EUREF Draft QC protocol for breast tomosynthesis systems
Version 0.15

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Thanks:

Dr. Friedrich Semturs and colleagues
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• Background/General remarks
• Proposed QC tests
  - Results of measurements
  - Discussion after each series of measurement
• We would like to have open discussions and are open to feedback / alternatives
• Sent feedback to: r.vanengen@lrcb.nl
• 15 minute coffee break at 15:30h
DBT systems

Full-field geometry

Scanning slot geometry
## DBT systems

<table>
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<tr>
<th>DBT System</th>
<th>General Electric Essential</th>
<th>Hologic Selenia Dimensions</th>
<th>IMS Giotto TOMO</th>
<th>Philips Microdose</th>
<th>Planmed Clarity3D</th>
<th>Siemens Mamnomat Inspiration</th>
<th>Fujifilm Amulet Innovaity</th>
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<tbody>
<tr>
<td>Type of geometry</td>
<td>Full-field</td>
<td>Full-field</td>
<td>Full-field</td>
<td>Scanning multislit</td>
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<td>Full-field</td>
<td>Full-field</td>
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<td>Detector type</td>
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<td>Energy integrating</td>
<td>Energy integrating</td>
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<td>85</td>
<td>50</td>
<td>83/166</td>
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<td>X-ray tube motion</td>
<td>Step-and shoot</td>
<td>Continuous</td>
<td>Step-and shoot</td>
<td>Continuous</td>
<td>Continuous, Sync-and-Shoot</td>
<td>Continuous</td>
<td>Continuous</td>
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<td>Target</td>
<td>Mo/Rh</td>
<td>W</td>
<td>W</td>
<td>W</td>
<td>W</td>
<td>W</td>
<td>W</td>
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<tr>
<td>Filter</td>
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<td>Al: 700 µm</td>
<td>Rh: 50 µm Ag: 50 µm</td>
<td>Al: 500 µm</td>
<td>Rh: 50 µm Ag: 75 µm</td>
<td>Al: 700 µm</td>
<td></td>
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<td>Angular range</td>
<td>25</td>
<td>15</td>
<td>40²</td>
<td>N/A⁶</td>
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<td>50</td>
<td>15/40</td>
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<td>Number of projection images</td>
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<td>15</td>
<td>13</td>
<td>21³</td>
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<td>15</td>
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<tr>
<td>Source to detector distance (mm)</td>
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<td>700</td>
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<td>660</td>
<td>650</td>
<td>655</td>
<td>650</td>
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<td>Distance between detector and centre of rotation (mm)</td>
<td>40</td>
<td>0</td>
<td>20</td>
<td>400⁴</td>
<td>4.4</td>
<td>47</td>
<td>46</td>
</tr>
</tbody>
</table>
DBT systems

- Type of images/modes on DBT systems to perform QC measurements
  - Unprocessed projection images
    Note: not available on scanning slot systems
  - Reconstructed focal planes
  - On some systems: phantom/QC modes available
    Note: not always clinically relevant image reconstruction
  - Synthesized 2D images (not in protocol)
DBT systems

• Dose measurements:
  -> Zero degree angle stationary mode
  Equal exposures as in DBT mode without the tube movement
  - Output Image?

For scanning slot systems: stationary mode is not possible, use tomosynthesis mode.
Most if not all systems will be able to perform FFDM and DBT imaging

Some QC tests could be performed in FFDM

Verify that the DBT mode is identical to FFDM

(target/filter, filter thickness, detector readout, etc.)

Divided QC tests in: essential, desirable, optional
### FFDM and DBT tests

#### Essential test items:

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<th>Performed:</th>
</tr>
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<td>4.1.1 Response function acc./routine</td>
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<td>5.2 Z-resolution acc./routine</td>
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<td>5.5 Missed tissue acc./routine</td>
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<td>5.6 Homogeneity of the reconstructed tomosynthesis image acc./routine</td>
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<td>5.7 Geometric distortion acc./routine</td>
<td></td>
</tr>
<tr>
<td>6.2.1 Assessing AGD with PMMA acc./routine</td>
<td></td>
</tr>
</tbody>
</table>

It must be verified whether the target, material and thickness of the filter and readout of the detector is equal in FFDM and DBT mode.

1 It must be verified whether the readout of the detector is equal in FFDM and DBT mode.

2 It must be verified whether the target, material and thickness of the filter is equal in FFDM and DBT mode.

Desirable test items:

1.2 Focal spot motion
1.3 Coincidence of reconstructed and irradiated volume
2.5 Exposure time and total scan time
4.5 System projection MTF
5.7 Geometric distortion
6.2.2 Assessing clinical breast doses

Optional test items:

1.1 Focal spot size
1.5.1 Tube voltage
1.6 Exposure distribution per projection image
5.3 MTF in the x-y plane
5.4 NPS in the x-y plane

The current draft QC protocol does not have all final answers.
Some tests use readily available QC equipment until a more sophisticated method of measurement is available.
Especially an image quality test of the reconstructed image is still missing.
Several tests are proposed to get some information on image quality.
More elaborate tests are work-in-progress.
DBT systems should fulfil:

- DICOM Supplement 125: Breast Tomosynthesis Image Storage SOP Class
  
  Note: this standard is not fully implemented yet

- The bad pixel map applied to the detector in tomosynthesis mode should be made available to the user.
DBT systems

• Limiting values:
  - Identical as in FFDM (e.g. stability)
  - Common sense (e.g. missed tissue)
  - FFDM limits used as reference values (e.g. dose)
  - Not given (e.g. z-resolution)
Proposed QC tests
1.1 Focal spot size (optional)

- **Method:** European Guidelines, 4\textsuperscript{th} edition
- Use projection images*, zero degree angle stationary mode image or FFDM image** for evaluation of focal spot size.
- For reference purposes at acceptance
1.2 Focal spot motion (optional)

- **Rationale:** geometric unsharpness due to focal spot motion
- **Method:** Measure the exposure time \( t_{proj} \) using the zero degree stationary mode and the time for a complete scan \( t_{scan} \). The focal spot motion length can be calculated.
- For reference purposes at acceptance
Alignment between X-ray field and reconstructed tomosynthesis image at chest wall side of the bucky

- **Rationale:** the irradiated volume may differ from the reconstructed volume
- **Method:** Position X-ray rulers and self-developing film perpendicular to the edges of the image field. Mark the position of the edge of the light field. Make an exposure to give sufficient blackening of the film.
X-ray generation

- **Setup:**

- **Limiting values:** Chest wall side: the irradiated volume must extend no more than 5 mm beyond the edge of the reconstructed tomosynthesis image.
1.4 Tube output

• *Method*: Measure tube output at all clinically used spectra.

• Full-field geometry:
  Position the dose meter on the bucky surface centred laterally and 60 mm from chest-wall side. Measure the incident air-kerma in zero degree angle stationary mode.
X-ray generation

• Scanning geometry:
  Position the dose meter on the bucky surface centred laterally and 60 mm from chest-wall side. Measure the incident air-kerma for the scanning beam.

• Tube output is measured for dosimetry purposes only
1.5.1 Tube voltage

- **Method:**

  Note: In DBT mode the measured tube voltage might differ from the FFDM mode due to the pulsed exposure.

- **Limiting values:**
  European Guidelines, 4th edition
1.5.2 Half Value Layer (HVL)

- **Method:** European Guidelines, 4th edition
  Measurements in the zero degree angle stationary mode.

  Note: In DBT mode the measured tube voltage might differ from the FFDM mode due to the pulsed exposure.

- Measured for the calculation of average glandular dose
1.6 Exposure distribution per projection image (optional)

- **Rationale**: For some DBT systems the exposure per projection varies.
- **Method**: Position the dose meter on the bucky surface centred laterally and 60 mm from chest-wall side. Measure the incident air-kerma in zero degree angle stationary mode for each projection image. Use the exposure parameters for a standard 45 mm thick PMMA phantom.
2.1 Back-up timer and security cut-off

- **Method**: European Guidelines 4\(^{th}\) edition
- **Limiting values**: The back-up timer and/or security cut-off should function according to specifications
2.2 Short term reproducibility

- **Method**: Position a 45 mm thick homogeneous PMMA phantom on the bucky and make 5 subsequent exposures in the clinically used AEC mode.
- Measure the average pixel value and standard deviation in the reference ROI in projection image 1 and calculate SNR. (alternative: sum AVG of all projection images and calculate the summed SD)
- Calculate the variation in current-time product and SNR.
- **Limiting values**: Variation in current-time product < 5%, variation in SNR < 10%.
### AEC system

<table>
<thead>
<tr>
<th>Exposure</th>
<th>Angle (°)</th>
<th>mAs</th>
<th>Average Pixelvalue ROI</th>
<th>Exposure</th>
<th>Angle (°)</th>
<th>mAs</th>
<th>Average Pixelvalue ROI</th>
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<td>1</td>
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<td>5.00</td>
<td>229.5</td>
<td>14</td>
<td>-3.00</td>
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<tr>
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<td>151.5</td>
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<td>6</td>
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<td>26</td>
<td>19.98</td>
<td>5.38</td>
<td>173.1</td>
</tr>
</tbody>
</table>
• Projection images are low-dose
• Summed projections could be used for stability measurements to improve accuracy

<table>
<thead>
<tr>
<th>DBT image</th>
<th>SNR projection 1</th>
<th>SNR summed projections</th>
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<tr>
<td>variation (%)</td>
<td>3.7</td>
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</tr>
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</table>
2.3 Long term reproducibility

- **Method:** Position a 45 mm thick homogeneous PMMA phantom on the bucky and initiate an exposure in the clinically used AEC mode.
- Measure the average pixel value and standard deviation in the reference ROI in projection image 1 and calculate SNR.
- Track current-time product and SNR over time.
• **Limiting values:**
  
  The variation in current-time product, average pixel value and SNR in the reference ROI should be less than 10% if the exposure factors remain unchanged.
2.4 Object thickness compensation

- This is a test using readily available QC equipment.
- *Method*: European Guidelines 4<sup>th</sup> edition: Image in clinically relevant AEC mode an aluminium sheet of dimensions 10x10 mm and 0.2 mm thick, wedged between 20 to 70 mm PMMA.
AEC system

- setup

200 µm Al object (10 x 10 mm)

60 mm

10 mm

10 mm

ROIs (5 x 5 mm)

200 µm Al object (10 x 10 mm)
• Measure pixel value and SD in the reference ROI’s of the first projection images

• Calculate the SDNR of the aluminium object for all PMMA thicknesses:

\[
SDNR = \frac{PV(signal) - PV(background)}{SD(background)}
\]
AEC system

• *limiting values:*
  SDNR values are calculated for reference purposes, to ensure stability and to compare settings within the same brand of system.
System 1 and 2 use filtered backprojection for the reconstruction of the focal planes.
System 3 iterative reconstruction

- SDNR can not be calculated from the DBT focal planes!
2.5 Exposure time and total scan time

• *Rationale:* Exposure time per projection and total scan time may lead to motion unsharpness and/or artefacts.

• *Method:* Position the standard test block on the bucky and make an exposure in the full automatic mode. Measure the time of each projection image and the time between the start of the first and the end of the last exposure.
• **Limiting values:**

No limiting values set, clinical evaluations are required to evaluate potential motion artefacts. Measured values can be used to ensure stability and similar settings on the same type of system.
3.1 Compression force

- Method and limiting values: European Guidelines, 4th edition
4.1.1 Response function

- Response function is measured in the first projection image (to avoid influence of lag/ghosting) or zero degree mode image.
- Measure the mean PV and SD in the reference ROI on the first projection image (or zero degree mode image).
Plot mean pixel value against mAs (or incident air kerma at the detector)

- *Limiting values:*
  The response of the detector should correspond to the specification of the manufacturer.
• Detector gain is increased in tomo mode
• Typical detector air kerma ~20 µGy (cf 80 µGy for 2D)
4.1.2 Noise analysis

- The images from 4.1.1 Response function are used
  
  *Method*: European Guidelines, 4th edition

- *Limiting values*: Use the noise coefficients for reference purposes to ensure stability and similar settings/quality on the same brand of system.
Image receptor

System 1

FFDM

DBT projection image 1

fraction of total variance

K (µGy)

0.0

0.1

0.2

0.3

0.4

0.5

0.6

0.7

0.8

0.9

1.0

1

10

100

1000

fraction of total variance

K (µGy)

0.0

0.1

0.2

0.3

0.4

0.5

0.6

0.7

0.8

0.9

1.0

0

20

40

60

quantum

fixed pattern

electronic

quantum

fixed pattern

electronic
System 2

**FFDM**

- Blue line: quantum
- Black line: fixed pattern
- Red line: electronic

**DBT projection image 1**

- Blue line: quantum
- Black line: fixed pattern
- Red line: electronic
4.2 Detector element failure

- **Method:**
  Obtain the most recent “bad pixel map” for tomosynthesis mode from the system.

- **Limiting value:**
  At present no limits have been established. It is suggested that the manufacturer’s limits are used.
4.3  Uncorrected defective detector elements

- Projection images or zero degree angle stationary mode images
- **Method**: Make 5 images of the standard test block. Determine whether any pixel deviates more than 20% compared to the average value in an ROI of 5 mm x 5 mm for all 5 images.
- **Limiting value**: No uncorrected defective detector elements should be visible.
4.4 System projection MTF (optional)

- Projection images: blurring included due to focus size, focus motion, detector MTF (x-ray converter MTF and pixel sinc MTF) and detector binning.

- Zero degree angle stationary mode includes the same blurring sources with the exception of focus motion.

Note: Blurring due to focus size and focus motion depends on the position of the rotation point and the position in the z-direction of the object.
• **Method:** setup as in European Guidelines 4\textsuperscript{th} edition. Position the MTF edge on the bucky.

- Perform a DBT scan (AEC exposure factors for 45mm PMMA). Repeat the measurement with the MTF edge at 40 mm and 70 mm above the bucky surface using low contrast supports.
• Calculate the MTF for each image using appropriate software (e.g. OBJ_IQ_reduced as described in NHSBSP Equipment Report 0902). Calculate the spatial frequency for MTF values of 50% and 10%.

• *Limiting values*: The MTF values for spatial frequency for 50% and 10% points should be within 10% of previous test and baseline.
For DBT with moving tube, MTF in projection images is anisotropic due to focus motion.
5.1 Stability of image quality in the x-y plane

- At this moment it is not possible to quantify image quality in reconstructed focal planes images. However it is important to investigate in-plane resolution, even though the method of testing does have limitations.

- A test object which is used for this purpose should be able to test some measure of resolution and SNR. An example of such a test object is the CDMAM or TORMAM phantom.
Image quality of the reconstructed image

- **Method:** Image the CDMAM phantom in the middle of a 40 mm stack of PMMA using exposure factors as would be selected automatically for a 60 mm equivalent breast. Repeat to obtain a total of 8 images, moving the phantom slightly between exposures.

- Score the reconstructed tomosynthesis images of the CDMAM phantom using human observers and calculate the CD-curve according to the supplement to the fourth edition of the European Guidelines.
Image quality of the reconstructed image

• For some DBT systems it might be possible to score the focal plane where the image of the CDMAM phantom is in focus using CDCOM. In this case 16 CDMAM images (as in FFDM) could be used. It is advised to remove the low frequency trend in the tomosynthesis plane before CDCOM is used.

• Converting the results of this automated analysis to predicted human values using the method described in the Supplement has not been validated for DBT systems.
Stability of the reconstructed image

CDMAM suggested in the protocol
  - Other test objects can be used

Assesses sharpness and noise in-plane (detail SNR)

Not final IQ test object
  - Gold cylinders (wide angle systems)
  - Validation of CDCOM for DBT?
  - No overlying anatomy -> does not test ability of system to suppress overlying anatomical noise
• *Limiting values:*

The measured contrast threshold values can be used for reference purposes to ensure stability and similar settings/quality of the same type of system.

Note: The limiting values for FFDM image quality measurements should not be applied to DBT.
5.2 Z-resolution

- The z-resolution is related to the ability to remove overlying structures and the amount of artefact and noise due to out-of-focus structures in the image.
Image quality of the reconstructed image

- The FWHM of the slice sensitive profile of aluminium spheres with a diameter of 1 mm is taken as measure of z-resolution.
**Method:** Position five 10 mm thick slabs of PMMA on the bucky. Position a 5 mm thick phantom with aluminium spheres (diameter 1 mm) between the first and second slab and make an exposure.

- Position the 5 mm PMMA with aluminium spheres between the second and third slab and make an exposure.
- Repeat this procedure until the phantom with aluminium spheres is between the fourth and fifth slab.
Image quality of the reconstructed image

- To determine the SSP, reslice the focal planes into vertical planes parallel to the chest wall edge for each sphere. Calculate the SSP of the aluminium spheres.
- Calculate FWHM (SSP=0.5)
- This analysis is most easily carried out by using dedicated software, which will be made available on the EUREF website.
Image quality of the reconstructed image

• *Limiting values*:
  
  To be determined, the FWHM values can be used for reference purposes and to ensure stability and similar settings/quality of the same brand of system.
5.3  MTF in the x-y plane (optional)

- The use of linear system theory metrics on reconstructed images is under debate.
- The method given does not give the 3D MTF but instead the in-plane MTF (x-y) in tube travel and chest wall-nipple directions.
Image quality of the reconstructed image

• Setup

5 mm PMMA
Tungsten wire
10 mm PMMA

Tungsten wire

φ ≈ 3°

60 mm

30 mm spacer
Image quality of the reconstructed image

- In-plane sharpness
  - MTF measured using 25 µm Φ W wire
  - Wire supported using a 0.5 mm PMMA plate
- Sharpness an-isotropy seen in the projections follows through to planes
Image quality of the reconstructed image

- Example for tube-travel direction
  - MTF in-plane seems to follow MTF in projections
- MTF is important aspect of IQ but not the final word
- Detectability is determined by signal to noise ratio (SNR):
  - Depends on system noise, anatomical noise, sharpness, target (size, shape, position etc)
5.4 **Noise Power Spectra (optional)**

- Under development. It is not clear yet how to normalize the NPS.
5.5 Missed tissue

- European Guidelines, 4th edition. In addition an evaluation is also made of missed tissue at the top and bottom of the compressed volume.

- Method: Position two X-ray rulers (or phantom with markers) on the bucky perpendicular and aligned to the chest wall edge, acquire an image.

- Evaluate the amount of missed tissue beyond the chest wall edge on the reconstructed plane corresponding to the surface of the bucky.
Image quality of the reconstructed image

• Place several small high contrast objects (for example staples) on the bucky surface (e.g. 20 mm PMMA) and acquire an image.

• Repeat with the small objects attached to the underside of the compression paddle.

• *Limiting values:

Width of missed tissue at chest wall side ≤ 5 mm. Check in the reconstructed image that all the objects are brought into focus in one of the bottom or top focal planes.
Image quality of the reconstructed image

- Example system 1: Object in focus in top and bottom focal plane
5.6 Homogeneity of the reconstructed image

- **Method**: Position a 45 mm thick PMMA block on the bucky covering the whole field of view and make an exposure in the clinically used AEC mode. The reconstructed tomosynthesis planes are divided in ROIs of 5.0 x 5.0 mm and averaged with adjacent focal planes covering a vertical range of 5mm. Calculate average pixel value, standard deviation and variance in each ROI.
Image quality of the reconstructed image

• **Limiting values:**
  No disturbing artefacts should be present.
Image quality of the reconstructed image

**Mean signal - slice 22 through 24**

- **Rows**: 2500
- **Columns**: 2000
- **Pixel value**: 6000-8000
Image quality of the reconstructed image

SNR - slice 21 through 25

SNR

Rows

Columns
5.7 Geometric distortion

- Images of a phantom containing a rectangular array of 1mm diameter aluminium spheres may be used to assess geometric distortion
Image quality of the reconstructed image

• *Method*: The phantom is imaged at the bottom, middle and top of a 60 mm stack of PMMA. These images can also be used for the evaluation of missed tissue at top and bottom side of the image.

• Analysis software can be used to find the position of each sphere in the x, y and z directions. This software will be made available via the EUREF website.
• **Limiting values:**
  Any distortion or scaling error should be within the manufacturer’s specification, and can be used to compare systems.

• If the image is to be used for localisation purposes then the magnitude of any distortion or scaling error becomes important.
\[ D_T = K_T \cdot g \cdot c \cdot s \cdot T \]

\[ T = \frac{1}{N} \cdot \Sigma \ t(\theta)_i \]

(if exposure for all projection images is equal)

\( K_T \): Incident Air Kerma in zero degree position

\( g \)-factor, \( c \)-factor, \( s \)-factor: conversion factors

\( t(\theta)_i \)-factor: correction for geometry of projection image \( i \)
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<th>PMMA thickness (mm)</th>
<th>Breast thickness (mm)</th>
<th>$T_{\text{Fujifilm} \pm 7.5^\circ}$</th>
<th>$T_{\text{Fujifilm} \pm 20^\circ}$</th>
<th>$T_{\text{GE} \pm 12.5^\circ}$</th>
<th>$T_{\text{Hologic} \pm 7.5^\circ}$</th>
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• Dose measurements:
  -> Zero degree angle stationary mode
      Equal exposures as in DBT mode without the tube movement
• Not available on all systems
Dosimetry

System 1

System 2

System 3
• Detector uniformity varies with projection
• Flat field correction is made in the 0° projection only
  – Siemens Inspiration
• Should lag/ghosting be measured in projection images?
Should the local density test be included?
• View in Cine-mode:
  – Synchronization between sending images of focal planes and display on monitor: Are all focal planes displayed?
  – Response time of monitor?

We do not know the relevance of these items
Thank you for your attention