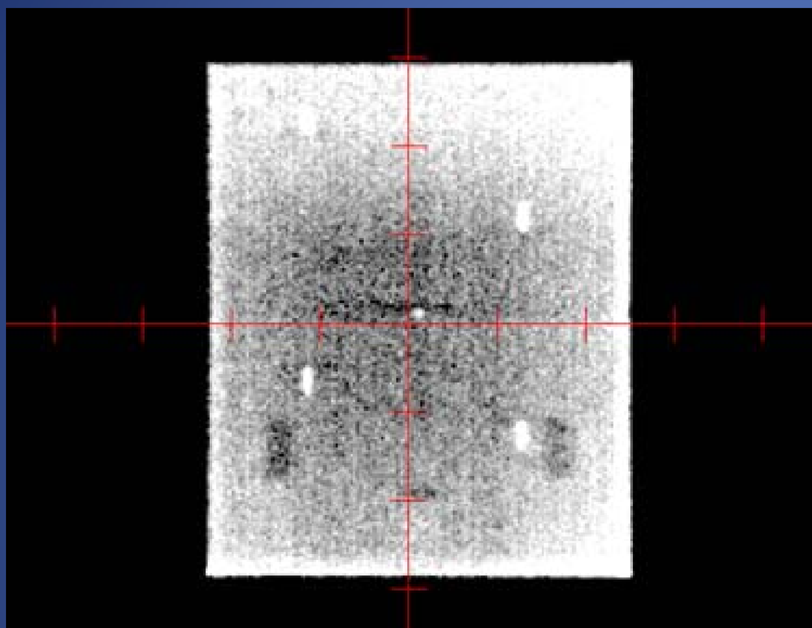
- place Isocenter Cube tool on couch top at isocenter using lasers & crosshairs
- load QA patient & take port films at four cardinal angles
- at each angle measured difference between center of steel ball & digital graticule

| Gantry Angle | difference (cm) | Pass/Fail ($\leq$0.15cm) |
|---|---|---|
| 0 | 0.05 | **Pass** |
| 90 | 0.04 | **Pass** |
| 180 | 0.05 | **Pass** |
| 270 | 0.06 | **Pass** |





# III. EPID Imaging & Treatment Isocenter Coincidence



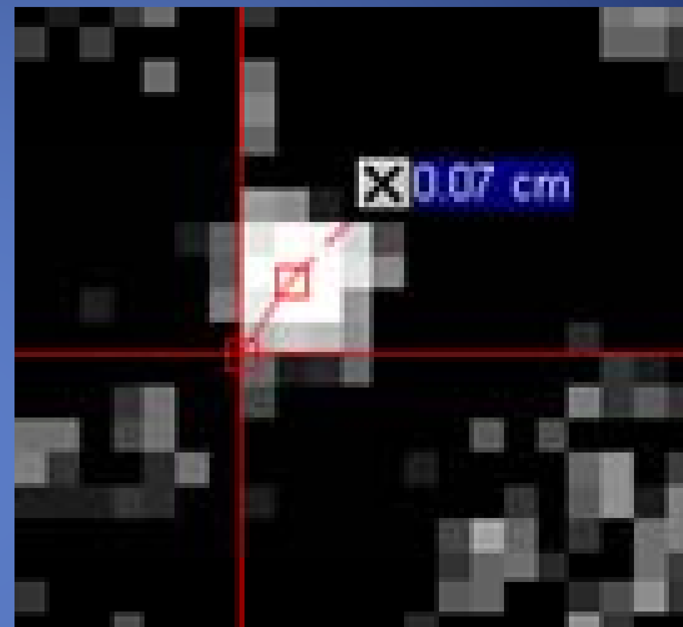



Image at all four cardinal angles

TG 142 tolerance
≤ 2 mm non SRS/SBRT
≤ 1 mm SRS/SBRT

| Gantry Angle | difference (cm) | Pass/Fail (≤0.15cm) |
|---|---|---|
| 0 | 0.07 | **Pass** |
| 90 | 0.04 | **Pass** |
| 180 | 0.05 | **Pass** |
| 270 | 0.06 | **Pass** |

# EPID Monthly QA

## IV. Scaling

- measure Isocenter Cube tool image in X & Y directions

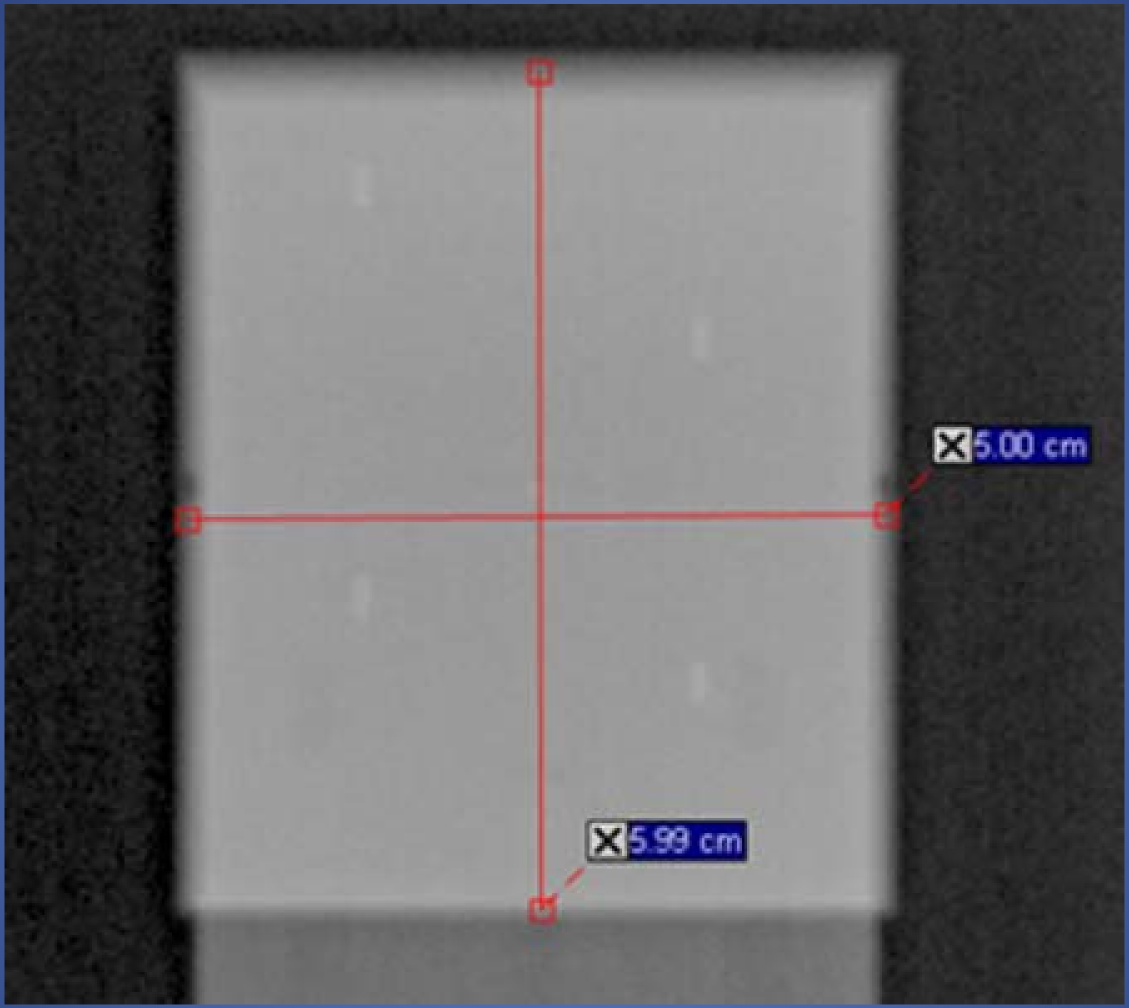
| Direction | expected (cm) | measured (cm) | diff. (cm) | % diff | Pass/Fail ($\leq$ 1%) |
|---|---|---|---|---|---|
| X | 5.0 | 5.00 | 0.00 | 0.00% | **Pass** |
| Y | 6.0 | 5.99 | -0.01 | 0.17% | **Pass** |

TG 142 tolerance

$\leq$ 2 mm

measured at SSD typically used for imaging

# IV. Scaling




TG 142 tolerance

$\leq$ 2 mm

measured at SSD typically used for imaging

# EPID Monthly QA

**V.EPID Calibration** AM Maintenance

1. Dark & Flood Fields

a. Low Dose & High Quality Images

- Imager position: -50.0, 0.0, 0.0
- Jaw Settings: X = 26.7 Y = 20.0

| Technique | Energy | Rep Rate | Dark | Flood |
|---|---|---|---|---|
| Low Dose | 6 | 300 | X | X |
| " | 6 | 400 | X | X |
| " | 18 | 400 | X | X |
| High Quality | 6 | 300 | X | X |
| " | 6 | 400 | X | X |
| " | 18 | 400 | X | X |

b. Integrated Image

- Imager position: -5.0, 0.0, 0.0 (P5)
- Jaw Settings: X = 38.1 Y = 28.6

| Technique | Energy | Rep Rate | Dark | Flood |
|---|---|---|---|---|
| Int. Image | 6 | 300 | X | X |
| " | 6 | 400 | X | X |
| " | 18 | 400 | X | X |

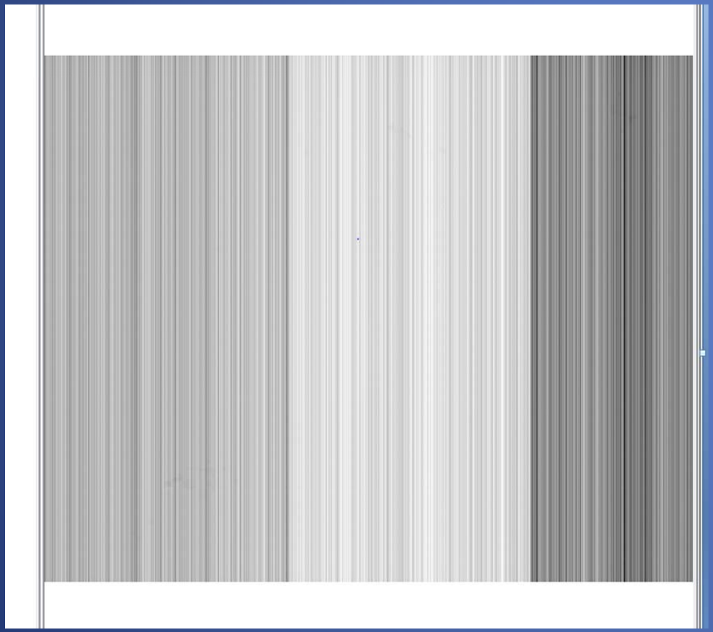
2. Dosimetry Calibration

- Imager position: -5.0, 0.0, 0.0 (P5)
- Jaw Settings: X = 10.0 Y = 10.0

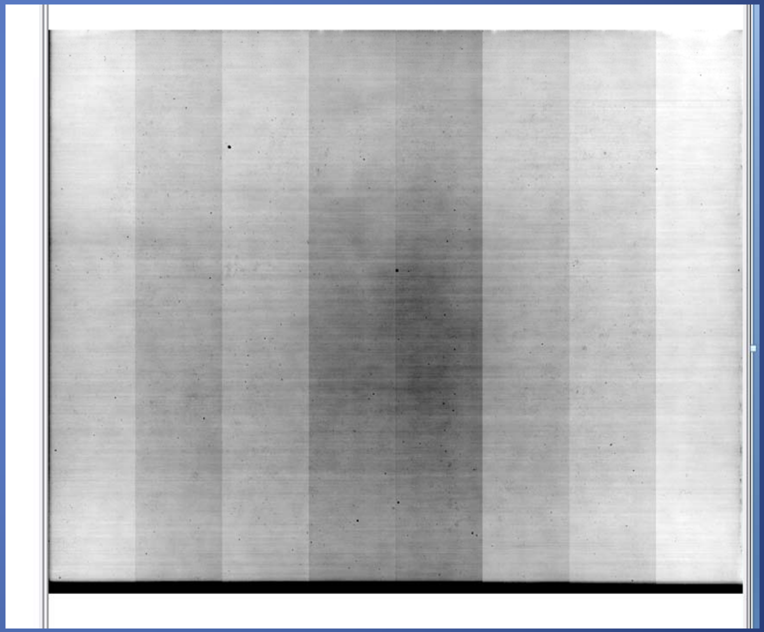
| | | Previous | | Current | |
|---|---|---|---|---|---|
| Energy | Rep Rate | Date | Value | Date | Value |
| 6 | 300 | 4/2/2014 | 0.0988869 | 5/1/2014 | 0.0989403 |
| 6 | 400 | 4/2/2014 | 0.0993320 | 5/1/2014 | 0.0993493 |
| 18 | 400 | 4/2/2014 | 0.112799 | 5/1/2014 | 0.112593 |

# V. EPID Calibration

Dark Fields

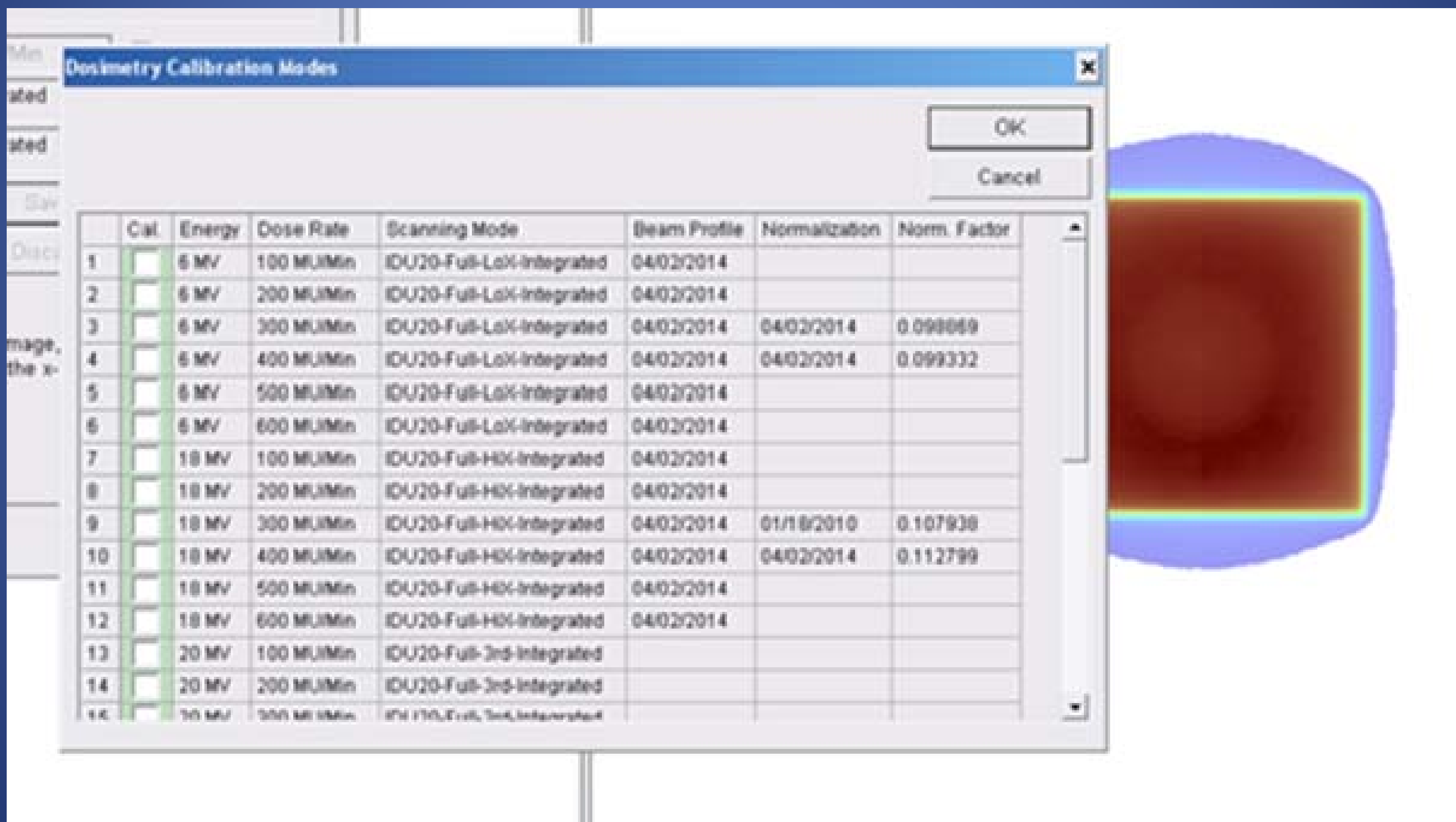


Flood Fields



# V. EPID Calibration

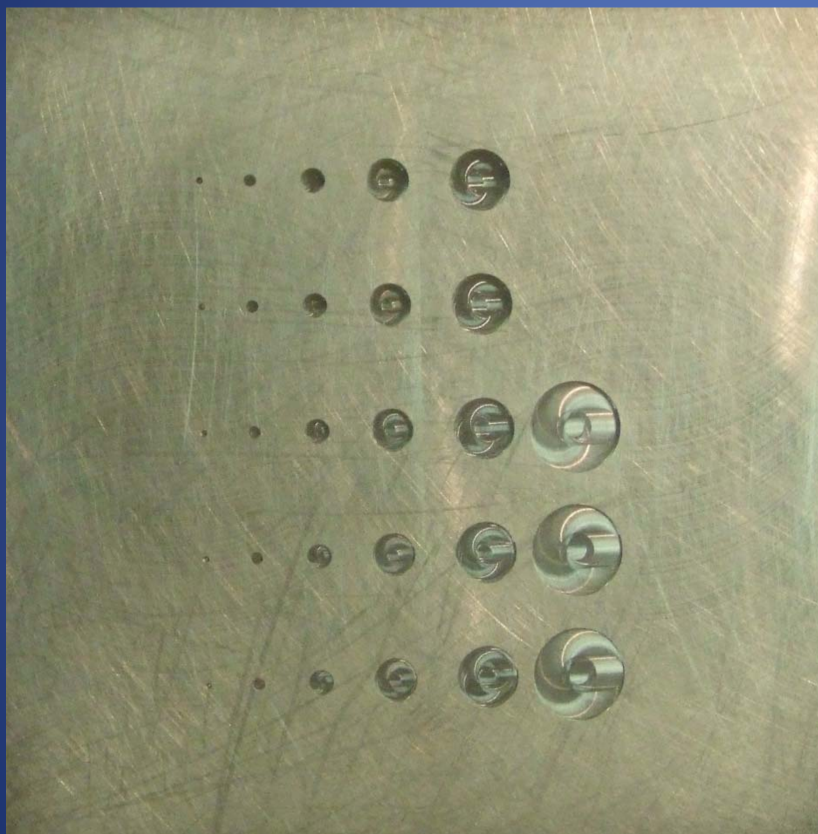
## Dosimetry Calibration




| | Cal | Energy | Dose Rate | Scanning Mode | Beam Profile | Normalization | Norm. Factor |
|---|---|---|---|---|---|---|---|
| 1 | | 6 MV | 100 MU/Min | IDU20-Full-LoX-Integrated | 04/02/2014 | | |
| 2 | | 6 MV | 200 MU/Min | IDU20-Full-LoX-Integrated | 04/02/2014 | | |
| 3 | | 6 MV | 300 MU/Min | IDU20-Full-LoX-Integrated | 04/02/2014 | 04/02/2014 | 0.098869 |
| 4 | | 6 MV | 400 MU/Min | IDU20-Full-LoX-Integrated | 04/02/2014 | 04/02/2014 | 0.099332 |
| 5 | | 6 MV | 500 MU/Min | IDU20-Full-LoX-Integrated | 04/02/2014 | | |
| 6 | | 6 MV | 600 MU/Min | IDU20-Full-LoX-Integrated | 04/02/2014 | | |
| 7 | | 18 MV | 100 MU/Min | IDU20-Full-HiX-Integrated | 04/02/2014 | | |
| 8 | | 18 MV | 200 MU/Min | IDU20-Full-HiX-Integrated | 04/02/2014 | | |
| 9 | | 18 MV | 300 MU/Min | IDU20-Full-HiX-Integrated | 04/02/2014 | 01/18/2010 | 0.107938 |
| 10 | | 18 MV | 400 MU/Min | IDU20-Full-HiX-Integrated | 04/02/2014 | 04/02/2014 | 0.112799 |
| 11 | | 18 MV | 500 MU/Min | IDU20-Full-HiX-Integrated | 04/02/2014 | | |
| 12 | | 18 MV | 600 MU/Min | IDU20-Full-HiX-Integrated | 04/02/2014 | | |
| 13 | | 20 MV | 100 MU/Min | IDU20-Full-3rd-Integrated | | | |
| 14 | | 20 MV | 200 MU/Min | IDU20-Full-3rd-Integrated | | | |

# VI. Image Quality (Resolution / Contrast & Noise)

Vegas Phantom



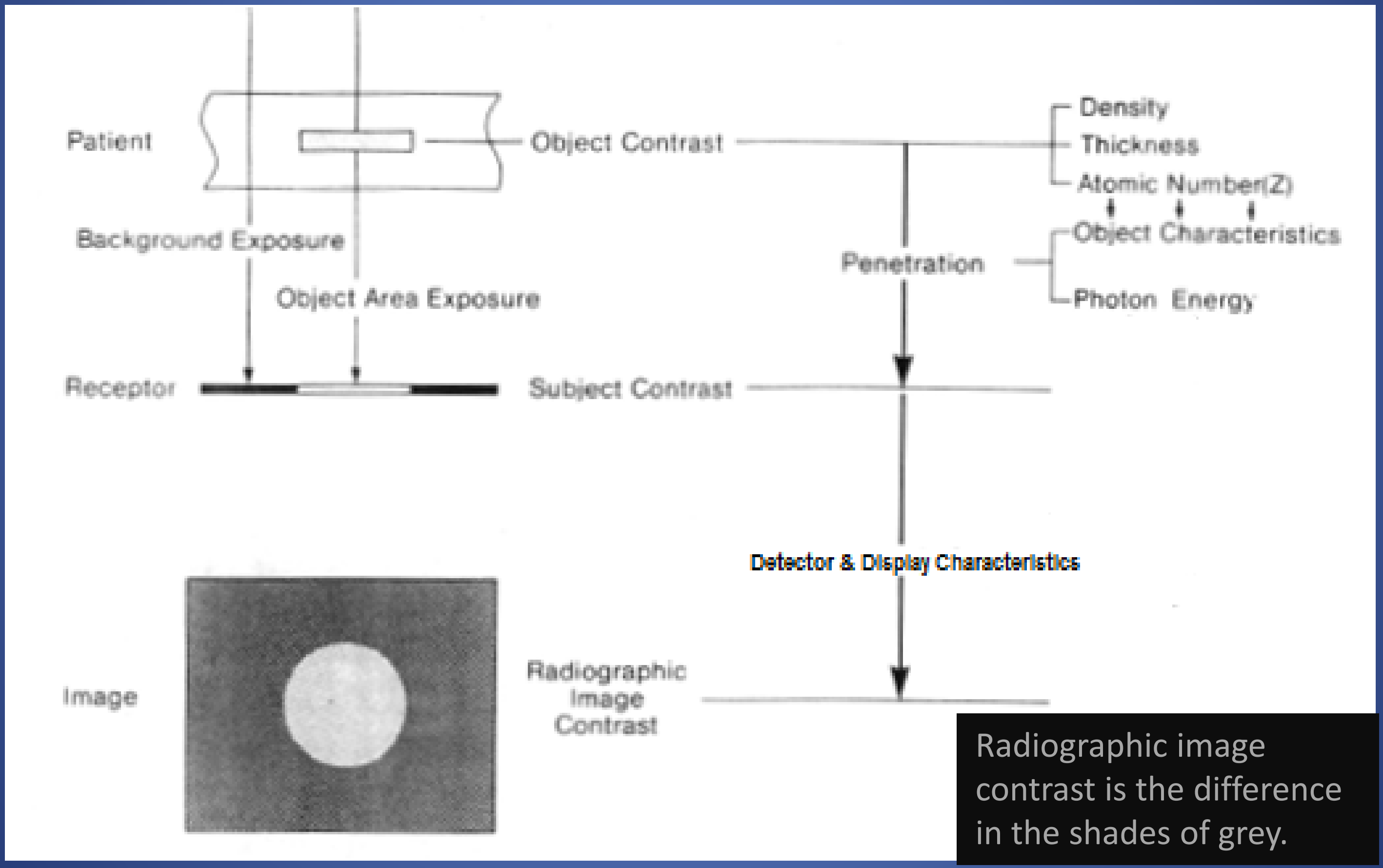
Note: phantom above is flipped over to show holes normally placed hole side down on the table for imaging

- Aluminum block with columns of circles machined to different depths
  - less depth equates to less contrast
- Rows of circles with decreasing diameters
  - the smaller the diameter equates to greater detail

# VI. Image Quality (Resolution / Contrast & Noise)

## <u>Contrast  = Difference</u>

- Contrast is the most fundamental characteristic of an image.




Stages of Contrast Development in Radiography

adapted from Sprawls , *"Physical Principles of Medical Imaging"*

# VI. Image Quality (Resolution / Contrast & Noise)

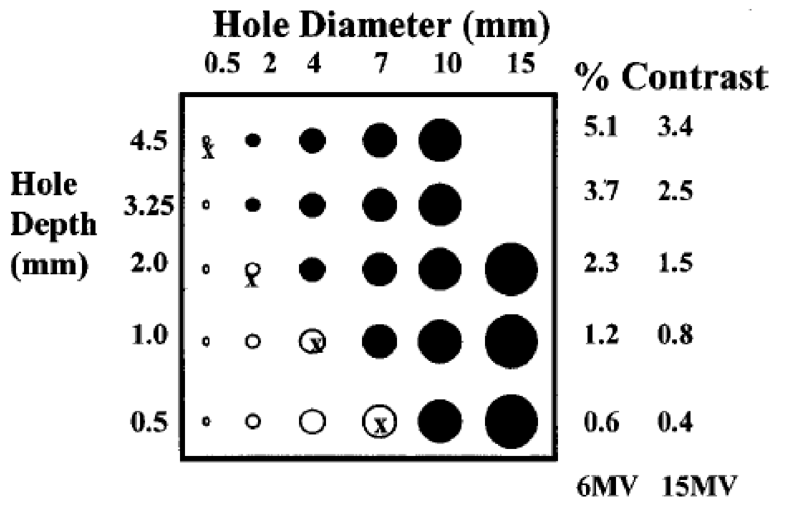


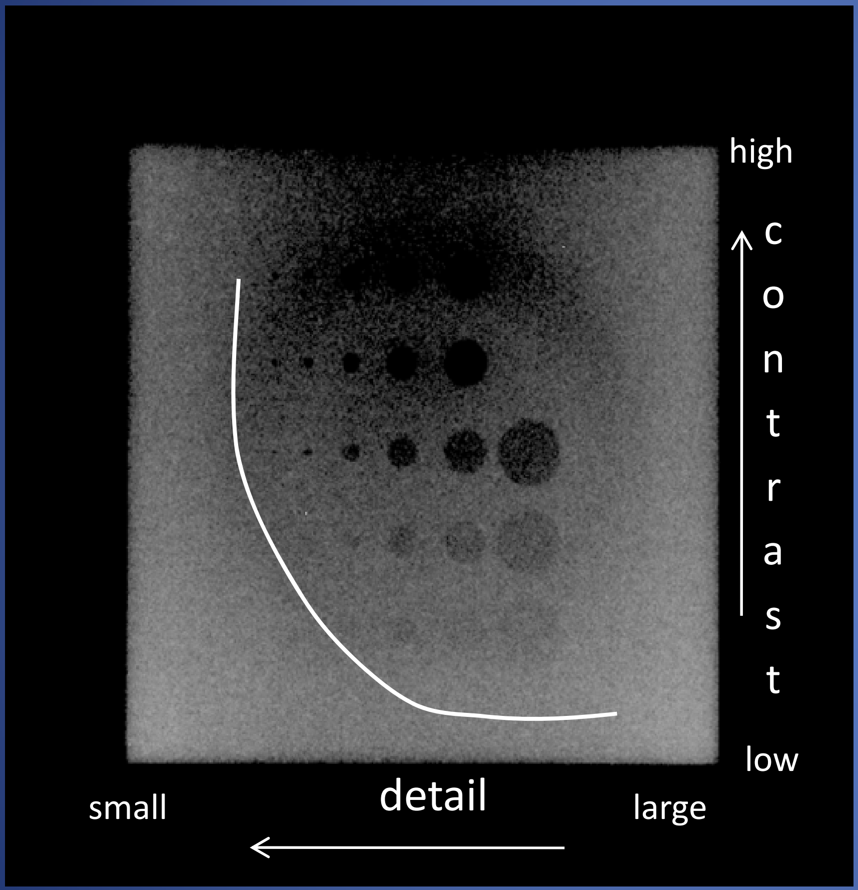

FIG. 10. Aluminum Las Vegas phantom for EPID image contrast and spatial resolution.

from AAPM TG-58

- The Vegas phantom is a contrast–detail phantom.
- Selection of the least visible circle along a column (y-axis) provides a measure of contrast.
- Selection of the smallest visible diameter along a row (x-axis) provides a measure of detail (object size).

## VI. Image Quality (Resolution / Contrast & Noise)

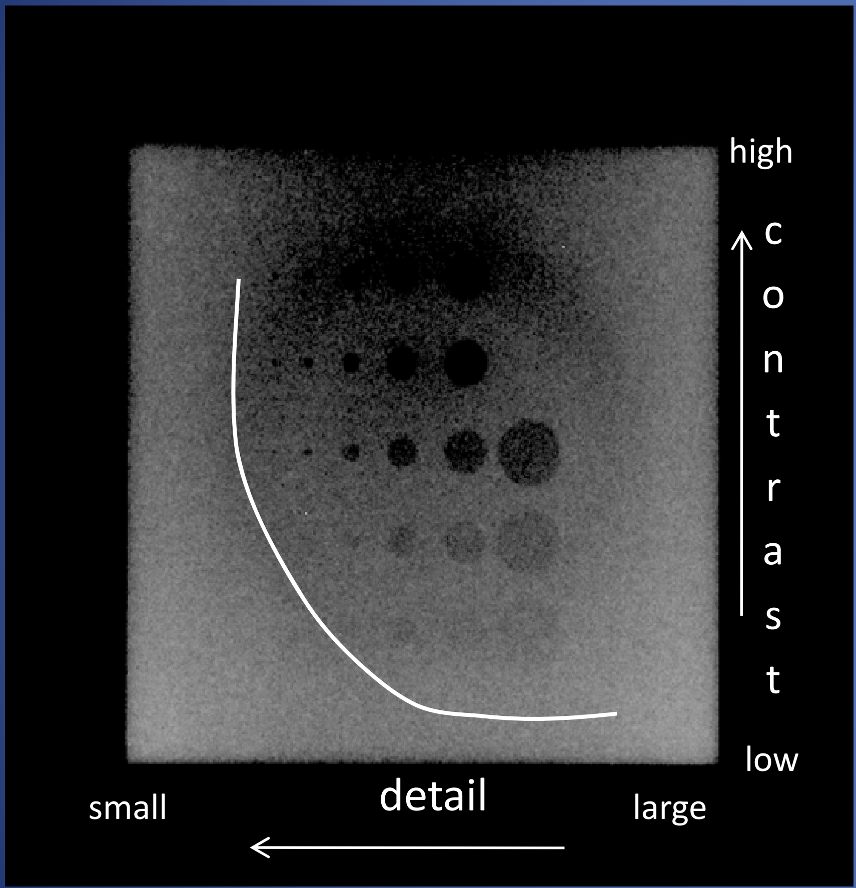
Contrast-Detail Curve




- The image of the Vegas phantom produces a contrast–detail curve.
- The y-axis corresponds to contrast.
- The x-axis corresponds to detail.

## VI. Image Quality (Resolution / Contrast & Noise)

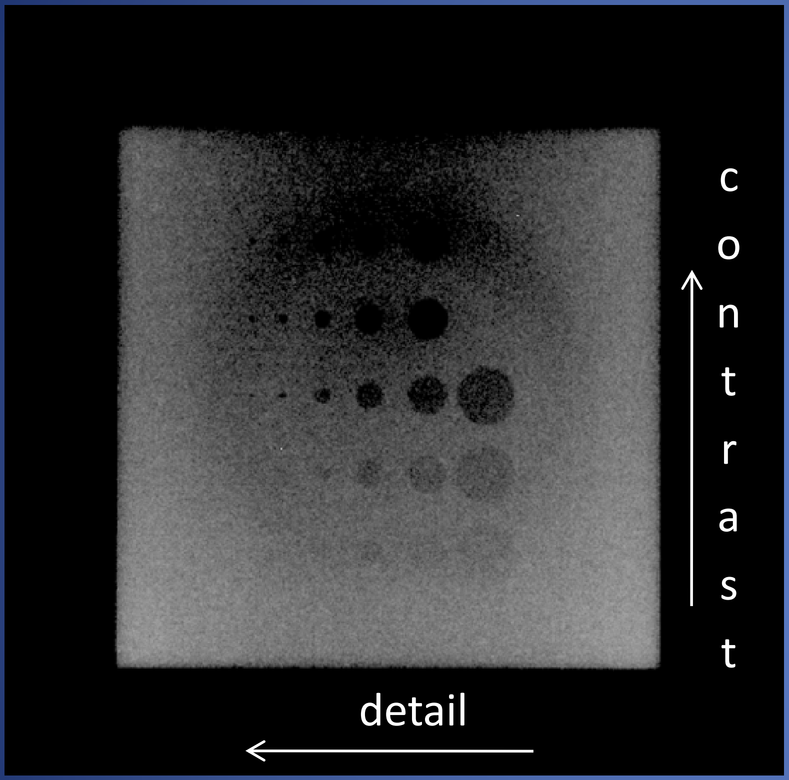
Contrast-Detail Curve




- As the holes get smaller and less in depth they become more difficult to visualize due to decreased contrast.
- The curve on the image is analogous to a visibility threshold.

# VI. Image Quality (Resolution / Contrast & Noise)

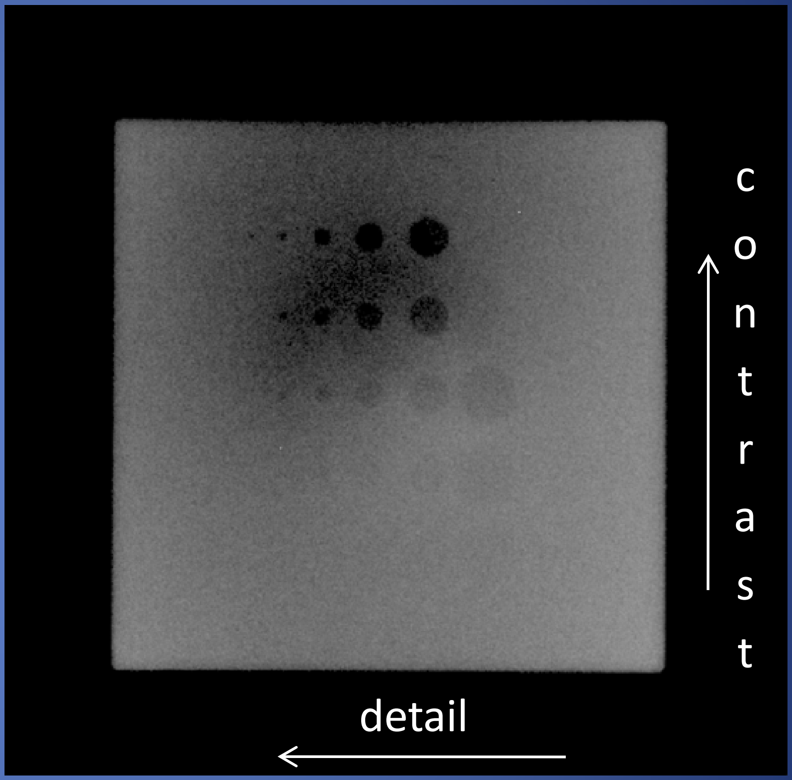
<u>6 MV</u>




6 MV: less penetration of the holes to that of the background

<u>Increased Contrast</u>

<u>18 MV</u>




18 MV: greater penetration of the holes to that of the background

<u>Decreased Contrast</u>

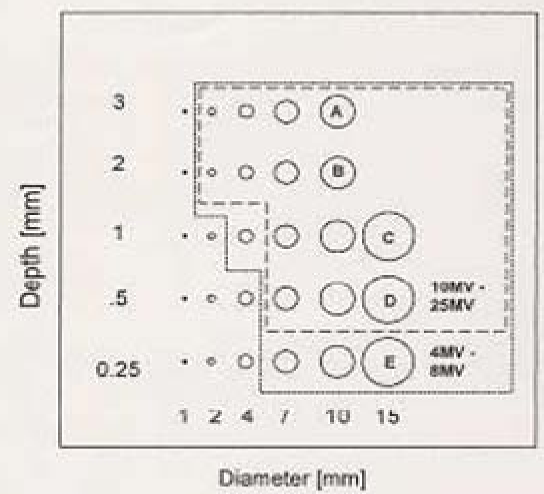
# VI. Image Quality (Resolution / Contrast & Noise)

- Imager position: -40.0, 0.0, 0.0 Jaws: 20 X 20
- Acquisition Technique: High Quality Image (4 MU) 6X & 18X 400 MU/min
- Vegas phantom centered @ 100 cm SSD on couch
- Use window & level functions.  Adjust ambient lighting.

# VI. Image Quality (Resolution / Contrast & Noise)

| Energy | column dia. (mm) | row depth (mm) | % Object Contrast | Pass/Fail |
|---|---|---|---|---|
| 6 | 7.0 | E | 0.15 | Pass |
| 18 | 4.0 | D | 0.18 | Pass |

| Photon Energy (BJR 11) | Holes at least visible in PV Phantom |
|---|---|
| 4 MV | A, B, C, D, E |
| 6 MV | A, B, C, D, E |
| 8 MV | A, B, C, D, E |
| 10 MV | A, B, C, D |
| 15 MV | A, B, C, D |
| 18 MV | A, B, C, D |
| 25 MV | A, B, C, D |




<u>TG 142 tolerance</u>
Baseline

TG-142: Baseline means that the measured data are consistent with or better than ATP data.

# OBI Monthly QA

## OBI Monthly QA

by : P Imbergamo    Date: 05/01/14

Location: SNR - Woonsocker, RI
Unit: 21 EX    Serial # 2811

**I. Collision Interlocks** - alarm sounds & all motions disabled

| Location | Pass | Fail | Comments |
|---|---|---|---|
| Arms: | Pass | | |
| Detector: | Pass | | |

**II. kV Detector Positioning & Reproducibility**

cover to detector distance (cm): 3.0

- rotate gantry to 90° so kV detector is at floor
- measure distance to detector grid & shift at two different detector distances

| Detector Position | | | distance (cm) | | Diff or Shift (<0.2 cm) | | | |
|---|---|---|---|---|---|---|---|---|
| Vertical | Long | Lat | expected | measured | diff. | (<0.2 cm) | Sup/Inf | Rt/Lt |
| 60.0 | 0.0 | 0.0 | 55.2 | 55.1 | 0.1 | Pass | P | P |
| 20.0 | 0.0 | 0.0 | 15.2 | 15.2 | 0.0 | Pass | P | P |

**III. kV Source Positioning**

source to faceplate distance (cm): 14.5

- place kV source at 100, 0, 0 (P1)
- rotate gantry to 270° so kV source is at floor
- measure from source face plate to isocenter

| kV Source Position | | | distance (cm) | | Diff (<0.2 cm) | |
|---|---|---|---|---|---|---|
| Vertical | Long | Lat | expected | measured | diff. | (<0.2 cm) |
| 100.0 | 0.0 | 0.0 | 85.5 | 85.5 | 0.0 | Pass |

**IV. Imager Alignment & Scaling**

1. Scaling

- setup blade calibration plate on couch top @ 100 cm SSD
- level gantry to 90° so kV detector is at floor
- place kV source at 100, 0, 0 & detector at 50, 0, 0
- In OBI Maintenance take an image using Single Pulse Full Resolution
- measure distance between 10 x 10 pair of lines in X & Y directions

| technique: | Single Pulse Full Resolution | | | | |
|---|---|---|---|---|---|
| kVp: | 60 | mA: | 16.0 | ms: | 8.0 |

| Direction | expected (cm) | measured (cm) | diff. (cm) | Pass/Fail (<0.2 cm) |
|---|---|---|---|---|
| X | 10.0 | 10.00 | 0.00 | Pass |
| Y | 10.0 | 10.00 | 0.00 | Pass |



2. Imager Alignment

- using the image from above zoom out until the center circle on the plate is visible
- select the Area Histogram Icon & select "Show Details".
- change Hor Pos to 1024 & Vert Pos to 768
- drag the upper left hand corner of the ROI box until it intersects the center of the circle
- record the Hor Pos & Vert Pos of the center pixel position

| | center pixel position | | | Pass/Fail |
|---|---|---|---|---|
| | expected | measured | diff. | (≤10 pixels) |
| Horizontal position | 1024 | 1021.30 | 2.70 | Pass |
| Vertical position | 768 | 771.49 | 3.49 | Pass |

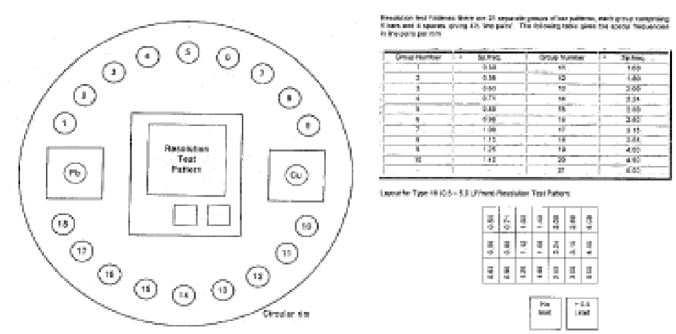
**V. OBI Imaging & Treatment Isocenter Coincidence**

- place Isocenter Cube tool on couch top at isocenter using lasers & crosshairs
- place kV source at 100, 0, 0 & detector at 50, 0, 0
- In OBI Maintenance take an images at four cardinal angles
- at each angle measured difference between center of steel ball & digital graticule

| technique: | FF Last Image Hold | | | | |
|---|---|---|---|---|---|
| kVp: | 50 | mA: | 16.0 | ms: | 8.0 |

| Gantry Angle | kV source Angle | difference (cm) | Pass/Fail (≤0.15cm) |
|---|---|---|---|
| 270 | 180 | 0.11 | Pass |
| 0 | 270 | 0.10 | Pass |
| 90 | 0 | 0.07 | Pass |
| 180 | 90 | 0.12 | Pass |

**VI. Image Quality - Leeds Test Tool**



# OBI Monthly QA

I. Collision Interlocks
II. kV Detector Positioning & Reproducibility
III. kV Source Positioning
IV. Imager Alignment & Scaling
V. OBI Imaging & Treatment Isocenter Coincidence
VI. Image Quality – Leeds Test Tool
    1. High Contrast Resolution (spatial resolution)
    2. Low Contrast Resolution

# OBI Monthly QA

**I. Collision Interlocks** - alarm sounds & all motions disabled

| Location | Pass | Fail | Comments |
|---|---|---|---|
| Arms: | Pass | | |
| Detector: | Pass | | |

**II. kV Detector Positioning & Reproducibility**

| | |
|---|---|
| cover to detector distance (cm): | 3.0 |

- rotate gantry to 90° so kV detector is at floor
- measure distance to detector grid & shift at two different detector distances

| Detector Position | | | distance (cm) | | Diff or Shift (<0.2 cm) | | | |
|---|---|---|---|---|---|---|---|---|
| Vertical | Long | Lat | expected | measured | diff. | (<0.2 cm) | Sup/Inf | Rt/Lt |
| 60.0 | 0.0 | 0.0 | 55.2 | 55.1 | 0.1 | Pass | P | P |
| 20.0 | 0.0 | 0.0 | 15.2 | 15.2 | 0.0 | Pass | P | P |

**III. kV Source Positioning**

| | |
|---|---|
| source to faceplate distance (cm): | 14.5 |

- place kV source at 100, 0, 0 (P1)
- rotate gantry to 270° so kV source is at floor
- measure from source face plate to isocenter

| kV Source Position | | | distance (cm) | | Diff (<0.2 cm) | |
|---|---|---|---|---|---|---|
| Vertical | Long | Lat | expected | measured | diff. | (<0.2 cm) |
| 100.0 | 0.0 | 0.0 | 85.5 | 85.5 | 0.0 | Pass |

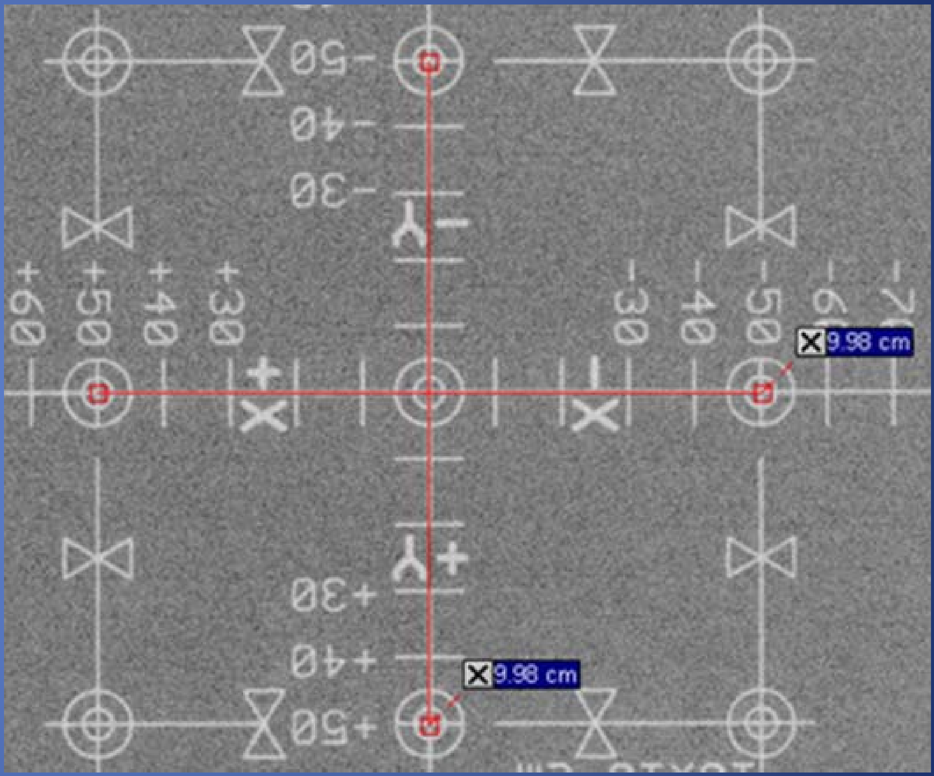
# IV. Imager Alignment & Scaling

1. Scaling

- setup blade calibration plate on couch top @ 100 cm SSD
- level gantry to 90° so kV detector is at floor
- place kV source at 100, 0, 0 & detector at 50, 0, 0
- in OBI Maintenance take an image using Single Pulse Full Resolution
- measure distance between 10 x 10 pair of lines in X & Y directions

| technique: | Single Pulse Full Resolution | | | | |
|---|---|---|---|---|---|
| kVp: | 60 | mA: | 16.0 | ms: | 8.0 |

| Direction | expected (cm) | measured (cm) | diff. (cm) | Pass/Fail (<0.2 cm) |
|---|---|---|---|---|
| X | 10.0 | 9.98 | 0.02 | **Pass** |
| Y | 10.0 | 9.98 | 0.02 | **Pass** |



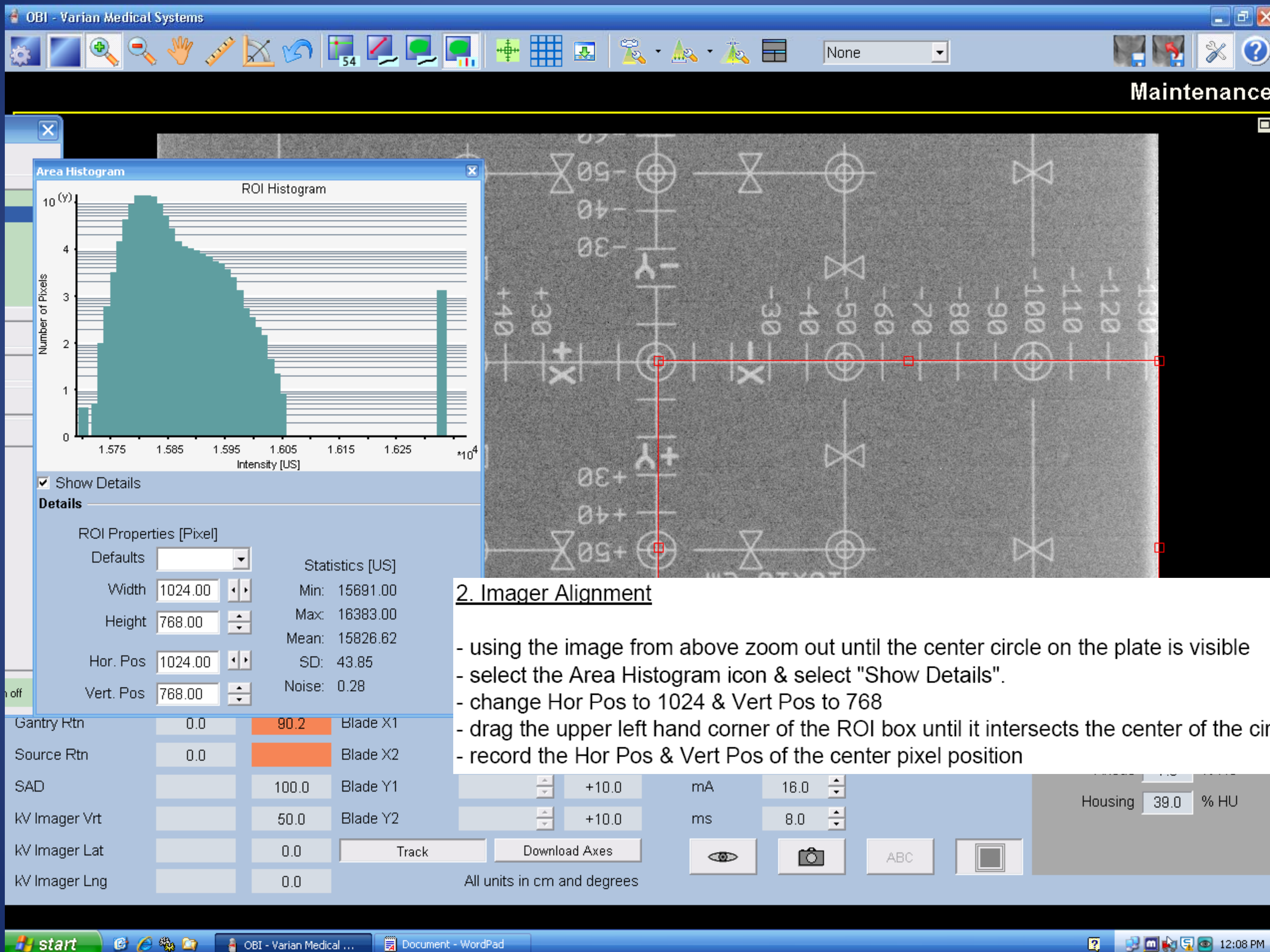

TG 142 tolerance

≤ 2 mm non SRS/SBRT

≤ 1 mm SRS/SBRT

Calibration plate should be accurately aligned to isocenter so the image may be used for the alignment test

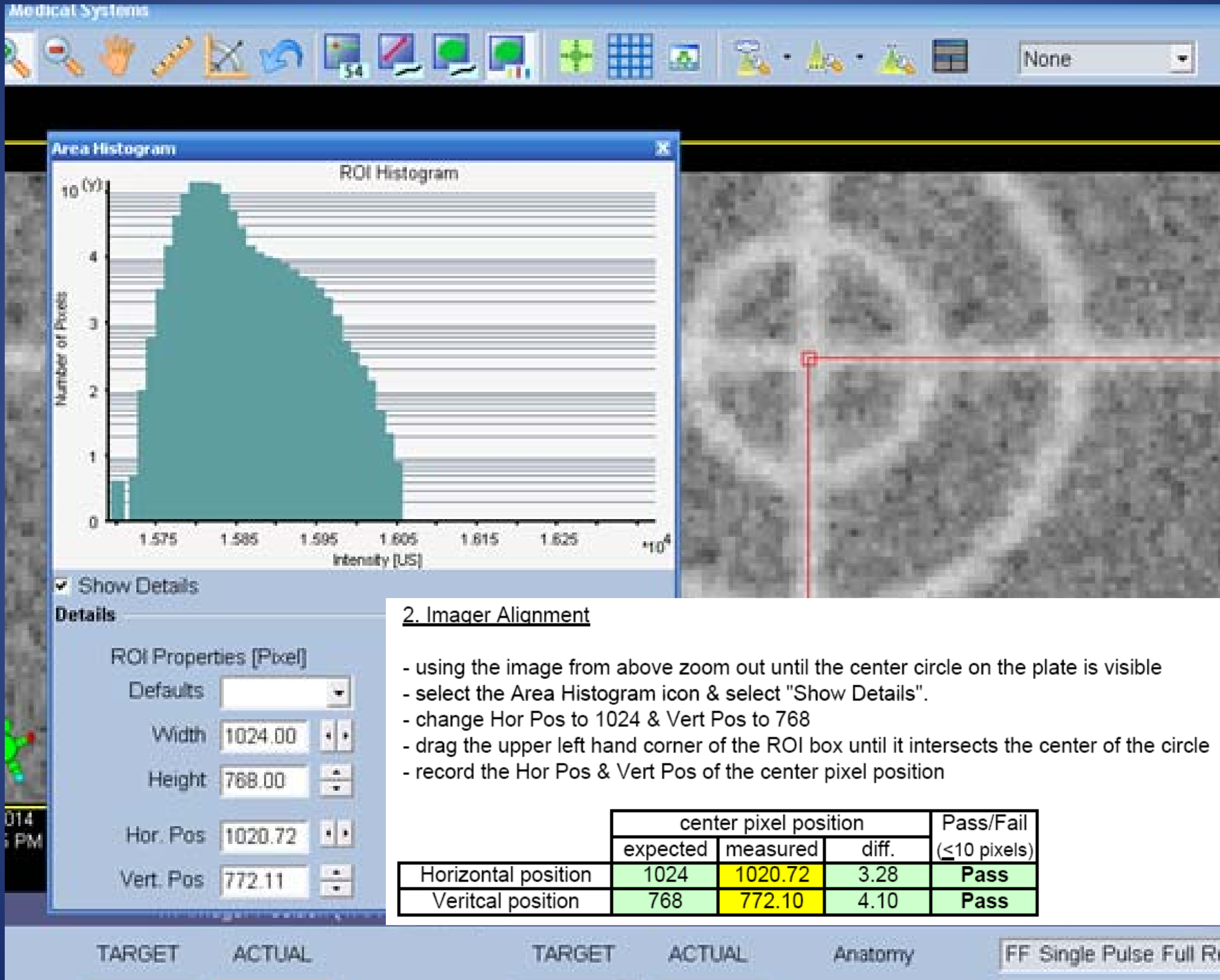
# kV Imager Alignment




<u>2. Imager Alignment</u>

- using the image from above zoom out until the center circle on the plate is visible
- select the Area Histogram icon & select "Show Details".
- change Hor Pos to 1024 & Vert Pos to 768
- drag the upper left hand corner of the ROI box until it intersects the center of the circle
- record the Hor Pos & Vert Pos of the center pixel position

# kV Imager Alignment




2. Imager Alignment

- using the image from above zoom out until the center circle on the plate is visible
- select the Area Histogram icon & select "Show Details".
- change Hor Pos to 1024 & Vert Pos to 768
- drag the upper left hand corner of the ROI box until it intersects the center of the circle
- record the Hor Pos & Vert Pos of the center pixel position

| | center pixel position | | | Pass/Fail |
|---|---|---|---|---|
| | expected | measured | diff. | (≤10 pixels) |
| Horizontal position | 1024 | 1020.72 | 3.28 | **Pass** |
| Veritcal position | 768 | 772.10 | 4.10 | **Pass** |

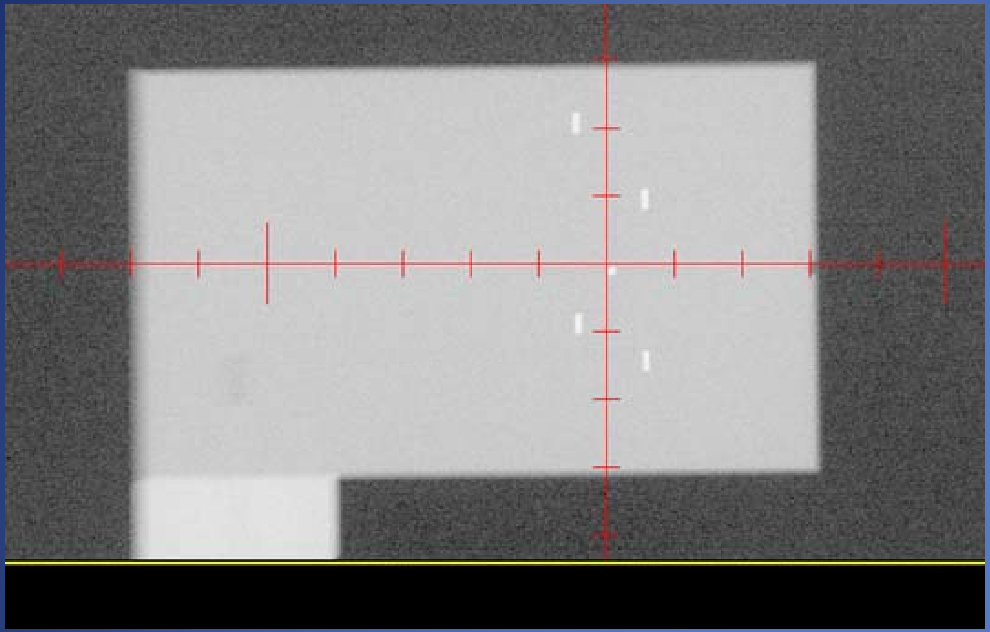
## V. OBI Imaging & Treatment Isocenter Coincidence

- place Isocenter Cube tool on couch top at isocenter using lasers & crosshairs
- place kV source at 100, 0, 0 & detector at 50, 0, 0
- in OBI Maintenance take an images at four cardinal angles
- at each angle measured difference between center of steel ball & digital graticule

| technique: | FF Last Image Hold | | | | |
|---|---|---|---|---|---|
| kVp: | 50 | mA: | 16.0 | ms: | 8.0 |

| Gantry Angle | kV source Angle | difference (cm) | Pass/Fail (≤0.15cm) |
|---|---|---|---|
| 270 | 180 | 0.11 | **Pass** |
| 0 | 270 | 0.13 | **Pass** |
| 90 | 0 | 0.07 | **Pass** |
| 180 | 90 | 0.12 | **Pass** |

# V. OBI Imaging & Treatment Isocenter Coincidence



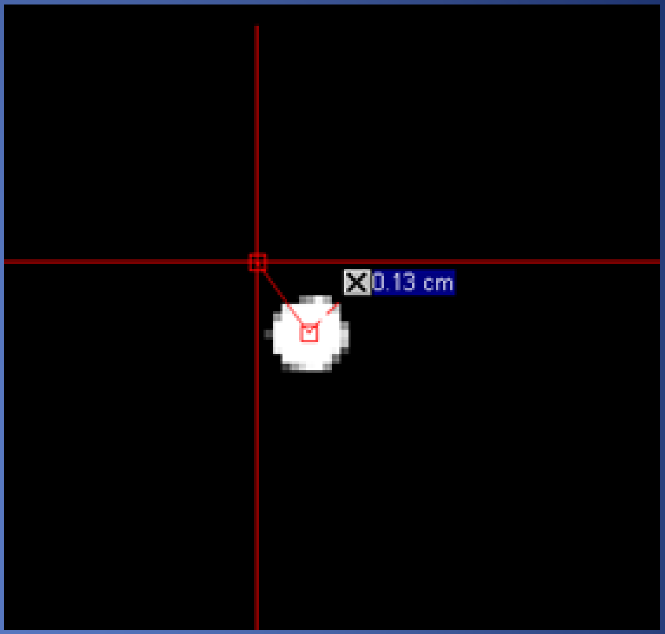



Image at all four cardinal angles

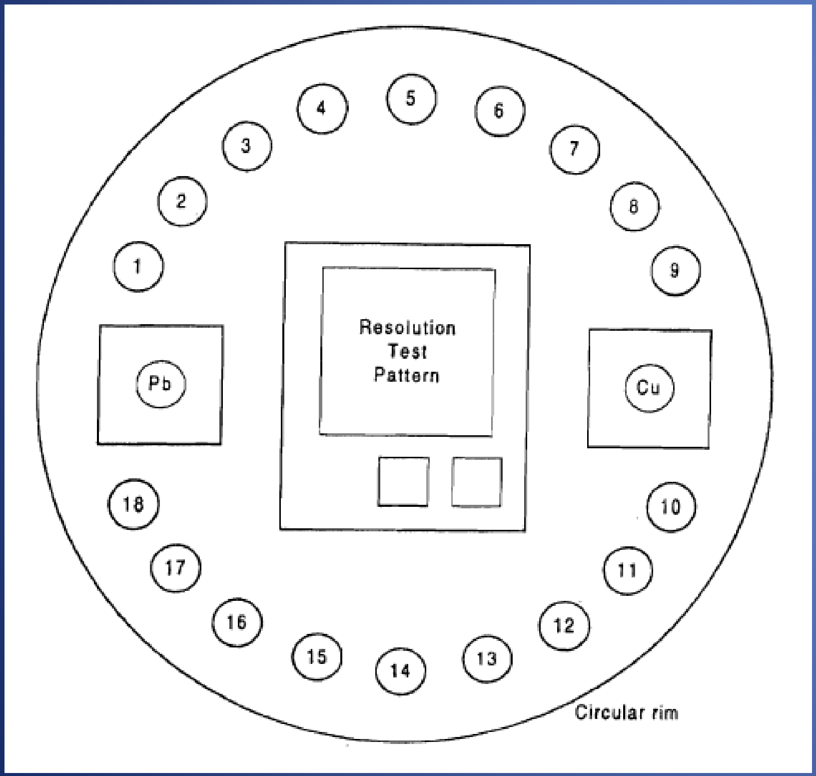
<u>TG 142 tolerance</u>
$\leq$ 2 mm non SRS/SBRT
$\leq$ 1 mm SRS/SBRT

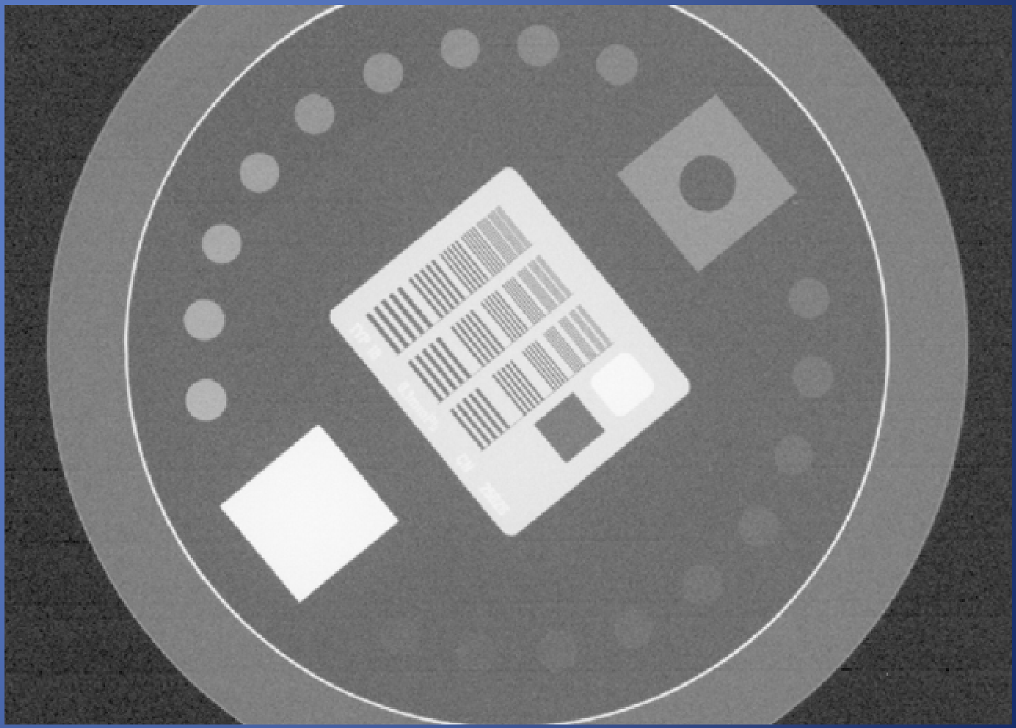
| Gantry Angle | kV source Angle | difference (cm) | Pass/Fail ($\leq$0.15cm) |
|---|---|---|---|
| 270 | 180 | 0.11 | **Pass** |
| 0 | 270 | 0.13 | **Pass** |
| 90 | 0 | 0.07 | **Pass** |
| 180 | 90 | 0.12 | **Pass** |

# OBI Monthly QA

## VI. Image Quality - Leeds Test Tool

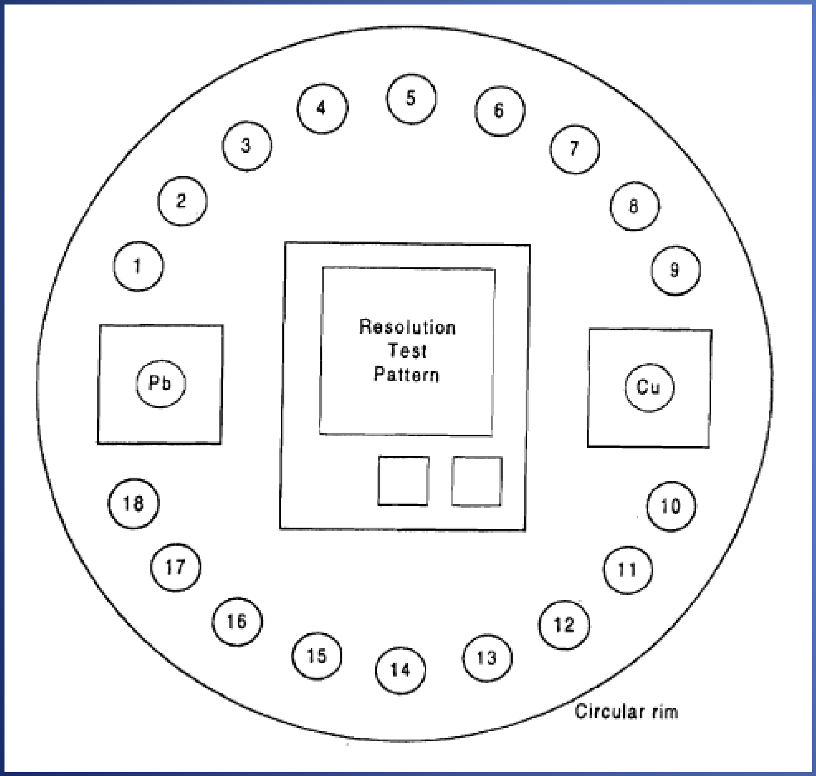
1. High Contrast Resolution
2. Low Contrast Resolution



# VI. Image Quality - Leeds Test Tool

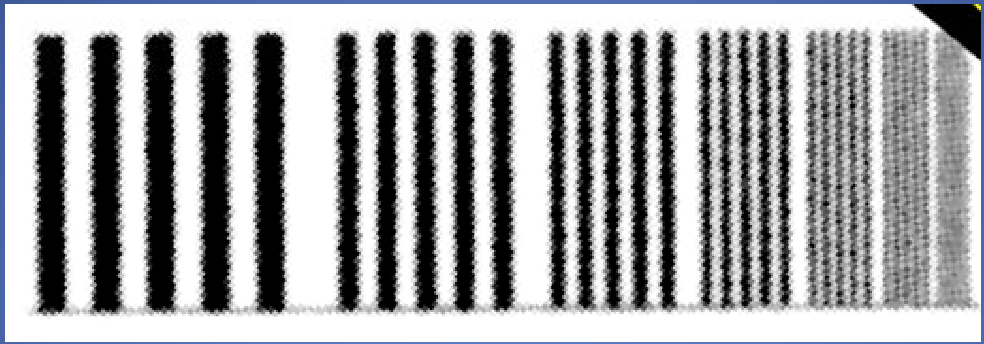
Leeds TOR 18FG Phantom




- 18 circular discs of 8 mm diameter with decreasing contrast used to assess low contrast resolution.
- Line pair test pattern centered in phantom to assess high contrast resolution.
- Measurement of low and high contrast resolution require different imaging techniques.

# VI. Image Quality - Leeds Test Tool

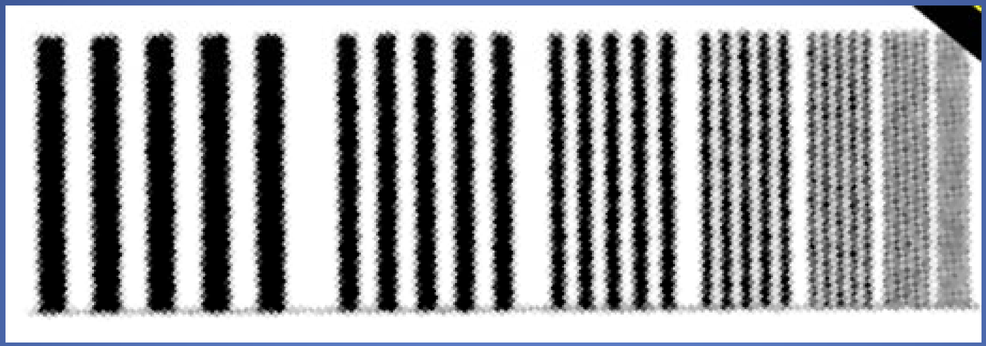
1. High Contrast Resolution



- High Contrast or Spatial Resolution describes the ability of an imaging system to seperate (resolve) objects that are close together.

# VI. Image Quality - Leeds Test Tool

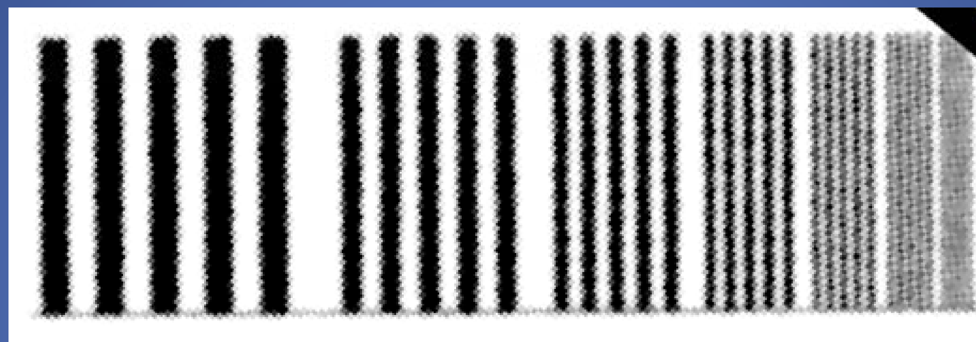
1. High Contrast Resolution



- High Contrast Resolution is measured by a line pair test pattern, a series of open spaces and Pb bars that repeat with increasing frequency.

## VI. Image Quality - Leeds Test Tool

1. High Contrast Resolution

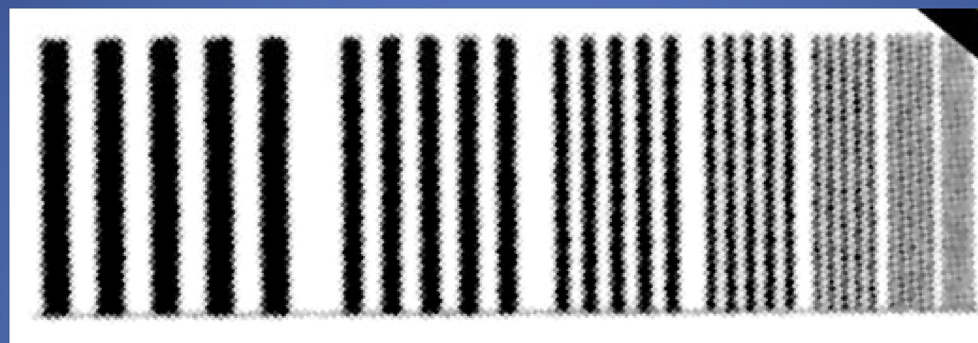


- The higher the spatial frequency (lp/mm) observed the greater the resolution.

Line pair (lp) = open space + Pb bar = 2 lines

## VI. Image Quality - Leeds Test Tool

1. High Contrast Resolution



- Spatial frequency is analogous to object size or resolution as given by:

$$F = 1/(2\Delta) \quad \text{or} \quad \Delta = 1/(2F) = 1/[2(lp/mm_{obs})]$$

where: $\Delta$ = object size resolved (mm)

$F$ = spatial frequency or # of lp/mm observed

# VI. Image Quality - Leeds Test Tool

1. High Contrast Resolution

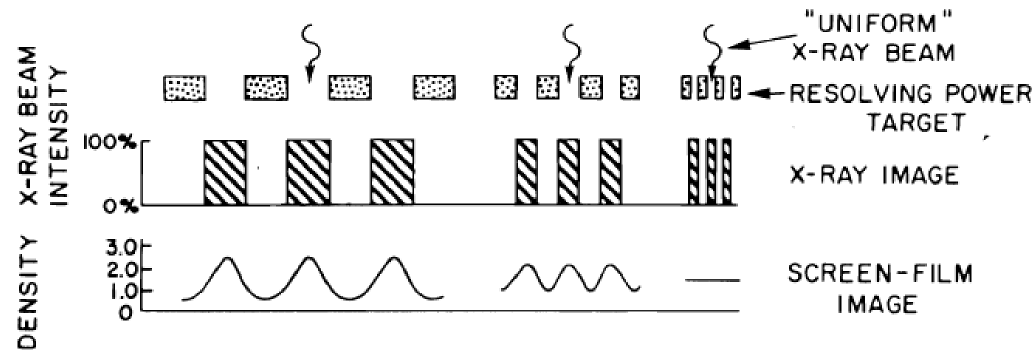
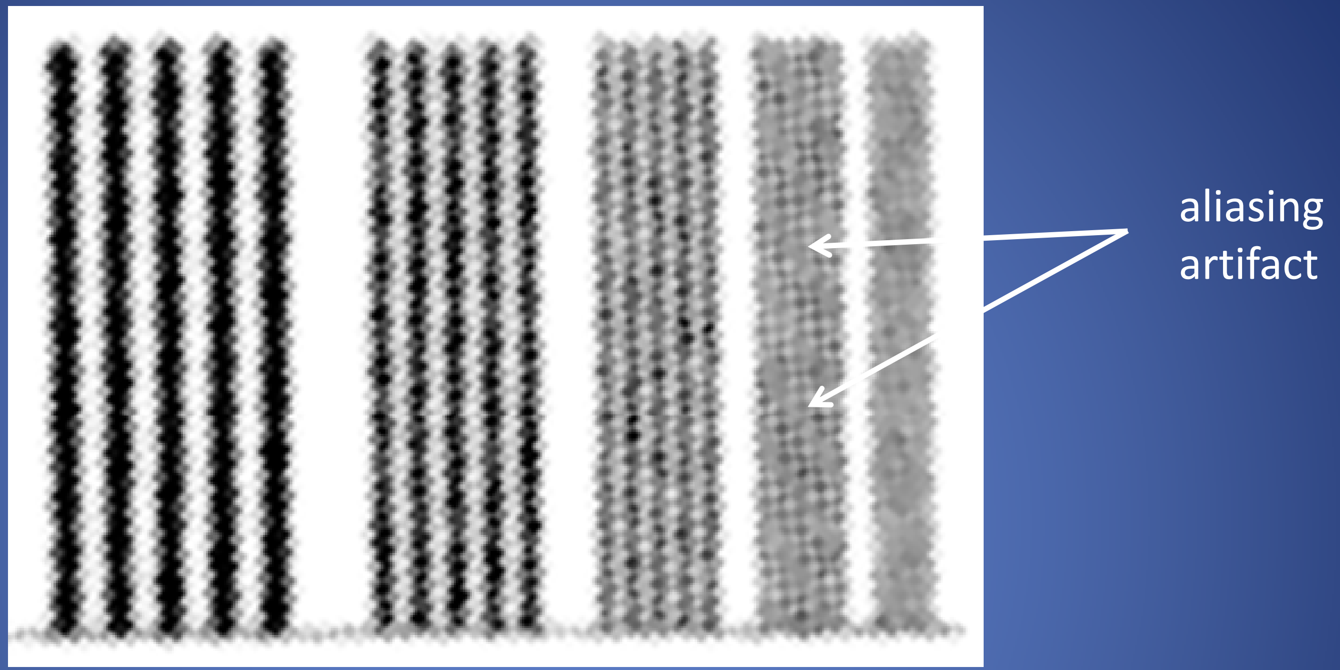



**Figure 14–12** As the information content of a resolving power target increases, the ability of the screen-film system to record the x-ray image of the target decreases

from *Christensen's Physics of Diagnostic Radiology*

- As spatial frequency increases the ability of the imaging system to record it decreases due to decreased image contrast between the objects.

# High Contrast Resolution & Aliasing




- Digital images can exhibit aliasing due to undersampling of higher frequencies per the Nyquist limit.
- Aliasing results in the frequency wrapping back onto the image at a lower frequency appearing as a blurring or moire pattern.

# VI. Image Quality - Leeds Test Tool

## 1. High Contrast Resolution

1. High Contrast Resolution

- place gantry to 90° so kV detector is at floor
- remove couch from beam path & remove any OBI filter
- place kV source at 100, 0, 0 & detector at 50, 0, 0
- place Leeds Test Tool on diagonal on detector cover
- image and window & level to resolve greatest lp/mm (see diagram)

| technique: | Single Pulse Full Resolution | | | | |
|---|---|---|---|---|---|
| kVp: | 50 | mA: | 50.0 | ms: | 6.0 |


- Measurement of high contrast resolution requires the test pattern to be imaged under conditions of high contrast (low kVp) and low noise (increased exposure).
- Place the phantom at a diagonal to avoid interference with line rastering.

# VI. Image Quality - Leeds Test Tool

1. High Contrast Resolution


TG 142 tolerance

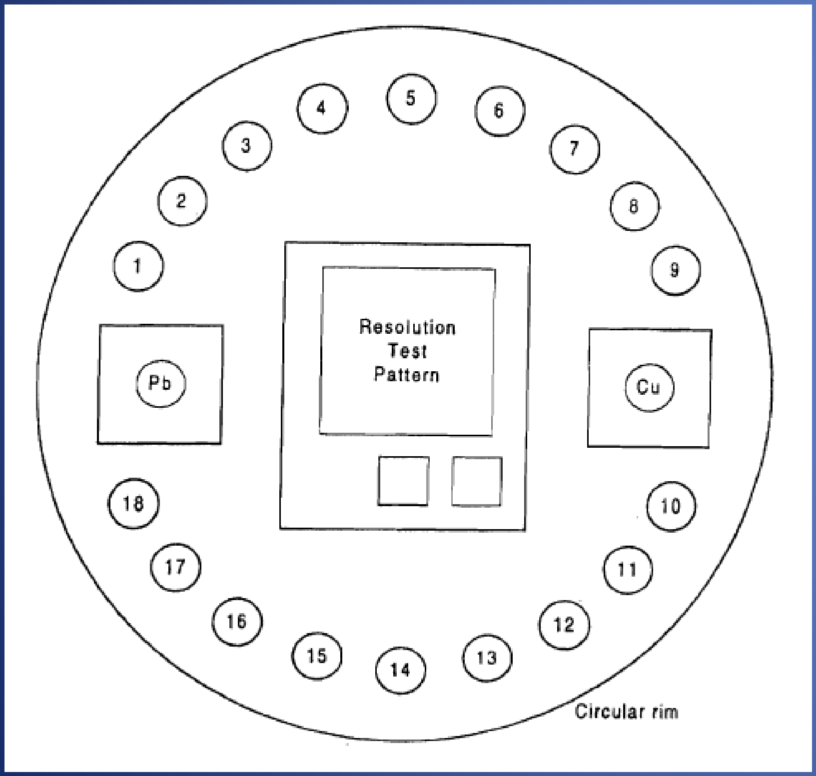
Baseline

- Magnify the resolution pattern
- Adjust window and level for the sharpest display.
- Adjust ambient lighting.
- Select highest lp/mm resolved.

# VI. Image Quality - Leeds Test Tool

2. Low Contrast Resolution

Leeds TOR 18FG Phantom

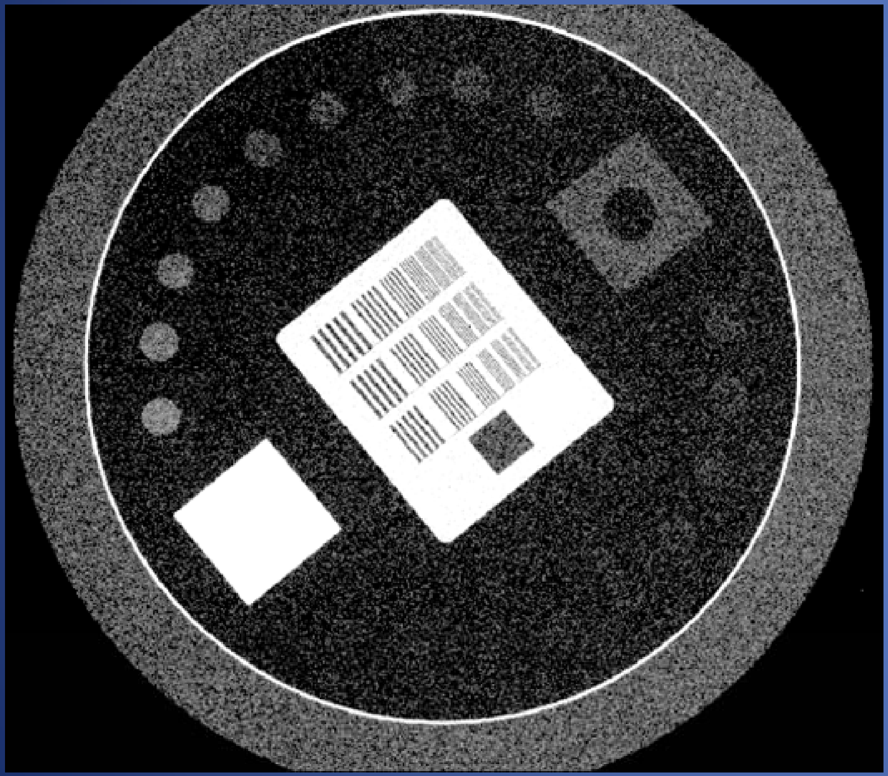



- 18 circular discs of 8 mm diameter with decreasing contrast used to assess low contrast resolution.
- Low contrast resolution is the ability to discern objects in an image that only slightly differ from each other (object & background).
- In other words, it is the ability to visualize grey on grey.

*<u>clinical example:</u> the ability discern liver mets from normal liver on CT*

# VI. Image Quality - Leeds Test Tool

2. Low Contrast Resolution



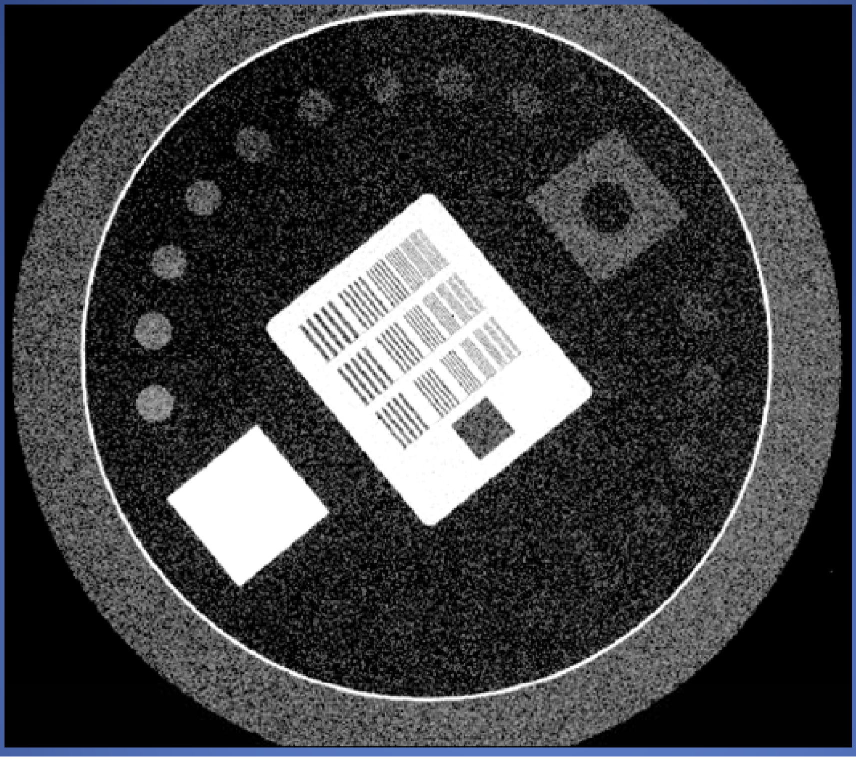
- The ability to visualize low contrast objects is limited by the noise present in the image.
- Low contrast resolution is noise limited and Signal to Noise Ratio (SNR) dependent.

# VI. Image Quality - Leeds Test Tool

2. Low Contrast Resolution

- 1 mm Cu filter at the x-ray tube and a higher kVp are used to create conditions of decreased contrast/signal from the phantom and increased noise.
- Resulting in a reduced SNR and a noisier image to assess low contrast resolution.

# 2. Low Contrast Resolution



**TG 142 tolerance**

Baseline

2. Low Contrast Resolution

- Use setup from above
- Attach 1mm Cu filter to kV source faceplate
- image and window & level to resolve the lowest contrast disc (highest disc # - see diagram)
- turn off lights & view from a distance, as necessary

| technique: | Single Pulse Full Resolution | | | | |
|---|---|---|---|---|---|
| kVp: | 85 | mA: | 50.0 | ms: | 4.0 |

| Disc # resolved | 12 | Pass/Fail ≥ 12 | **Pass** |
|---|---|---|---|

# CBCT Monthly QA

## CBCT Monthly QA - Pelvis

by : P Imbergamo  Date: 05/01/14

Location: SNR - Woonsocket, RI
Unit: 21 EX  Serial # 2811

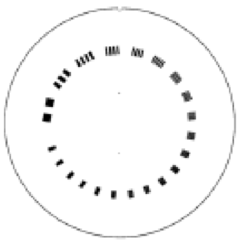
- center the CATPHAN phantom at isocenter
- Mode up a QA patient & perform standard pelvis head scans, per the following (DICOMRT - TESTPT_TT-OB-01357a - RP.3247.Catphan.dcm)

Standard Pelvis Scan Technique

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| slice (mm): | 2.5 | FOV: | 450 | resolution: | 384x384 | fan: | half |
| filter: | body | kVp: | 125 | mA | 80 | ms: | 8619 |

### I. High Contrast Resolution

- review the High Resolution Module & select the highest line pair/cm pattern (1-21) that is resolved



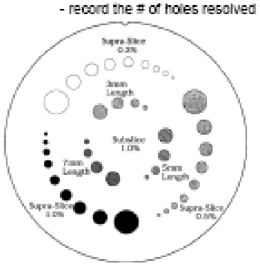
| | |
|---|---|
| Window Range : | Bone |

| | | | | | |
|---|---|---|---|---|---|
| Lp/cm resolved | 4 | mm resolved | 1.25 | Pass/Fail ≥ 4 lp/mm | Pass |

Spec: at least 4 lp/cm (1.25 mm) resolved

### II. Low Contrast Resolution

- review the Low Contrast Resolution Module
- record the # of holes resolved for the lowest % contrast level for the 1% Supra Slice targets




| | |
|---|---|
| Window Range : | liver |

| | | | | | |
|---|---|---|---|---|---|
| # of holes resolved | 5 | mm resolved | 6.0 | %Contrast resolved | 1.0 |

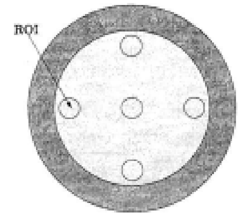
| | |
|---|---|
| Pass/Fail ≤ 15 mm | Pass |

Spec: 15 mm or less @ 1.0 % contrast



### III. Noise and Uniformity

- review the Image Uniformity Module & record the mean CT# and std dev for the water
- use 20 x 20 Area Histogram - show details

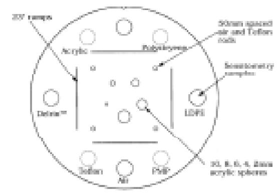



| Spatial Uniformity & Noise | | | |
|---|---|---|---|
| Location | CT # | s | % Noise |
| Center | 4.23 | 5.69 | 0.57 |
| Top | 4.83 | 7.35 | 0.74 |
| Right | 6.19 | 6.85 | 0.69 |
| Bottom | 6.83 | 6.20 | 0.62 |
| Left | 4.07 | 7.18 | 0.72 |
| % SU: | 0.276 | Range: | Pass |

Specification: Range: center +/- 40 HU

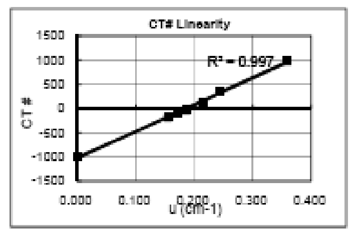
### IV. CT# Constancy, Linearity & Contrast Scale

- review the Sensitometry Module & record the mean CT# for the material inserts listed




1. CT # Constancy & Linearity

| Material | u | CT # | expected | diff | Pass/Fail |
|---|---|---|---|---|---|
| air | 0.000 | -994.37 | -1000 | -5.63 | Pass |
| pmp | 0.155 | -183.12 | -200 | -16.88 | Pass |
| ldpe | 0.172 | -92.53 | -100 | -7.47 | Pass |
| poly | 0.186 | -38.33 | -35 | 3.33 | Pass |
| acrylic | 0.214 | 126.39 | 120 | -6.39 | Pass |
| delrin | 0.243 | 346.94 | 340 | -6.94 | Pass |
| teflon | 0.359 | 978.55 | 990 | 11.45 | Pass |




2. Contrast Scale

| | | | |
|---|---|---|---|
| CT# $H_2O$: | 4.23 | CT# air: | -994.37 |
| CS (meas): | 1.81E-04 | CS: | 1.90E-04 |
| | | % Diff: | -4.60% |

Specifications:
- Plot should be linear with an $R^2$ value close to 1.0
- Measured & theoretical contrast scale should not differ significantly
- measured CT# & expected difference < 40 HU

### V. Spatial Linearity Accuracy

Measure distance between small rods in center of CT # Constancy image above

| | Measured | Expected | Diff | % Diff | Pass/Fail |
|---|---|---|---|---|---|
| Horizontal | 4.96 | 5.00 | -0.04 | 0.8% | Pass |
| Vertical | 4.96 | 5.00 | -0.04 | 0.8% | Pass |

spec: accurate to w/in 1%

# CBCT Monthly QA

I. High Contrast Resolution

II. Low Contrast Resolution (pelvis scan only)

III. Uniformity and Noise

IV. CT# Constancy, Linearity, & Contrast Scale

V. Spatial Linearity Accuracy

# Cone Beam Computed Tomography

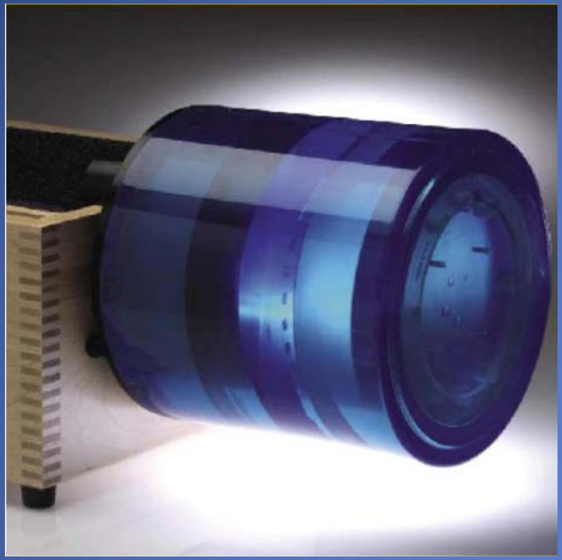
- Elekta and Varian both offer gantry mounted CBCT systems comprised of a kV x-ray source and flat panel detector that share a common isocenter with the MV beam.
- Both systems utilize full (360°) rotation and partial angle scans.
- Bow tie filters are used to attenuate the edges of the kV beam.

TABLE I. Relevant scan parameters for each system. For acquisition angle, cw means clockwise and ccw means counterclockwise rotation during image acquisition, as viewed from the patient table. The OBI can acquire images rotating either direction and chooses based on current gantry position. On the XVI, F0 is the designation for no filter and F1 is the designation for a full bowtie filter.

| | XVI | | | OBI | | |
|---|---|---|---|---|---|---|
| Scan site | Head | Chest | Pelvis | Head | Chest | Pelvis |
| kV collimator | S20 | M20 | M10 | – | – | – |
| kV filter | F0 | F1 | F1 | Full bowtie | Half bowtie | Half bowtie |
| kVp | 100 | 120 | 120 | 100 | 110 | 125 |
| mA | 10 | 40 | 64 | 20 | 20 | 80 |
| ms/projection | 10 | 40 | 40 | 20 | 20 | 13 |
| No. of projections | 361 | 643 | 643 | 360 | 655 | 655 |
| Total mA s | 36.1 | 1028.8 | 1646.1 | 145 | 262 | 680 |
| Acquisition angle | 350°–190° cw | 273°–269° cw | 273°–269° cw | 88°–292° cw/ccw | 88°–92° cw/ccw | 88°–92° cw/ccw |
| Acquisition time (s) | ~70 | ~120 | ~120 | ~30 | ~60 | ~60 |
| Axial field of view (cm) | 27 | 41 | 41 | 25 | 45 | 45 |
| Long. field of view (cm) | 26 | 26 | 12.5 | 18 | 16 | 16 |

from D. E. Hyer and D. E. Hintenlang, " Estimation of CBCT organ doses," Med. Phys. 37 (9), Sept 2010

# CBCT Monthly QA - Catphan



Diagrams taken from Catphan manuals, which are all available online.

## Catphan Phantom Family

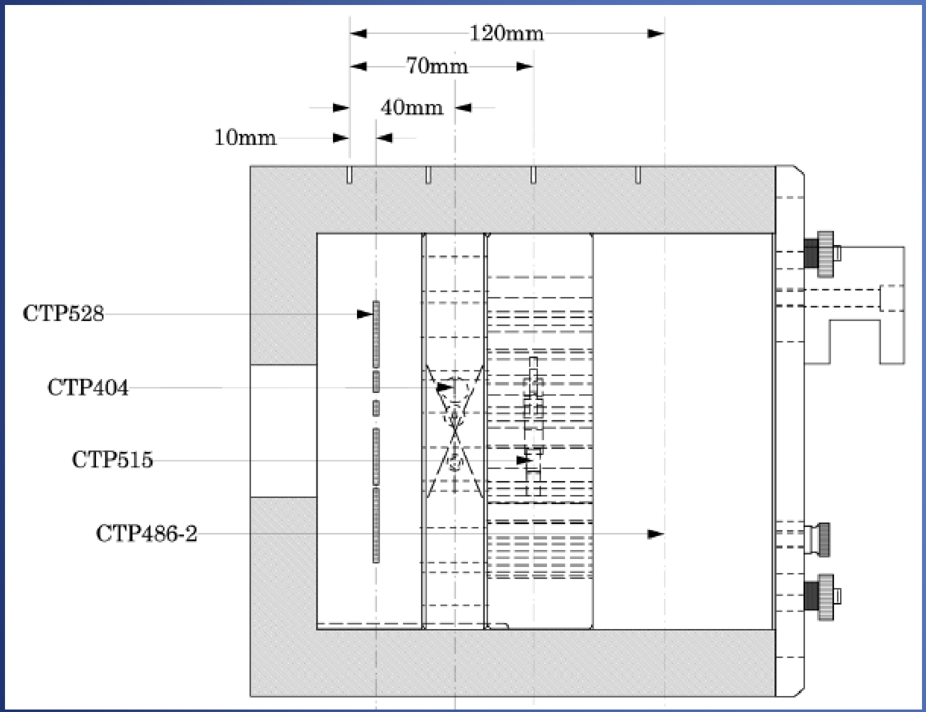
| Catphan | M1 | M2 | M3 | M4 | M5 | |
|---|---|---|---|---|---|---|
| 503 | 404 | 528 | 486 | | | Elekta |
| 504 | 528 | 404 | 515 | 486-2 | | Varian |
| 600 | 404 | 591 | 528 | 515 | 486 | Siemens |

*Module Inserts*

Slide provided by Mark Wiesmeyer of Standard Imaging

# CBCT Monthly QA

Catphan 504




Phantom composed of different test modules

- CTP528: High Contrast Resolution
- CTP404: CT# Constancy & Linearity, Contrast Scale, & Spatial Linearity Accuracy
- CTP515: Low Contrast Resolution
- CPT486-2: Uniformity and Noise

# CBCT Monthly QA

- Setup and center the phantom at isocenter.
- All imaging qa may be acquired in one scan if the longitudinal FOV covers the phantom.

# CBCT Monthly QA

- One scan at pelvis technique & bow tie filter

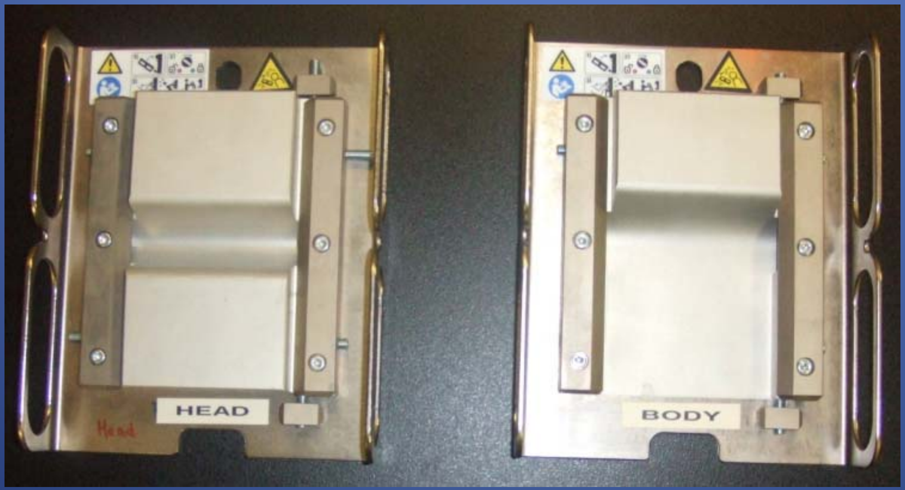
Standard Pelvis Scan Technique

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| slice (mm): | 2.5 | FOV: | 450 | resolution: | 384x384 | fan: | half |
| filter: | body | kVp: | 125 | mA | 80 | ms: | 8619 |

- One scan at standard dose head technique & bow tie filter

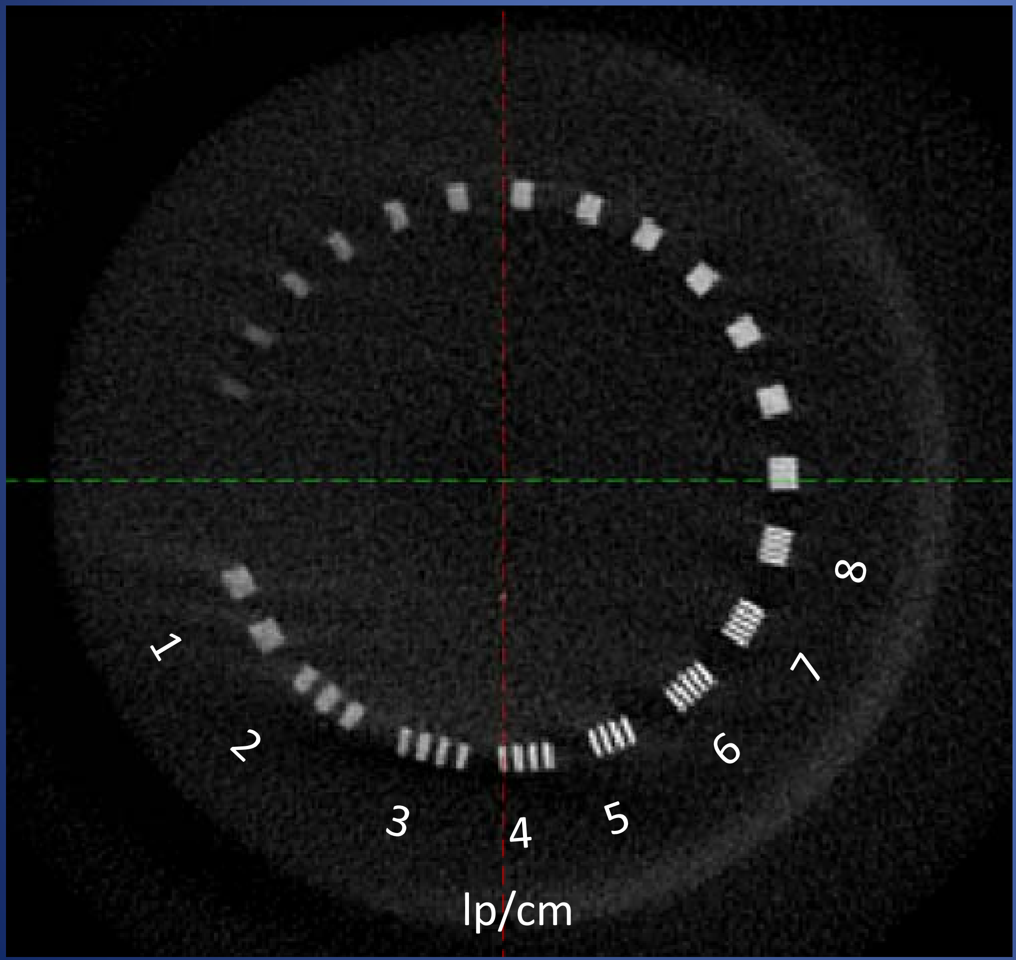
Standard Dose Head Scan Technique

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| slice (mm): | 2.5 | FOV: | 250 | resolution: | 384x384 | fan: | full |
| filter: | head | kVp: | 100 | mA | 20 | ms: | 7480 |



# CBCT Monthly QA

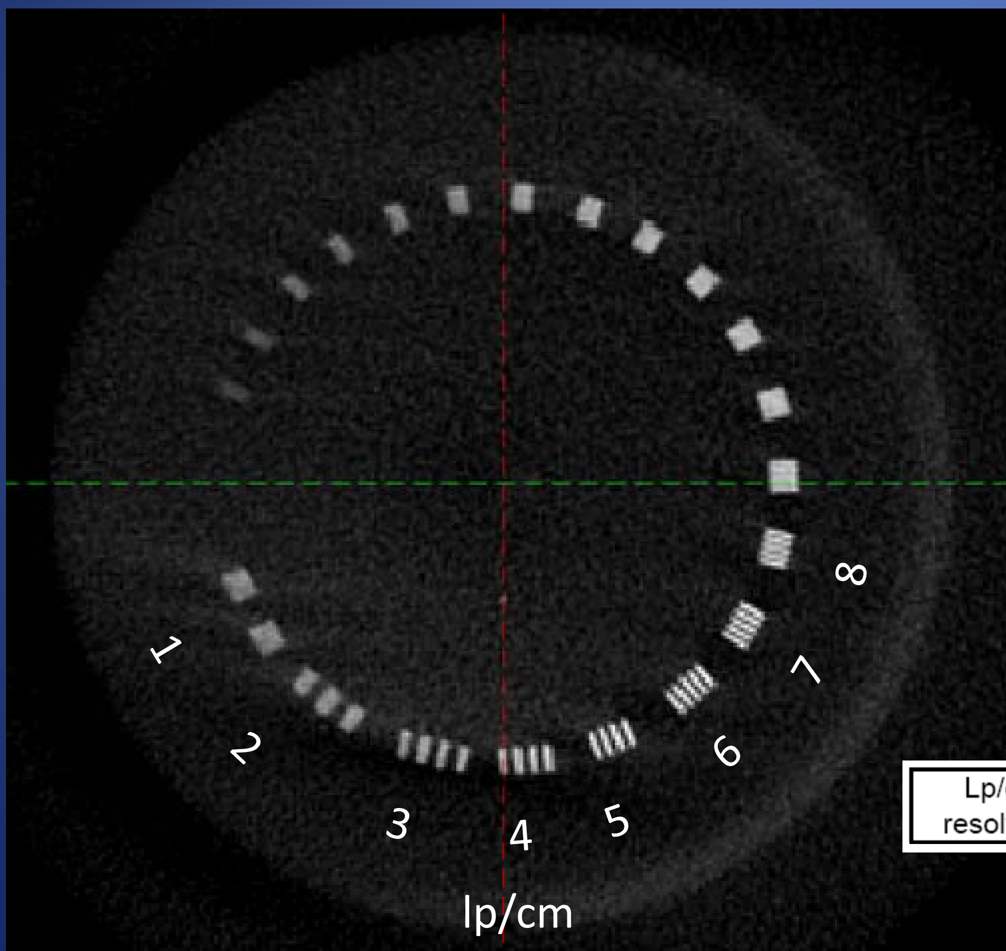
## I. High Contrast Resolution




- CTP528: High Contrast Resolution module
- Array of increasing lp/cm test patterns (1 -21 lp/cm)
- Select "bone window" and adjust for sharpest display
- Magnify as necessay and select highest lp/cm resolved

# CBCT Monthly QA

## I. High Contrast Resolution




- Image analysis is the same for CBCT high contrast resolution as that of the OBI.

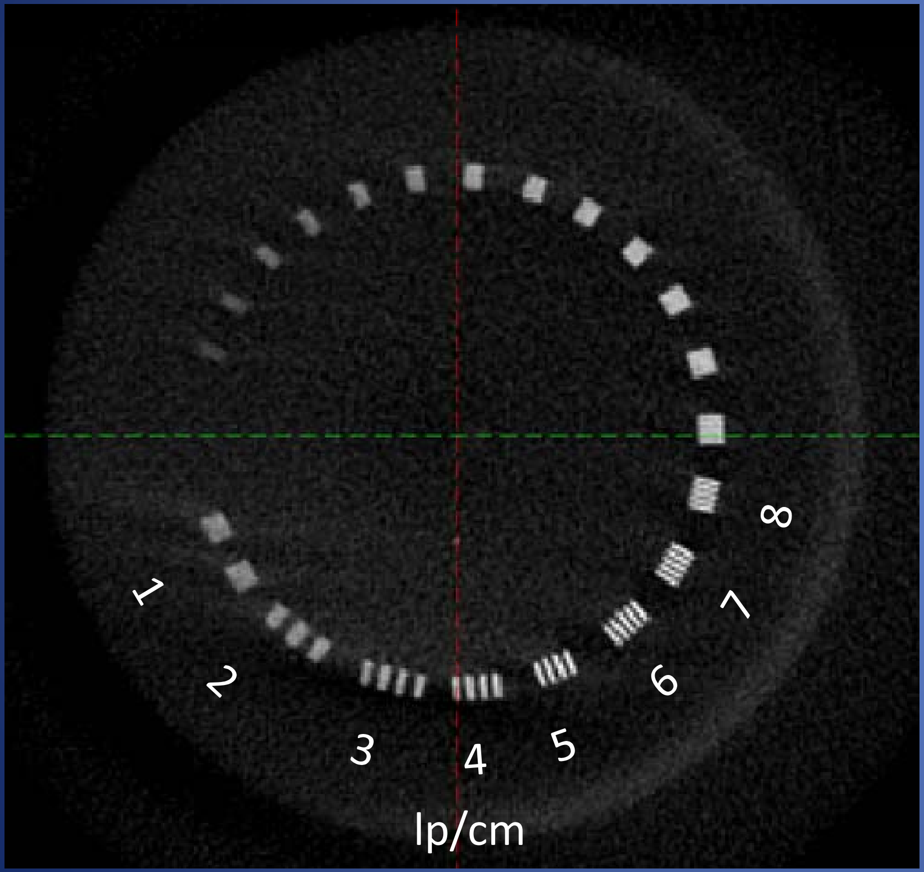
$$\Delta = 1/(2F) \;\; = 1/[2(lp/cm_{obs})]$$

where: $\Delta$ x 10 = object size resolved (mm)
F = spatial frequency or # of lp/cm observed

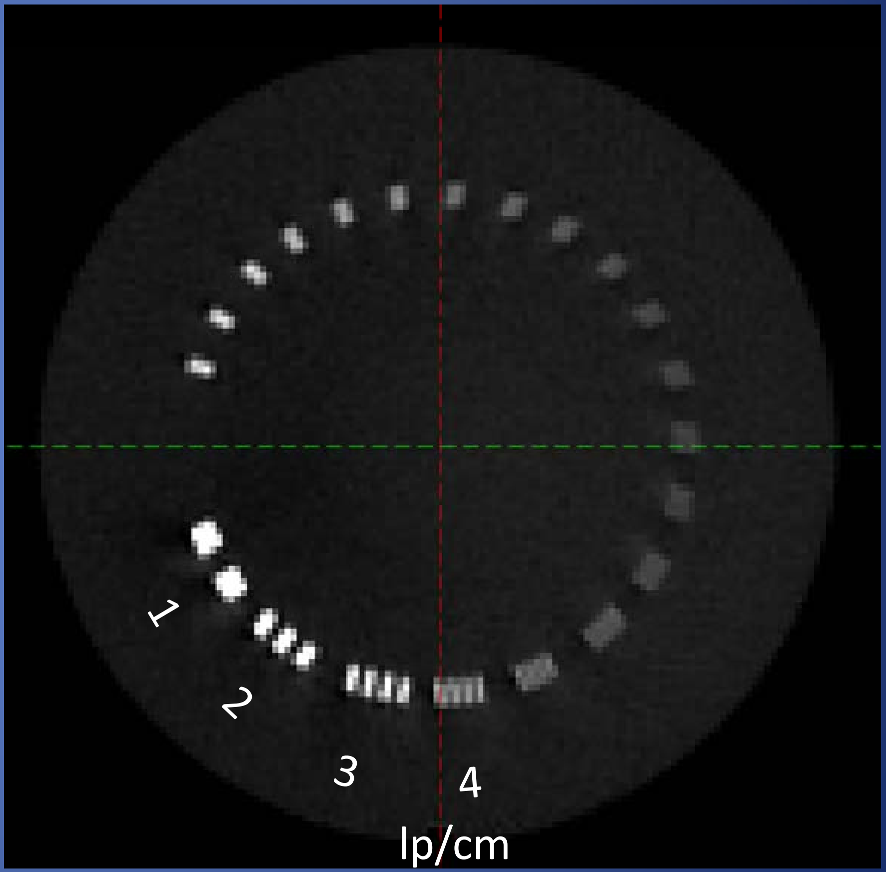
| Lp/cm resolved | 8 | mm resolved | 0.63 | Pass/Fail ≥ 6 lp/cm | **Pass** |
|---|---|---|---|---|---|

# CBCT High Contrast Resolution

## Head vs Pelvis Scan




Standard-Dose Head




Pelvis

# CBCT High Contrast Resolution

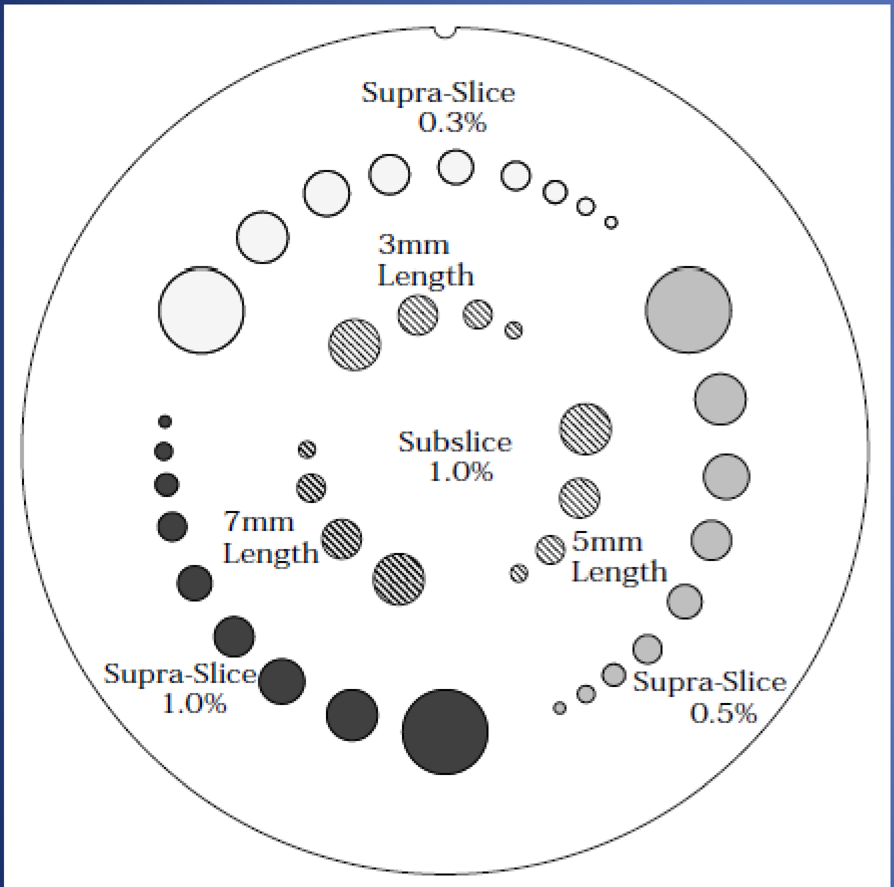
## Head vs Pelvis Scan

- High contrast or spatial resolution is greater for the head scan due to pixel size
- Varian uses a default matrix of 384 x 384
- Axial Field of View
  - Standard Head: 250 mm
  - Pelvis: 450 mm
- Varian acceptance specification
  - Standard Head: $\geq$ 6 lp/cm
  - Pelvis: $\geq$ 4 lp/cm

<u>TG 142 tolerance</u>
Baseline

# CBCT Monthly QA

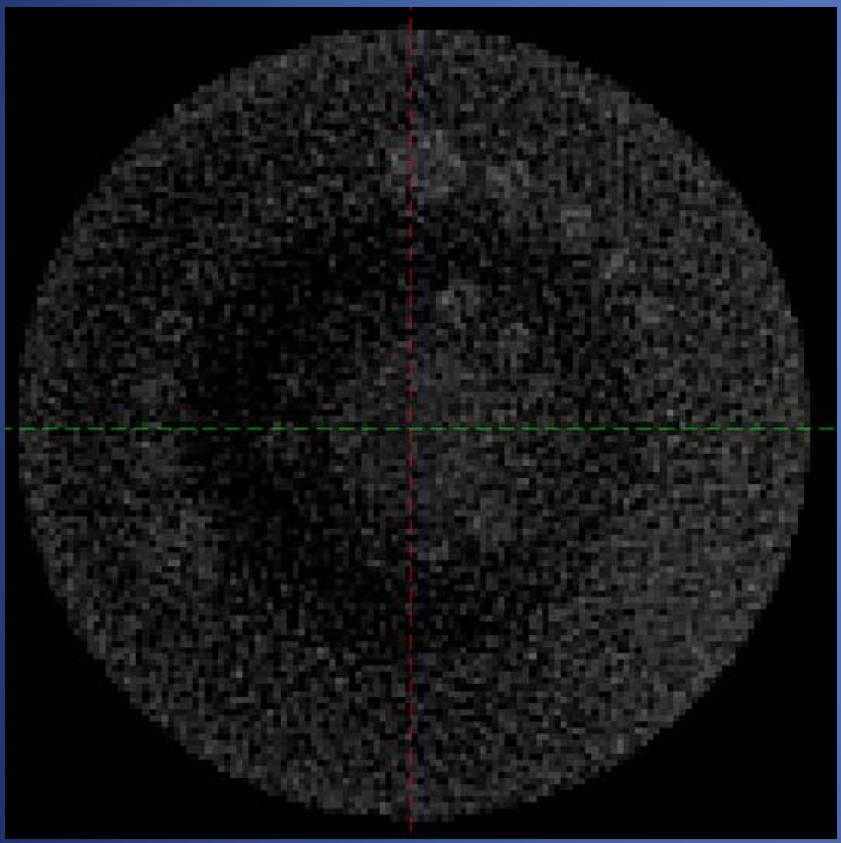
## II. Low Contrast Resolution




- CTP515: Low Contrast Resolution module
- Array of discs with decreasing diameters at different contrast levels (Supra-slice)
- Disc diameters decrease from 15 mm to 2 mm

# CBCT Monthly QA

## II. Low Contrast Resolution

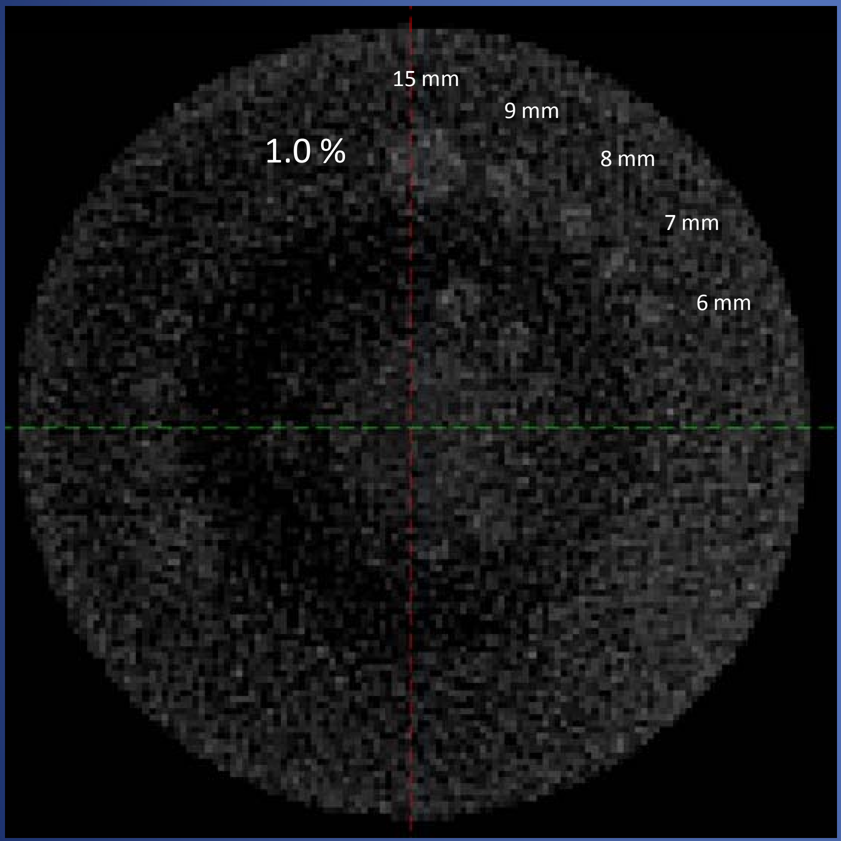


Pelvis Scan Techique

- The same conditions for low contrast resolution discussed for the OBI apply.
- ***Low contrast resolution is noise limited and SNR dependent.***
- Since the Standard Head scan is a low dose (mAs) technique this test does not apply.
- Pelvis scan only.

# CBCT Monthly QA

## II. Low Contrast Resolution




TG 142 tolerance
Baseline

- Dim or turn off room lights and view from a distance as necessary.
- Use a low contrast window setting such as liver or abdomen, and adjust as needed.
- Select smallest disc visible.

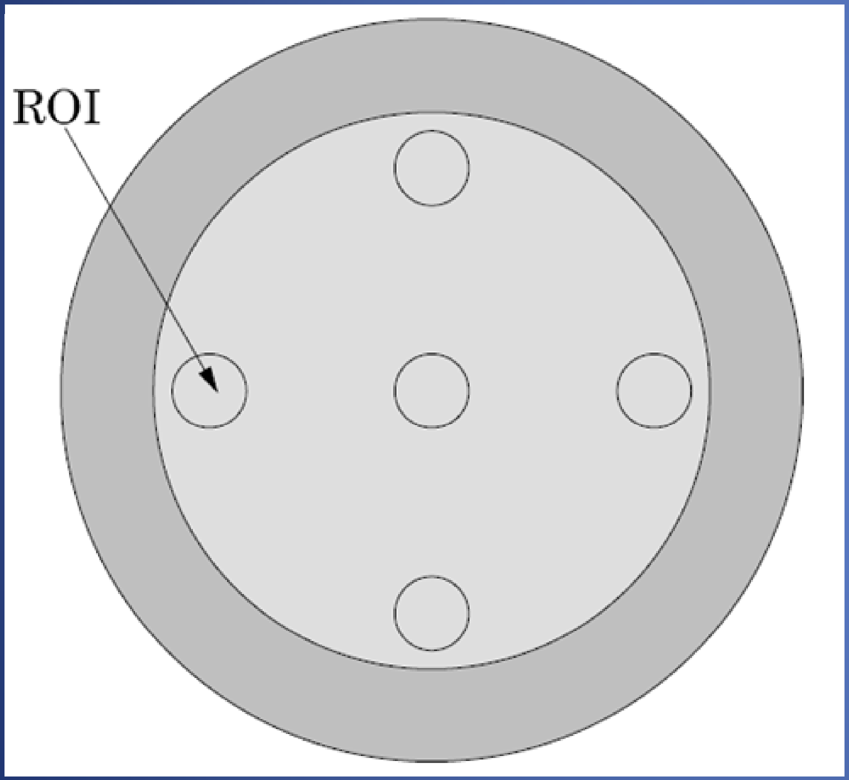
| # of holes resolved | 4 | mm resolved | 7.0 | %Contrast resolved | 1.0 |
|---|---|---|---|---|---|

| Pass/Fail ≤ 15 mm | Pass |
|---|---|

Spec: 15 mm or less @ 1.0 % contrast

# CBCT Monthly QA

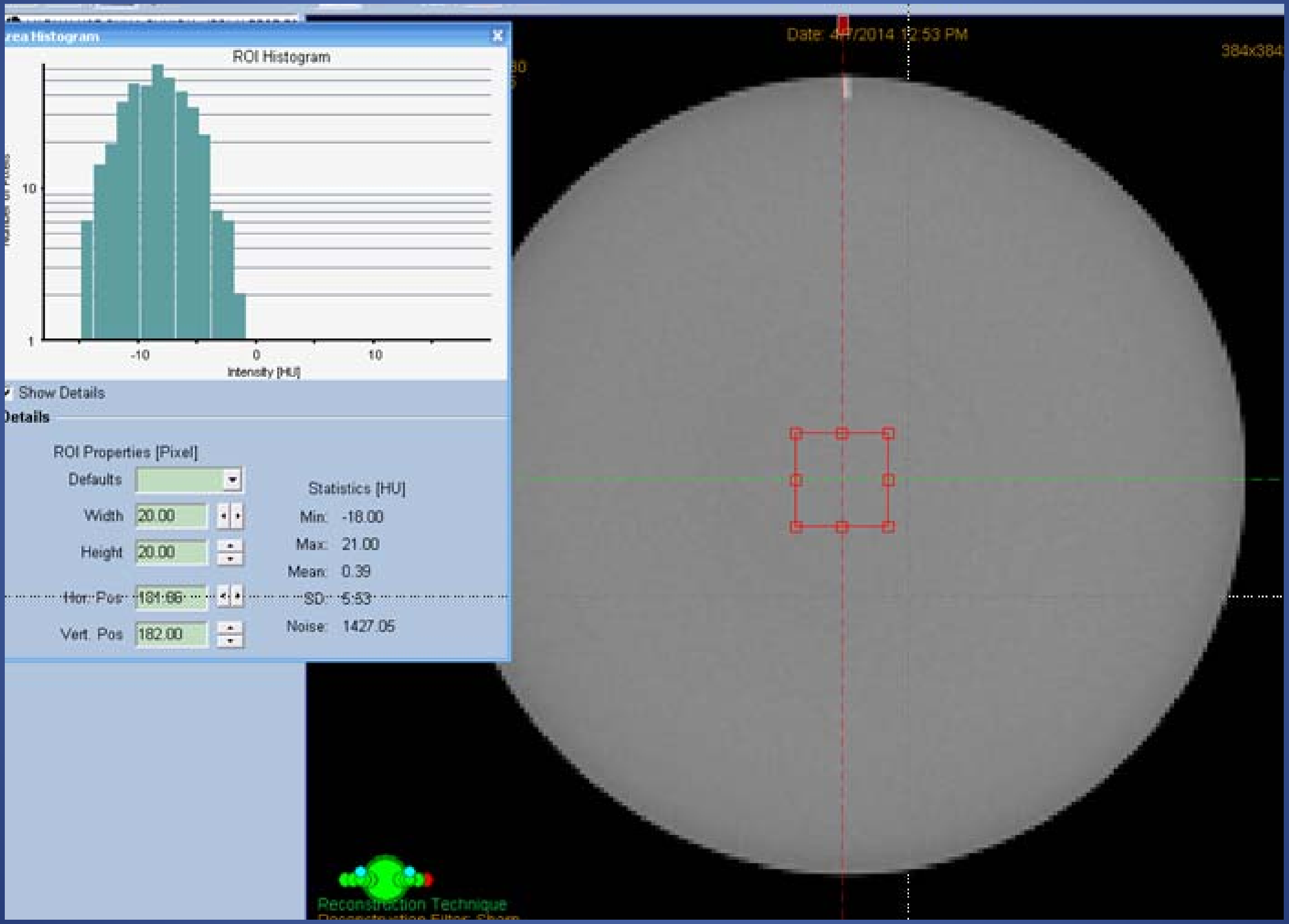
## III. Uniformity & Noise




- CTP486-2: Image Uniformity module
- Uniform material designed to be within 2% (20 HU) of water's density.

# CBCT Monthly QA

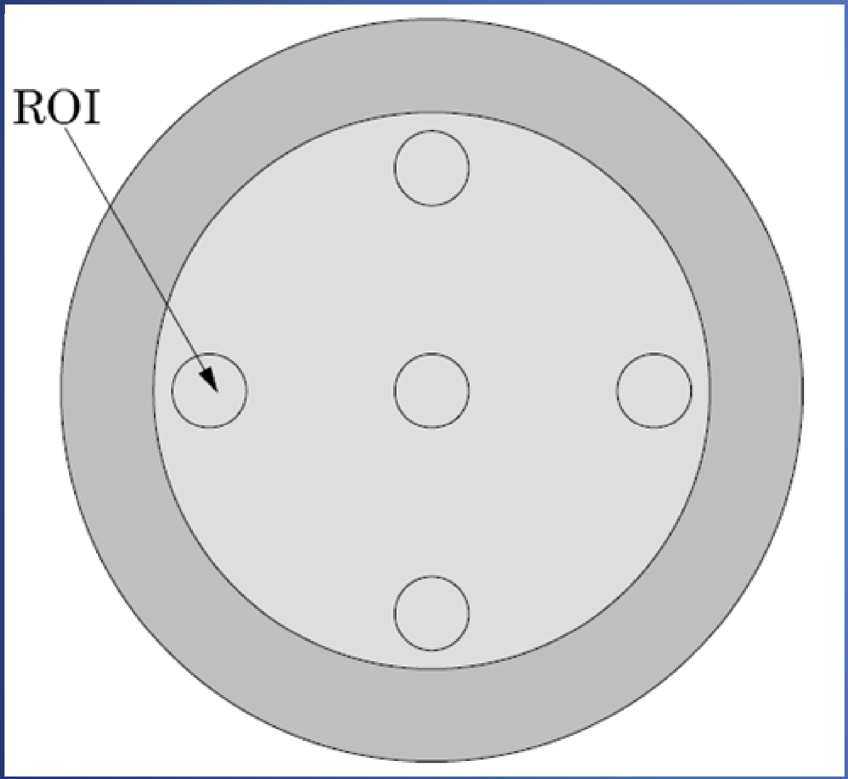
## III. Uniformity & Noise




CTP486-2: Image Uniformity module

# CBCT Monthly QA

## III. Uniformity & Noise



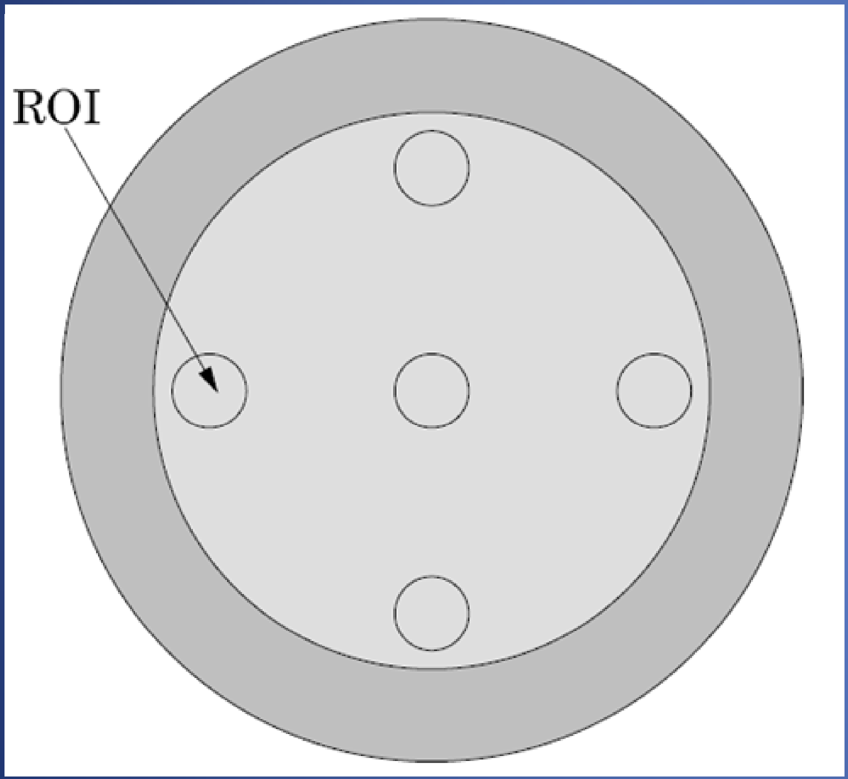

| Spatial Uniformity & Noise | | | |
|---|---|---|---|
| Location | CT # | s | % Noise |
| Center | 4.23 | 5.69 | 0.57 |
| Top | 4.83 | 7.35 | 0.74 |
| Right | 6.19 | 6.85 | 0.69 |
| Bottom | 6.83 | 6.20 | 0.62 |
| Left | 4.07 | 7.18 | 0.72 |
| % SU: | 0.276 | Range: | **Pass** |

Specification: Range: center +/- 40 HU

- Record the mean CT # & std dev for center & peripheal locations
- Use suitably sized ROI (20x20)
- Use center slice of module
- Avoid crescent shape artifact on head scans

# CBCT Monthly QA

## III. Uniformity & Noise

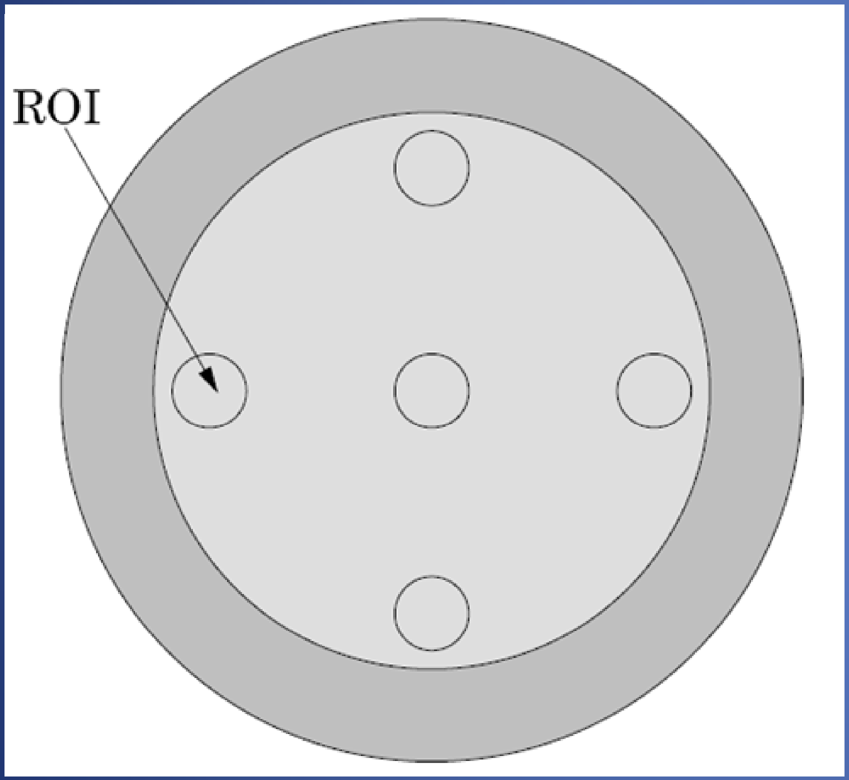



- % Spatial Uniformity is an expression of of the maximum contrast of the ROI's measured.
- % SU = $(CT\#_{max} - CT\#_{min})/10$
- Should be < 3%
- Varian spec: range +/- 40 HU from the center ROI HU

TG 142 tolerance
Baseline

# CBCT Monthly QA

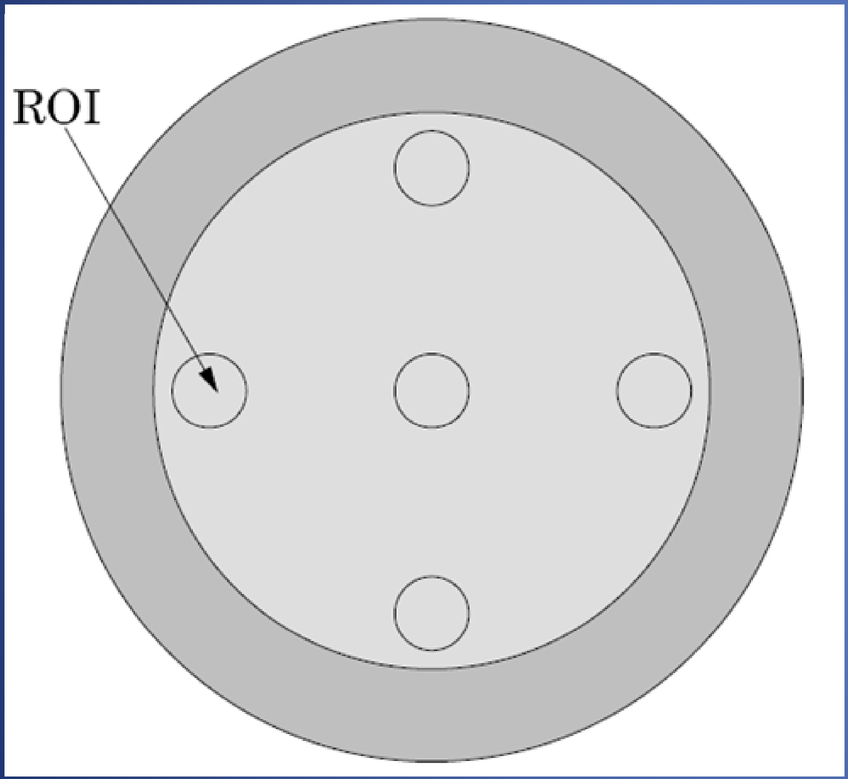
## III. Uniformity & Noise




- As stated previously noise limits the visiblity of low contrast detail.
- Noise in CT is the standard deviation of CT# (σ) expressed as a % of the linear attenuation coefficient of $H_20$ ($\mu_w$) corrected for contrast scale (CS).
- % Noise ≈ $(\sigma \cdot CS \cdot 100)/\ \mu_w$

# CBCT Monthly QA

## III. Uniformity & Noise

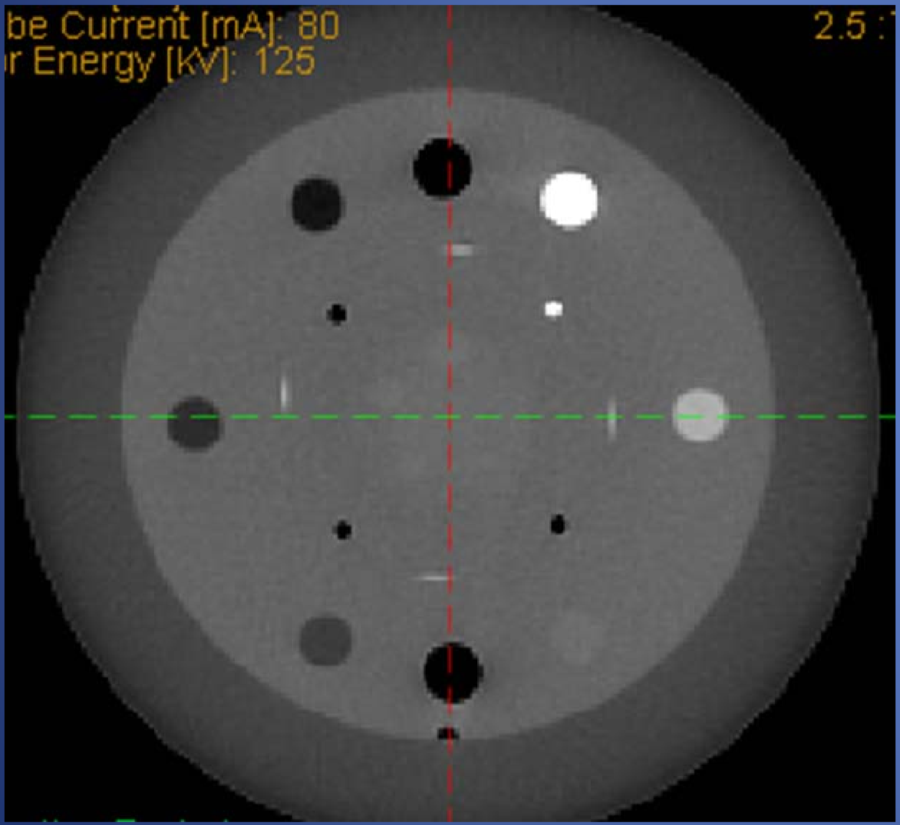



- Contrast Scale (CS) is the change in linear attenuation coefficient per CT# relative to that of $H_20$.
- CS $\approx 1.9 \times 10^{-4}$ CT#/cm$^{-1}$ & $\mu_w \approx 0.19$ cm$^{-1}$ for CT kVp ≈ 120 so,
- $\% N \approx (\sigma \cdot CS \cdot 100)/ \mu_w$
  $\% N \approx \sigma / 10$
- % Noise should be ≈ 1.0 % for the pelvis scan and ≈ 3.0 % for the head scan due to lower mAs used.

<u>TG 142 tolerance</u>
Baseline

# CBCT Monthly QA

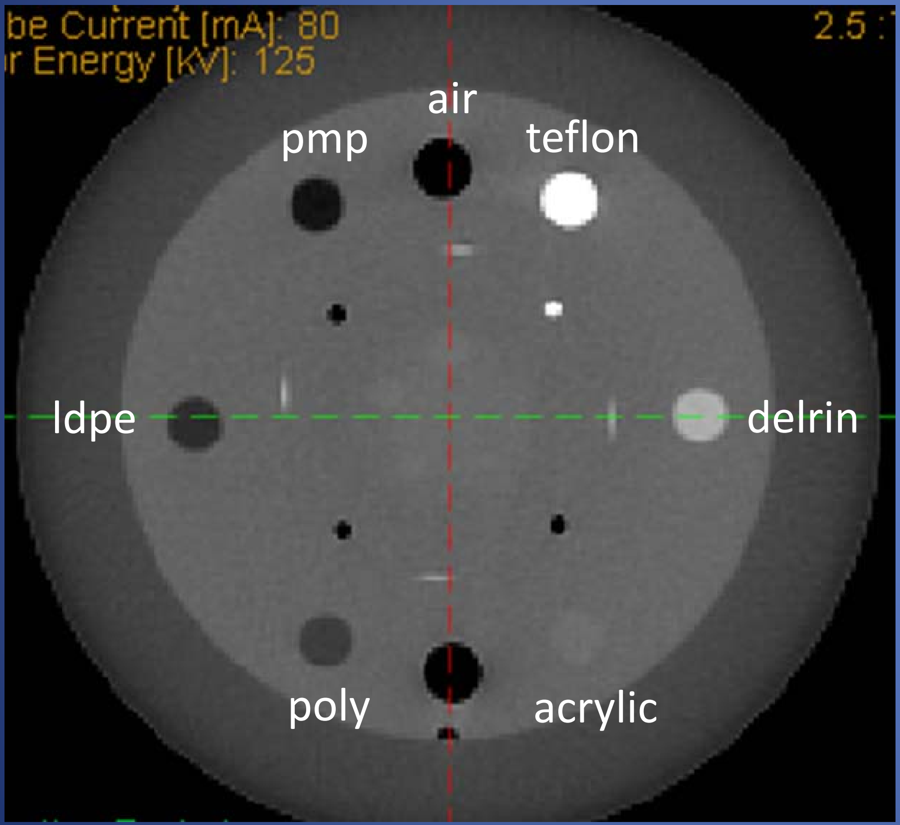
## IV. CT# Constancy, Linearity, & Contrast Scale




- CTP404 module
- Seven sensitometric targets used to assess:
    1. CT# Constancy & Linearity
    2. Contrast Scale

# VI. CT# Constancy, Linearity, & Contrast Scale

## 1. CT# Constancy & Linearity

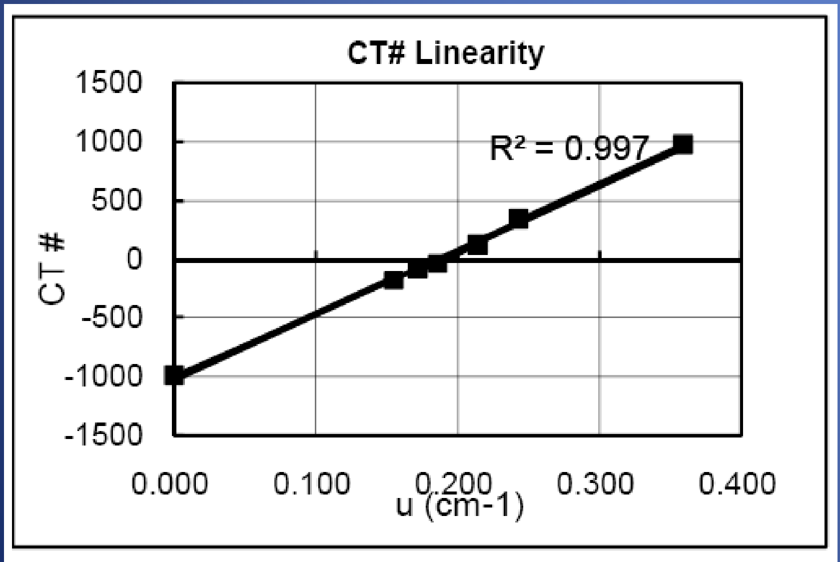



- Use center of the module to avoid partial volume effect. (4 wire ramps centered symmetrically in image)
- Window & level to visualize targets
- Draw ROI within target
- Measure CT# of the ROI of each target

# VI. CT# Constancy, Linearity, & Contrast Scale

## 1. CT# Constancy & Linearity

| Material | u | CT # | expected | diff | Pass/Fail |
|---|---|---|---|---|---|
| air | 0.000 | -994.37 | -1000 | -5.63 | Pass |
| pmp | 0.155 | -183.12 | -200 | -16.88 | Pass |
| ldpe | 0.172 | -92.53 | -100 | -7.47 | Pass |
| poly | 0.186 | -38.33 | -35 | 3.33 | Pass |
| acrylic | 0.214 | 128.39 | 120 | -8.39 | Pass |
| delrin | 0.243 | 346.94 | 340 | -6.94 | Pass |
| teflon | 0.359 | 978.55 | 990 | 11.45 | Pass |

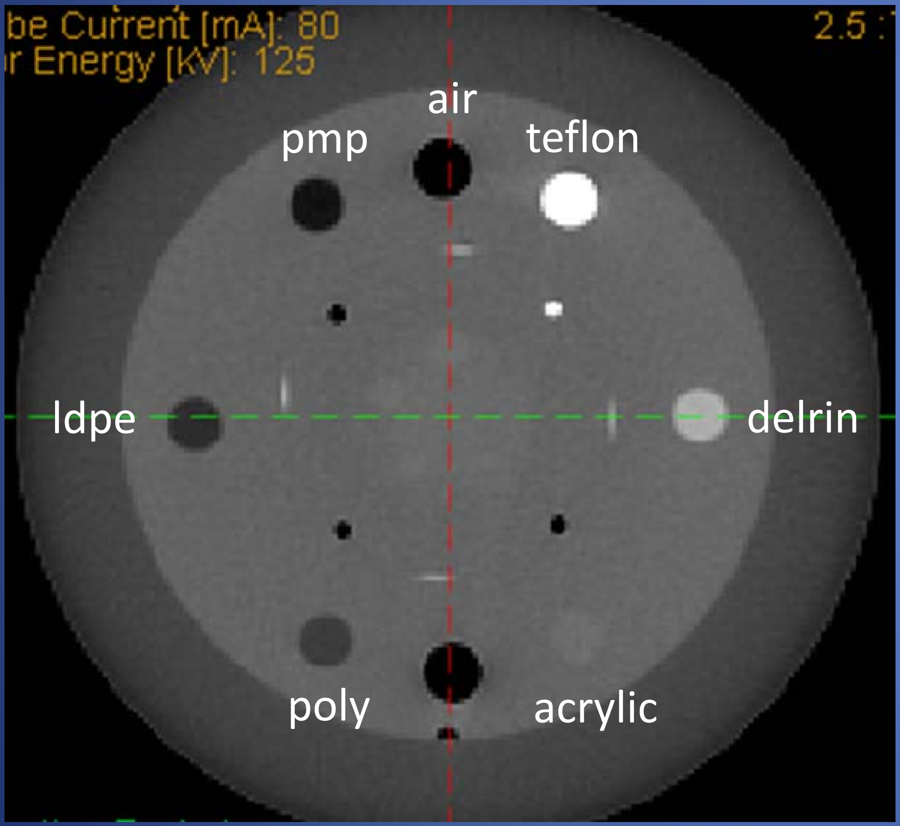



- Varian spec: measured and expected CT#'s should be within ± 40 HU
- Plot of CT# vs. µ should be linear with an $R^2$ value of close to 1.0

TG 142 tolerance
Baseline

# VI. CT# Constancy, Linearity, & Contrast Scale

## 2. Contrast Scale




- Contrast Scale (CS) is the change in linear attenuation coefficient per CT# relative to that of $H_20$.
- $CS \approx (\mu_m - \mu_w)/(CT\#_m - CT\#_w)$
- $CS_{theoretical} = 1.9 \times 10^{-4}$

  assuming: $\mu_w = 0.19\ cm^{-1}$ $CT\#_w = 0$ HU

  $\mu_m = 0.0\ cm^{-1}$ $CT\#_m = -1000$ HU

  ($w = H_20$ & $m$ = air)

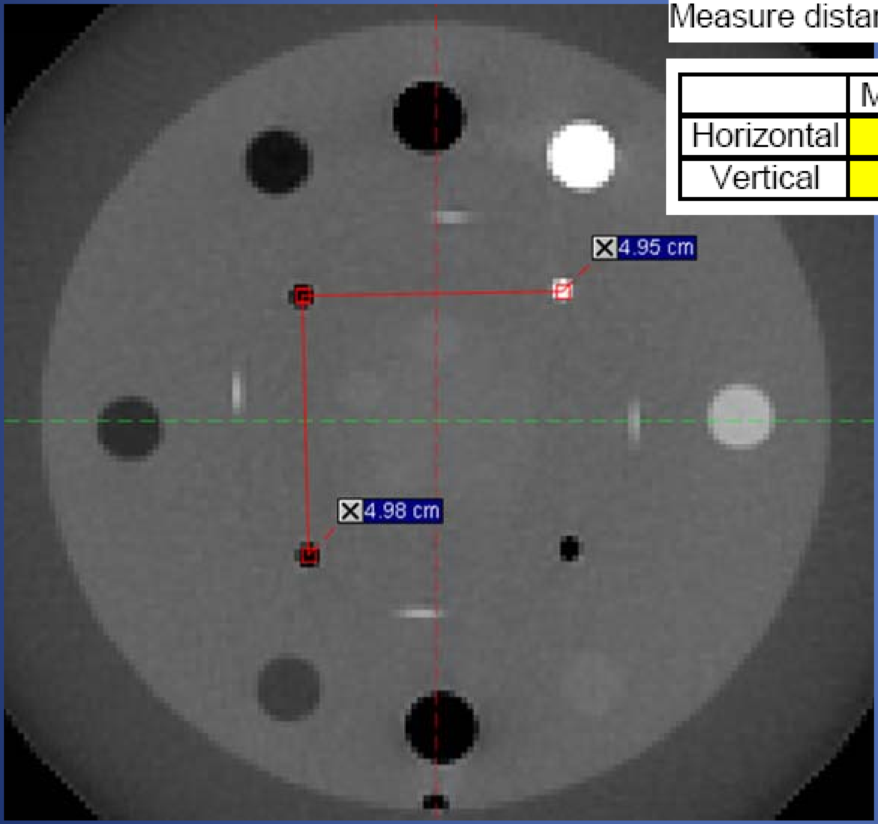
2. Contrast Scale

| | | | |
|---|---|---|---|
| CT# $H_20$: | 4.23 | CT# air: | -994.37 |
| CS (meas): | 1.90E-04 | CS: | 1.90E-04 |
| | % Diff: | 0.14% | |

- Measured & theoretical contrast scale should not differ significantly

# CBCT Monthly QA

## V. Spatial Linearity Accuracy




Measure distance between small rods in center of CT # Constancy image

| | Measured | Expected | Diff | % Diff | Pass/Fail |
|---|---|---|---|---|---|
| Horizontal | 4.95 | 5.00 | -0.05 | 1.0% | **Pass** |
| Vertical | 4.98 | 5.00 | -0.02 | 0.4% | **Pass** |

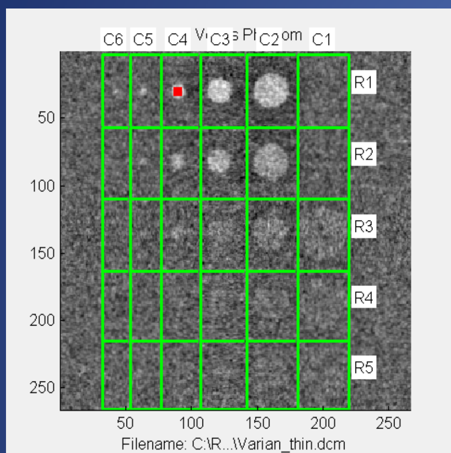
spec: accurate to w/in 1%

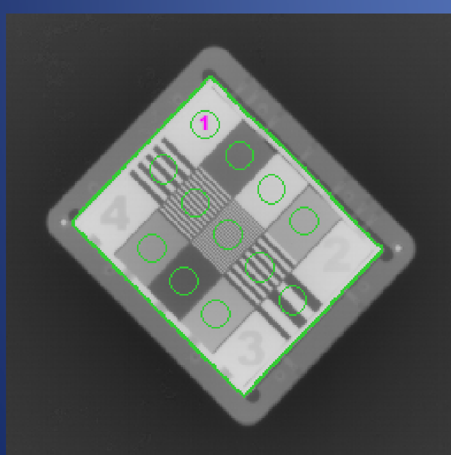
TG 142 tolerance

$\leq$ 2 mm non SRS/SBRT

$\leq$ 1 mm SRS/SBRT

# Comments on Automated Image Analysis

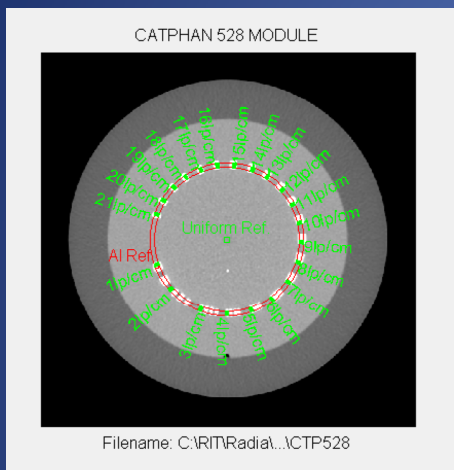


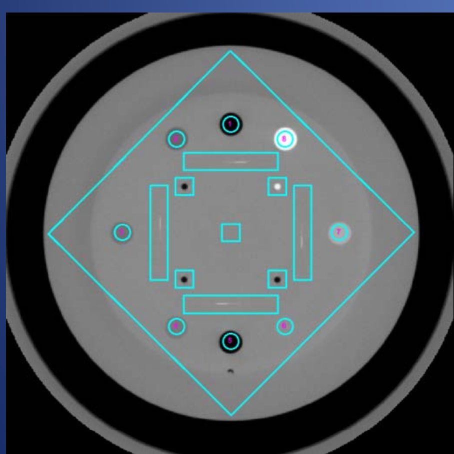



- Automated image analysis software and phantoms can be a useful tool in the collection, analysis, and trending of image qa data.
- They can eliminate viewer bias and provide calculation of advanced imaging metrics if proper and consistent techniques are used.
- As with any tool the user must understand its use and limitations, the expected results and how to interpret them.
- Without this understanding the process can become unnecessarily complicated and the results obtained may be confusing and meaningless.

Images provided by Mac Clements of RIT & Mark Wiesmeyer of Standard Imaging

# Comments on Automated Image Analysis



- Automated image analysis software is not an essential tool to implement a TG compliant imaging QA program.
- I recommend that before investing in an automated system a physicist first become familiar with image qa testing and understand the interpretation of the results by manual methods.
- This will allow you to become familiar with the tests, results, problems and pitfalls, as well as the strengths and weaknesses of the testing methodology.
- Thereby allowing you to better assess the utility and value of an automated system for your clinical application.

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# Acknowledgements

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- Mark Wiesmeyer, Standard Imaging