Ontario Breast Screening Program

Digital Mammography Quality Control for the Mammographic Physicist

Authors: G.E. Mawdsley, A.K. Bloomquist, M.J. Yaffe

March 2014
Revision 3.2

Mammographic Physics Consulting Group
Ontario Breast Screening Program

Main:
Research Building, Room S6-32
Sunnybrook & Women’s College Health Sciences Centre
2075 Bayview Avenue
Toronto, ON M4N 3M5

QC Support:
Sunnybrook Imaging Research

Telephone: 416.480.5705
Fax: 416.480.6719
# Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table of Contents</td>
<td>3</td>
</tr>
<tr>
<td>I. Introduction</td>
<td>5</td>
</tr>
<tr>
<td>II. Description of digital mammography technologies</td>
<td>11</td>
</tr>
<tr>
<td>1. X-Ray Source</td>
<td>12</td>
</tr>
<tr>
<td>2. Imaging Geometry</td>
<td>13</td>
</tr>
<tr>
<td>3. Types of Digital Mammography Systems</td>
<td>14</td>
</tr>
<tr>
<td>III. Artefacts</td>
<td>21</td>
</tr>
<tr>
<td>IV. FFDM Quality Control Tests</td>
<td>35</td>
</tr>
<tr>
<td>1. Procedure: Mammography Unit Assembly Evaluation</td>
<td>36</td>
</tr>
<tr>
<td>2. Procedure: Compression force and thickness accuracy</td>
<td>40</td>
</tr>
<tr>
<td>3. Procedure: Technique Chart / AEC Evaluation</td>
<td>44</td>
</tr>
<tr>
<td>4. Procedure: Artefact Evaluation</td>
<td>51</td>
</tr>
<tr>
<td>5. Procedure: Breast Entrance Exposure and Beam Quality Assessment</td>
<td>56</td>
</tr>
<tr>
<td>6. Procedure: Average Glandular Dose</td>
<td>60</td>
</tr>
<tr>
<td>7. Procedure: Evaluation of Ghosting</td>
<td>65</td>
</tr>
<tr>
<td>8. Procedure: Collimation and Light Field Brightness Assessment</td>
<td>69</td>
</tr>
<tr>
<td>9. Procedure: Evaluation of System Resolution/Modulation Transfer Function (MTF)</td>
<td>75</td>
</tr>
<tr>
<td>10. Procedure: Noise and Linearity</td>
<td>80</td>
</tr>
<tr>
<td>11. Procedure: Spatial Linearity and Geometric Distortion of the Detector</td>
<td>84</td>
</tr>
<tr>
<td>12. Procedure: Monitor Display Quality</td>
<td>87</td>
</tr>
<tr>
<td>14. Procedure: Monitor Luminance Response and Viewing Conditions</td>
<td>95</td>
</tr>
<tr>
<td>15. Procedure: Viewbox Luminance and Room Illuminance</td>
<td>102</td>
</tr>
<tr>
<td>V. Evaluation of the Mammography Site’s Technologist QC Program</td>
<td>109</td>
</tr>
<tr>
<td>VI. Summary Reporting Forms</td>
<td>110</td>
</tr>
<tr>
<td>VII. Importing and Exporting Images and Miscellaneous Tips</td>
<td>114</td>
</tr>
<tr>
<td>VIII. Glossary</td>
<td>119</td>
</tr>
<tr>
<td>IX. References</td>
<td>135</td>
</tr>
</tbody>
</table>
I. INTRODUCTION

The success of mammography, whether for screening or diagnosis, depends on the production of high-quality images at appropriate doses. Production of such images is a complex and difficult task. Poor quality mammograms lower the detection rate of early breast cancer, reducing the patient’s chances of survival and undermining the public’s confidence in the value of mammography. Furthermore, substandard mammography generates equivocal examinations leading to increased cost and anxiety to the patient. Achieving high-quality studies at acceptable dose requires vigilant attention to quality control, not only on the part of the radiologist and mammography QC technologist, but also on the part of the medical physicist.

This section of the Digital Mammography Quality Control Manual provides detailed procedures for tests to be conducted at least semi-annually by a medical physicist specialized in mammography to help assure proper mammographic system performance. These tests are designed to assess the continuing performance of digital mammography equipment. Similar tests are included for the mammography quality control (QC) technologist, detailing the procedures appropriate for routine QC testing.

The testing has been set up to separately test the acquisition system and display devices, assuming that facilities might have a number of models of acquisition systems, and diagnostic review stations from different vendors, all sharing the same PACS system. We are establishing the principle that if a workstation properly displays test images emulating those from a given acquisition device, that workstation will be a Verified Workstation. This does not validate that image hanging protocols will be properly followed, or that a given manufacturer’s image processing will be properly applied. There is minimal evaluation included for secondary display devices, which are not to be used for interpretation.

An automatic software package called “mammoQC” is being evaluated for use by the OBSP. The mammographic acquisition system automatically sends images of patients named QCDAILY, QCWEEKLY and QCMONTHLY to this program that performs a complete analysis of the image quality, reporting the results to OBSP Physics through the internet. This greatly reduces the effort involved in regular QC, and enables detection of subtle problems. This will allow the physics group to detect problems quickly, and intervene before a problem becomes critical as well as reduce clerical and technologist time requirements.

The physicist and technologist tests are designed to verify the correct operation of the entire imaging chain, and to serve as a screening tool, rather than as a diagnostic tool. Tests should be performed at technique factors used clinically for digital mammography. When problems are detected, further tests may be required to diagnose and isolate the cause of the problem so that it can be corrected. Depending on the resources available at the site and the nature of the problem, such diagnostic testing may be performed by the
Radiologic Technologist, the site’s Medical Physicist, equipment service personnel, or other suitably trained and qualified personnel.

It is the responsibility of the medical physicist conducting or reporting these tests to convey test results accurately to the facility in a written report, to make recommendations to the facility for corrective actions according to the test results, and to review the results with the radiologist and QC technologist. HARP inspectors check the medical physicist’s report to determine if the facility is in compliance with the regulations and if the medical physicist’s recommendations are acted upon by the facility. Although CAR allows the medical physicist 30 days from the date of the survey to send their report to the facility, a 30-day delay in getting the report to the facility allows the facility no time to take corrective actions. It is essential to note that the CAR requires immediate corrective action by the facility for failure of nine of the medical physicist’s tests: failure of some aspects of mammographic unit assembly evaluation (Medical Physicist Test # 1), excessive image artefact (Medical Physicist Test # 3), excessive breast dose (Medical Physicist Test # 6), excessive ghosting (Medical Physicist Test # 7), deficient Modulation Transfer Function (Medical Physicist Test # 9), excessive geometric distortion (Medical Physicist Test #11) and problems with the softcopy display (Medical Physicist Test #s 12, 13, 14 and 15). If any of the aforementioned tests, excepting tests 12-15, fails, a facility may not conduct mammography with that equipment until the problem is corrected. If any of tests 12-15 fails, the tested display device may not be used to interpret digital mammograms until the problem is corrected. If the monitor being evaluated is on a review workstation, acquisition does not need to be stopped, unless repair cannot be achieved within three working days and no other approved review workstations are available for image interpretation. For a facility to comply with this new requirement, the medical physicist must not only collect test data during the survey, but must also immediately evaluate results and compare them to the pass/fail criteria. Most importantly, the medical physicist must immediately communicate this failure to the facility. It is strongly recommended that failures be immediately communicated to the facility both verbally and in written form. One way to accomplish this is by leaving the facility a preliminary report upon departure.

Communication of test results and recommendation of corrective actions are areas that can be improved in the practices of most medical physicists. Corrective actions should not be limited to repair of x-ray equipment by a qualified service person, but should include recommendations that will improve image quality, including recommendations concerning image receptors, technique factors, viewing conditions, hanging protocols, PACS / image archiving and technologist QC. The medical physicist should periodically review the results of technologist QC tests (at least semi-annually) and make recommendations regarding these tests, if needed. Furthermore, the medical physicist should participate in periodic reviews of the mammography QC program as a whole to assure that the program is meeting its objectives (See Section III).

Note that a new requirement for FFDM QC is that the physicist conducts baseline testing to establish target values for the technologist’s quality control program. Target values, action levels, acquisition device specific test images and forms specific to the facility
equipment are to be provided by the Medical Physicist. As such, procedures for establishing QC baselines are included in this document. Baselines should be established at equipment acceptance, and re-established when significant changes or repairs have been made to the unit, when the equipment is known to be operating correctly.

To assist the medical physicist in communicating test results, recommendations, and target value information, Summary Forms have been included in the physicist’s excel spreadsheet. A Preliminary Results form is provided for the medical physicist to leave brief, handwritten results for the facility prior to departure. This immediate communication is particularly essential to allow adequate time for the facility to take corrective action should any tests fail.

A list of resources and additional references relevant to digital mammography is included at the end of this manual. There is a Glossary that explains words and acronyms used in this document which are unique to digital mammography, and also some that might not be clear to those new to the field.

An equipment evaluation must be performed on all units and all tests must be passed before the unit is used on patients. This evaluation is to be performed by, or the tests should be reviewed by a medical physicist qualified in digital mammography. Equipment evaluations involve the performance of all technologist’s and physicist’s QC procedures (except retake analysis) in this manual, ensuring that the basic minimum criteria are met for each test. The values obtained during the initial equipment evaluation are to be used as baseline values, and then referred to during future evaluations to determine if equipment performance is deteriorating.

Images are generally provided to PACS systems in a “For Presentation” form, which assumes that the display device complies with the DICOM gray scale display standard. Most of the tests in this Quality Control program require images in the “For Processing” or “Raw” format. The raw format produces pixel values which are directly related to the radiation interacting in that pixel which enables the evaluation of signal levels and noise without histogram modification or frequency modification which is sometimes performed on “For Presentation” images. It may be important to ensure that the “auto-push” DICOM server is set to the appropriate state to collect these “raw” images at the beginning of a test session, and returned to the original state at the completion of the testing.

Before performing the tests on the unit, open the spreadsheet provided, and save it with the following suggested naming scheme:

YYYmmd_d_CityOrTown_SiteNameInitials_UnitNameIfNecessary.xls,

where YYYYmmdd is the year month and day the tests are performed, for example, 2008Apr16_MyTown_ABC.xls or 2008Dec21_ThisCity_ABC_Lorad.xls.

Move the sheets that don’t apply to your type of unit to the end of the spread sheet pages.
after the worksheet “end of tests” to show the following sheets can be ignored. Deleting sheets may result in the failure of some automatic functions. The original document was designed to make data entry at the test site easier. For the published report, reorder the sheets into numerically increasing order based on the number in the sheet name. Sheets without a number can be moved past the “end of tests” sheet.

Where specific settings are recommended in this document, the closest setting that meets the logical intent of the test should be used.

The physicist is also required to upload test images to the facility PACS system for the evaluation of monitor performance. For sites that are using Gladys, a separate manual will be provided for the installation of the software, and a training manual for the technologist will be supplied.

In addition to the generic tests specified in this manual, manufacturers may also specify tests which they consider must be performed, the results of which should be checked by the medical physicist, but the performance of the tests in the format specified in this document takes precedence. This is essential to allow comparison of equipment across manufacturers, and across medical physicists.

The following table lists the physicist’s test procedures and their recommended frequencies.

**Table 1: FFDM Medical Physicist’s QC Procedures**

<table>
<thead>
<tr>
<th>Test #</th>
<th>Procedure Name</th>
<th>FFDM System</th>
<th>Minimum Frequency</th>
<th>Timeframe for Corrective Action</th>
<th>Relevant Forms</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mammographic Unit Assembly Evaluation</td>
<td>All</td>
<td>Semi-Annually</td>
<td>Immediately/Within 30 days of the test date depending on the problem</td>
<td>Chart 1</td>
</tr>
<tr>
<td>2</td>
<td>Compression force and thickness accuracy</td>
<td>All</td>
<td>Semi-Annually</td>
<td>Immediately/At next scheduled servicing depending on the problem</td>
<td>Chart 1</td>
</tr>
<tr>
<td>3</td>
<td>Technique Chart/AEC Evaluation (SDNR)</td>
<td>All</td>
<td>Semi-Annually</td>
<td>Within 30 days of the test date</td>
<td>Chart 2</td>
</tr>
<tr>
<td>4</td>
<td>Artefact Evaluation</td>
<td>All</td>
<td>Semi-Annually</td>
<td>Within 30 days of the test date or immediately depending on clinical significance</td>
<td>Chart 3, Tech. Baselines</td>
</tr>
<tr>
<td>5</td>
<td>Breast Entrance Exposure and Beam Quality Assessment</td>
<td>All</td>
<td>Semi-Annually</td>
<td>Within 30 days of the test date</td>
<td>Chart 4</td>
</tr>
<tr>
<td>6</td>
<td>Average Glandular Dose</td>
<td>All</td>
<td>Semi-Annually</td>
<td>Immediately</td>
<td>Chart 5</td>
</tr>
<tr>
<td>7</td>
<td>Evaluation of Ghosting</td>
<td>All</td>
<td>Equipment Evaluation</td>
<td>Immediately</td>
<td>Chart 6</td>
</tr>
</tbody>
</table>
HARP regulations require that quality control records be “maintained for at least six years from the time of their making in the facility in which the x-ray machine to which the records referred is operated”. These records must include type and result of test, frequency of testing and actions taken to correct each deficiency identified. In addition, OBSP policy is that QC test images must be retained according to Table 2.

Table 2: OBSP Requirements for Mammography QC Test Image Retention

<table>
<thead>
<tr>
<th>QC Images</th>
<th>Retention</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily QC</td>
<td>previous 30 days.</td>
</tr>
<tr>
<td>Weekly QC</td>
<td>previous 12 weeks.</td>
</tr>
<tr>
<td>Monthly QC</td>
<td>until the next semi-annual inspection has been completed</td>
</tr>
<tr>
<td>Quarterly QC</td>
<td>until the next semi-annual inspection has been completed</td>
</tr>
<tr>
<td>Semi-Annual QC tests</td>
<td>until the next semi-annual inspection has been completed and a Medical Physicist has determined that the facility is in compliance with the quality assurance requirements. The OBSP recommends that images documenting test failures be provided to the facility to assist them in making corrective actions.</td>
</tr>
<tr>
<td>Mammography</td>
<td>The OBSP recommends that images documenting test settings be documented.</td>
</tr>
</tbody>
</table>

OBSP Digital Mammography QC-Physicist-Rev 3.2-Final.doc March 31 2014
Equipment Evaluations failures be provided to the facility to assist them in making corrective actions. See Table 3.

The following table lists the images generated by the physicist’s tests which need to be kept for OBSP and archival purposes, along with a suggested patient naming convention. Suggested Patient names are given. “Patient” IDs should be chosen in a manner that aids in identifying the image and does not conflict with actual clinical data in the hospital PACS or HIS/RIS system.

Table 3: Images generated by physicist’s tests of digital mammography unit. For the suggested patient ID, U specifies the unit number, YY are the last two digits of the year of testing, MM specifies the two-digit testing month number and DD specifies the two-digit testing date.

<table>
<thead>
<tr>
<th>#</th>
<th>Procedure Name</th>
<th>Suggested Patient Name</th>
<th>Suggested Patient ID</th>
<th># of Images Expected</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Technique Chart/ AEC Evaluation (SDNR)</td>
<td>Physics, Tracking</td>
<td>9902UYYMMDD</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>Artefact Evaluation</td>
<td>Physics, Artefacts</td>
<td>9904UYYMMDD</td>
<td>2 or more</td>
</tr>
<tr>
<td>7</td>
<td>Ghost/Lag Image Evaluation</td>
<td>Physics, Ghosting</td>
<td>9907UYYMMDD</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>Collimation Assessment</td>
<td>Physics, XRField</td>
<td>9908UYYMMDD</td>
<td>1 or more</td>
</tr>
<tr>
<td>9</td>
<td>Evaluation of System Resolution/MTF</td>
<td>Physics, MTF</td>
<td>9909UYYMMDD</td>
<td>2 or more</td>
</tr>
<tr>
<td>10</td>
<td>Noise and Linearity</td>
<td>Physics, NLR</td>
<td>9910UYYMMDD</td>
<td>4 or more</td>
</tr>
<tr>
<td>11</td>
<td>Spatial Linearity and Geometric Distortion</td>
<td>Physics, Distortion</td>
<td>9911UYYMMDD</td>
<td>1 or more</td>
</tr>
<tr>
<td>16</td>
<td>Evaluation of Image Quality</td>
<td>Physics, Phantom</td>
<td>9916UYYMMDD</td>
<td>1</td>
</tr>
</tbody>
</table>
II. DESCRIPTION OF DIGITAL MAMMOGRAPHY TECHNOLOGIES

A summary of the digital systems commercially available at the time of writing is available in Table 3.

Table 3: Characteristics of digital mammography systems

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Model</th>
<th>Del Size</th>
<th>Detector Dimensions (cm x cm)</th>
<th>Image Matrix Size</th>
<th>Bit Depth</th>
<th>Technology</th>
<th>Grid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat panel detectors</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GE</td>
<td>Senographe 2000 D</td>
<td>100</td>
<td>19 x 23</td>
<td>1914 x 2294</td>
<td>14</td>
<td>CsI on α-Si</td>
<td>Y</td>
</tr>
<tr>
<td>GE</td>
<td>Senographe DS</td>
<td>100</td>
<td>19 x 23</td>
<td>1914 x 2294</td>
<td>14</td>
<td>CsI on α-Si</td>
<td>Y</td>
</tr>
<tr>
<td>GE</td>
<td>Senographe Essential</td>
<td>100</td>
<td>24 x 31</td>
<td>2394 x 3062</td>
<td>14</td>
<td>CsI on α-Si</td>
<td>Y</td>
</tr>
<tr>
<td>Lorad/Hologic</td>
<td>Selenia</td>
<td>70</td>
<td>24 x 29</td>
<td>3328 x 4096</td>
<td>14</td>
<td>α-Se</td>
<td>Y</td>
</tr>
<tr>
<td>Siemens</td>
<td>Mammomat Novation</td>
<td>70</td>
<td>24 x 29</td>
<td>3328 x 4084</td>
<td>14</td>
<td>α-Se</td>
<td>Y</td>
</tr>
<tr>
<td>Siemens</td>
<td>Inspiration</td>
<td>85</td>
<td>24 x 30</td>
<td>2800 x 3518</td>
<td>13</td>
<td>α-Se</td>
<td>Y</td>
</tr>
<tr>
<td>Planmed Oy</td>
<td>Nuance</td>
<td>85</td>
<td>17 x 24 24 x 30</td>
<td>2816 x 3584</td>
<td>13</td>
<td>α-Se</td>
<td>Y</td>
</tr>
<tr>
<td>IMS</td>
<td>Giotto</td>
<td>85</td>
<td>24 x 30</td>
<td>2816 x 3584</td>
<td>13</td>
<td>α-Se</td>
<td>Y</td>
</tr>
<tr>
<td>Fujifilm</td>
<td>AMULET</td>
<td>50</td>
<td>18 x 24 24 x 30</td>
<td>4740 x 5928</td>
<td>14</td>
<td>α-Se with DOS Technology</td>
<td>Y</td>
</tr>
<tr>
<td>Scanning systems</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Philips</td>
<td>Microdose</td>
<td>50</td>
<td>24 x 26</td>
<td>4915 x 5355</td>
<td>16</td>
<td>Si quantum counter</td>
<td>N</td>
</tr>
<tr>
<td>XCounter</td>
<td></td>
<td>50</td>
<td>24 x 30</td>
<td>4800 x 6000</td>
<td>16</td>
<td>Pressurized gas</td>
<td>N</td>
</tr>
</tbody>
</table>
1. X-RAY SOURCE

Normally the limiting factor governing spatial resolution in digital mammography should be the detector. The X ray source should have a focal spot that does not significantly degrade spatial resolution at the top surface of the breast beyond that determined by the detector. The heat loading capability of the source should be sufficient to support the required maximum daily throughput of the facility. This may be greater than that using screen-film mammography and may vary depending on whether diagnostic or screening mammography is being carried out. Typically scanning systems impose a higher heat loading on the X ray tube compared with the ‘snapshot’ systems discussed in the next section.
2. IMAGING GEOMETRY

There are two major acquisition geometries, “snapshot” and scanning systems.

Snapshot systems acquire the image using a full-area detector (that is, with dimensions equal to those of the projected imaged area) and a single, brief X ray exposure. Because of the single acquisition, no stitching operation is necessary, thereby eliminating the possibility of registration artefacts. Additionally, the rate at which multiple images may be produced can be important for screening mammography where the volume of examinations is high and possibly for future procedures that involve a rapid series of images.

Scanning systems use detectors that move across the breast in synchrony with one or more slit- or slot-shaped X ray beams. While these systems typically take many seconds to acquire the image, they do not require an anti-scatter grid and this generally provides a dose reduction advantage compared to the snapshot systems. Motion artefact with these systems is not evident as a blur, because any given area is imaged with a very short exposure time and high x-ray intensity. The need to scan the detector results in higher heat loading on the tube than for a snapshot image.

Other key geometric considerations are the detector size(s), thickness of the detector assembly and ability to image close to the chest wall. For smaller detectors, it may frequently be necessary to make several exposures to cover a single large breast. If exposed regions overlap the breast dose will increase. In addition, the radiologist will be faced with manipulating and interpreting more images. If the detector assembly is too large or too thick, it may be more difficult to position the breast and obtain optimal imaging of some women. It is always important to ensure that the detector has minimal “dead area” on the edge proximal to the patient’s chest wall so as little tissue as possible will be excluded from the mammogram.
3. TYPES OF DIGITAL MAMMOGRAPHY SYSTEMS

TYPE 1 – FLAT PLATE CS(I) WITH PHOTODIODE ARRAY

In these systems a CsI(Tl) phosphor layer is deposited directly onto a large-area matrix of photodiodes formed on a flat plate amorphous silicon substrate (Figure 1). Each light-sensitive diode element is connected by a thin-film transistor (TFT) switch to a series of control lines and data lines such that the charge produced on the diode in response to light emission from the phosphor is read out and can be digitized. On such systems, the initial signal forming the DICOM “for processing” image is linear with the amount of energy absorbed by the phosphor (subsequent nonlinear transformations are usually performed on the images – see the section on image processing later in this chapter).

Figure 1: The indirect flat plate detector based on a CsI scintillator with α-Si switching diodes or TFT-read out. The X rays absorbed in the CsI layer are first converted to light which is then converted to a charge signal by the photo-diodes and ultimately digitized.

TYPE 2 – FLAT PLATE AMORPHOUS SELENIUM WITH ELECTRODE ARRAY

This system does not employ a phosphor. Instead, X rays are absorbed in a layer of amorphous selenium, which is deposited on an array of electrodes formed on a large area amorphous silicon substrate (see Figure 2). An electric field is imposed across the plate to collect the electron-hole pairs liberated upon X ray absorption. The charges drift to the electrode pads and are collected there. During the readout procedure, TFT switches on each del are sequentially activated, one row at a time via control lines and the charge is collected along data lines (running between columns of dels) connecting each detector element to readout electronics, similar to those in a Type 1 system [64]
Figure 2: The direct flat plate detector utilizing α-Se as the X ray absorber. When a voltage is applied across the α-Se layer, the charges produced are collected by the electrodes and digitized.

TYPE 3 – SLOT SCANNING PHOTON COUNTING DETECTOR

In this system, the energy of absorbed X rays is converted to charge in a set of many single-line detectors based on depleted crystalline silicon or on high pressure gas ionization strips. The charge arising from the absorption of an individual X ray photon is collected to form a pulse, which is counted to register that X ray. Individual linear detector arrays are arranged adjacently or spaced apart and the assembly is scanned in a direction orthogonal to the detector lines to acquire the image (see Figure 3).
Figure 3: Philips Microdose Multi-slit scanning unit. Narrow slit collimators define fan beams that image part of the breast. Post breast collimators further reduce the impact of scatter. The multi-slit device moves across the breast ensuring that all breast tissue is imaged. The crystal-Si detector elements are also unique in that they collect and record the energy from individual x-ray quanta.

GENERAL COMMENTS ABOUT THE EQUIPMENT TYPES

One important consideration in equipment purchase is the rate at which images can be acquired. Some systems may require an extensive detector preparation cycle between images. The required interval is likely to change as technology evolves so it is important, especially in high volume facilities, to establish from the vendor what the inter-image time is.

System performance, in terms of spatial resolution, starts with the effective size of the del and the spacing between dels or “pitch”. The effective size or aperture can be smaller than the pitch if part of the del is insensitive to X rays. In the case of flat panel detectors, this is the “real estate” occupied by the switches and the readout lines, resulting in a reduced “fill factor” and directly influences the efficiency of use of the incoming X rays. A smaller aperture causes the image to be sharper, but can cause a reduction in detector sensitivity and can result in information being missed. When the aperture is smaller than the pitch, undersampling occurs and a phenomenon called “signal aliasing” is more likely to be observed. Aliasing causes information to be incorrectly rendered in the image, both suppressing some spatial frequencies and giving the impression of signal information that doesn’t actually exist. Noise aliasing is a similar process that causes an increase in the apparent image noise. In most current digital mammography systems, signal aliasing is not clinically apparent, while noise aliasing may be measurable.

The effective aperture can also be larger than the pitch. This can be due to blurring by
spread of light in a CsI phosphor. In this case the image may be less sharp, however, one possible benefit of this blurring is the reduction of aliasing. This phenomenon may be important in considering differences in performance between direct conversion and phosphor-based systems. In the former, the effective del aperture is more likely to be close to the pitch, giving rise to an inherently sharper image with more aliasing, whereas in the latter, the larger effective aperture caused by slight blurring may result in the opposite being true, so there may be a trade-off between sharpness and noise.

AUTOMATIC EXPOSURE CONTROL (AEC) ON DIGITAL MAMMOGRAPHY SYSTEMS

There are several differences in the design of the AEC in digital units compared with those used with analogue mammography X ray units. First, the dose to the detector no longer must be constrained to the relatively narrow range suitable for screen-film. Thus, doses can be lower or higher and can be widely varied as required, according to the breast thickness. This extra freedom also extends to the choice of the technique factors such as kV, target and filter materials. Generally, digital systems will select X ray spectra that are more penetrating than would be the case with screen-film systems. This is possible because the loss of subject contrast may be compensated by enhancement of displayed contrast during image viewing as well as by additional computer image processing. As well, if desired, greater detector dose can be used leading to better image noise characteristics.

It is important to understand that once the dose is increased beyond a noise-limited image, the image provides very little subjective indication that the dose is excessive, and “dose creep” may well result in long term increases beyond optimal levels.

Most DR systems use a measurement of the compressed thickness (produced by a sensor in the compression mechanism) to choose some of the technique factors (e.g., kV, target, filter) to be employed in the exposure. Further, some DR units use a trial exposure to determine the transmission through the breast. The image from this trial exposure may or may not be incorporated into the resultant image formation and/or included in the specified post exposure mAs. In a further refinement of this approach to determining the exposure factors some DR systems use sophisticated AECs that identify the area of greatest attenuation within a defined area of the detector during this trial exposure. This is then used to select an appropriate kV, filtration and sufficient exposure to achieve a pre-determined pixel value, contrast or detector dose set by the manufacturer. As a result, the dose received by inhomogeneous real breasts and the image quality may not be easily predictable from measurements of such physical quantities as signal difference to noise ratio (SDNR) and mean glandular dose (MGD) obtained using uniform blocks of PMMA.

STANDARD IMAGE FORMATS

To facilitate inter-compatibility of digital images, The Digital Imaging and Communications in Medicine (DICOM) Committee have created a standard for digital
medical images. This standard has specific provisions, known as “DICOM MG” for digital mammograms. DICOM conforming images contain a header that provides general information describing the characteristics of each image, followed by the image data. Some CR products use the CR DICOM header which may or may not include all of the required information for proper workflow on IHE compliant Mammographic workstations.

Two types of DICOM image formats have been defined for mammography (see Figure 4). The DICOM “for processing” image is the image initially provided by the detector. Some basic corrections for detector non-uniformity and possibly detector blurring have been applied to these images. These images can then be processed to create DICOM “for presentation” images which are suitable for display on a monitor or for printing.

![Figure 4: Concept of the DICOM “for processing” and “for presentation” formats.](image)

**IMAGE PROCESSING**

Image processing is an important feature of all digital mammography systems and processing operations may be applied at several stages of image formation (see Figure 4).

**DICOM “for processing” image**

The initial operations that take place in creating the “for processing” image generally include a “flat-field” or gain correction, where spatial non-uniformity in the detector...
sensitivity can be corrected by imaging a uniformly-attenuating object and creating a gain map that can be used to correct all subsequently-acquired images. For flat panel systems and scanning systems, this transformation corrects for non-uniformities in the X ray field (e.g., heel effect) as well. Presence of the uncorrected heel effect in digital images can affect the results of image noise measurements in QC [1]. Other corrections that can occur at this stage include:

1. Partial correction for detector blurring through image processing by de-convolving the blurring function of the detector. This procedure can be very effective, but if overdone will also enhance image noise. It is therefore important that the inherent detector resolution be adequate and that the image noise level is acceptable. The latter is accomplished in part through careful design of low-noise detectors and also through appropriate design and use of automatic exposure control and/or automatic technique control.

2. Removal of “bad” pixels. If a single detector element is defective, its signal can be replaced by some weighted combination of signals from adjacent dels. This is acceptable if the defective dels are isolated and few in number, but is of greater concern if signals from entire patches or lines of the detector are absent or incorrect. Manufacturers specify the number and type of such defects that are acceptable.

**DICOM “for presentation” image**

Additional processing is generally carried out to adapt the image for display and interpretation by the radiologist. Processing operations differ among manufacturers, but may include:

1. Peripheral compensation to flatten the signal level at the edge of the breast. This essentially suppresses the effect of thickness reduction near the edge and reduces the dynamic range of image signal that the display system must accommodate, allowing higher contrast settings to be used in image display. It is important that when such software is used it does not unduly distort the contour of the breast.

2. Inversion of the grey scale (black represents high X ray transmission) and nonlinear transformation (logarithm, square root, etc.) of the image.

3. Background suppression and masking.

4. Other image enhancements, for example histogram equalization. These are also employed to attempt to optimize contrast throughout the image of the breast and best utilize the limited dynamic range of the display system.

Image enhancement techniques are proprietary to each vendor and frequently can be applied or not at the user’s discretion. The best way to evaluate these algorithms is to observe the rendition of key structures (spiculations, microcalcifications and margins of benign and malignant lesions), with and without the enhancement activated, in a series of
sample cases including images of both dense and fatty breasts. It is also important to
know whether the results of image processing are only available locally at the viewing
workstation or whether they are preserved so that the enhanced image can be viewed
elsewhere.

DISPLAY SYSTEM

The display system plays a major role in influencing overall performance of the digital
mammography unit, in terms of both the ease of image interpretation and the image
quality presented to the radiologist [90]. While some radiologists use hard copy systems
(laser-printed films) for interpretation, in the long term, the benefits of digital
mammography and cost effectiveness will only be fully realized if soft copy display is
used.

Softcopy displays

Flat panel LCD displays are more compact and produce far less heat than the
conventional cathode ray tube (CRT), however they have a more limited viewing angle
than CRTs. The display must have a suitable number of high quality monitors (normally
two 5-megapixel (5MP) monitors are recommended) [92] to allow viewing of as much of
the mammogram as possible at the required resolution level. A 5MP monitor is capable
of displaying only a single mammogram with 100 μm dels at full resolution. If multiple
images or images with smaller dels are displayed simultaneously, as is normally the case
in mammography, then they will have to be viewed at reduced resolution and then the
images panned and zoomed to inspect structures of interest at full resolution.

The monitor on the acquisition station is often overlooked. Generally, a single 3MP
monitor is recommended. The quality must be high enough to allow the radiographer to
assess the adequacy of the acquired image without having to walk to the radiologist’s
workstation that may be located a considerable distance away. If needle localizations are
to be performed on the system, the image quality on this monitor and image manipulation
operations must be adequate to provide the required image quality.

Display software varies greatly between system types and is a major factor determining
user satisfaction with the digital mammography system where there is a natural tension
between the intellectual property interests of manufacturers and the need for seamlessly
integration between different systems. Some important points in monitor software
consideration include; (i) how convenient are basic image manipulation operations
especially for those that will be used with every image, (ii) what is the flexibility of
image hanging protocols and (iii) can the system handle images acquired on another
vendor’s system and display them acceptably well. These issues, particularly the last,
have taken on greater significance as digital mammography becomes more widely
accepted with facilities increasingly purchasing multiple acquisition units. To address
these issues, the IHE group [58] is developing guidelines and standards in the form of an
“Integration Profile” for image display and intersystem compatibility for mammography.
Future purchases should comply with this profile. Ongoing activity in this is a rapidly
moving area, can be seen at the IHE website (http://www.ihe.net). In a screening situation, automatic fetching and display of prior images is highly desirable and increases efficiency. Image annotation (patient name etc) must be displayed in a position such that it does not obscure the breast image.

III. ARTEFACTS

While the incidence of artefact on digital mammographic images is typically less than with film based mammography, artefacts can be produced on digital systems. This section provides a pictorial catalogue of some of the more common digital artefacts. More complete treatments may be found in the literature [104].

The process of ‘flat fielding’ is necessary to avoid machine-related non-uniformity of the image brightness or ‘drop out’ from defective pixels (see Figure 5). Other detector related artefacts include; electronics failure (Figure 7 and Figure 8), detector crystallization (Figure 11) and image lag (Figure 12).

Figure 5: A cluster of defective pixels (white arrow) is barely discernible in an image of a breast taken using magnification mammography. When electronically zoomed,
as in the insert, the cluster is clearly evident. The detector “dead del” map may need to be updated depending on the number of pixels or ‘dels’ implicated. In more extreme cases the detector may need to be replaced.

Figure 6: The top image is of a uniform QC test object displayed with a narrow window acquired with an early model scanning digital mammography unit and demonstrates linear registration artefacts shown with arrows. These arise from the image reconstruction method and are not regarded as clinically significant. The lower image, illustrating part of the same test object, indicates a more serious issue of an electronic [Application Specific Integrated Circuit (ASIC)] failure.
Figure 7: The image on the left demonstrates an odd looking well defined artefact which, when electronically zoomed, looks like a step wedge embedded in the breast. The direct cause of the artefact is a failure of an Application Specific Integrated Circuit (ASIC). In this case the fundamental cause was a failure of the room air conditioning, which allowed the temperature at the detector to exceed allowed tolerance.
Figure 8: An obvious example of an ASIC failure in an a-Se detector. Fortunately, in this instance it occurred near the nipple edge and not the chest wall so that the images of this patient did not require repeating.

Figure 9: An image of the ACR accreditation phantom on the left indicates additional detail in the form of a vertical line running parallel to the chest wall. Closer examination, using electronic zoom on the right, more clearly demonstrates that a line of detector elements has failed necessitating detector replacement.
Figure 10: The left hand image is part of an artefact free flat field image taken in contact mode. This should be compared with the magnification image on the right acquired subsequently with the same target/filter combination. A number of subtle dimple like artefacts are apparent. These are attributed to the flat field map acquired in contact mode not being able to correct for the difference between the grid environment and that with the magnification table in place.
Figure 11: Detector crystallization. (a) The arrows top left indicate a subtle artefact in the MLO image which appears to mimic calcification. (b) The subsequent MLO view of the other breast indicates that the artefact is in fact caused by the a-Se detector beginning to crystallize. The window and level in this image have been adjusted to highlight the problem. (c) A more obvious and serious example of a-Se detector crystallization is apparent in this image (see arrows).
Figure 12: The left image is a standard CC view of a breast and the right image is the MLO view acquired immediately afterwards. As indicated by the arrows, the CC view is still evident in this latter image. This is a totally unacceptable example of a-Se detector image lag and is caused, in this instance, by the room temperature not being high enough to maintain the detector temperature at the required level.
Figure 13: Image acquired with a uniform PMMA test object illustrates area of very slightly decreased detector sensitivity outside the region normally occupied by the compressed breast. Note that in this “processed image” a high pixel value would normally imply lower dose. This is often referred to as “ghosting” and is caused by the detector retaining a history of previous exposures and ultimately suffering minor radiation damage where it has intercepted the primary un-attenuated X ray beam. This particular example is not considered clinically significant because the image has been displayed with a very narrow window width and the difference in the pixel values (1466 versus 1452) in the two regions is minimal.
Figure 14: Two examples of image of a large uniform PMMA QC test object acquired immediately after an earlier image had been acquired with a slab of PMMA that covered only a part of the detector demonstrates image persistence or lag. The window width is extremely narrow as demonstrated by the small difference in pixel values in the regions within and outside the smaller slab. In either case, this is not regarded as clinically significant.

Extreme examples of motion blurring may still occur as exemplified by Figure 15. If the technologists do not view the images closely or fail to use the zooming tool, more subtle motion blurring may be missed, especially if the monitors on the digital acquisition workstation are of lower spatial resolution than those used by radiologists (see Figure 16).
Figure 15: An extreme example of motion artefact. In this instance caused by a CR cassette not being firmly locked in the cassette holder when the MLO view was acquired.
Figure 16: A more subtle example of a motion artefact is shown in the left hand images. The artefact was observed on the radiologist’s reporting workstation but only became apparent when electronic zoom was utilized on the acquisition workstation. The repeated image shown on the right demonstrates the calcification
more sharply.

Talcum powder may mimic calcification as illustrated in Figure 17 and calcifications on the skin may be misinterpreted as being in the body of the breast in some circumstances (Figure 18).

![Image of artefacts mimicking calcification caused by talcum powder](Image)

Figure 17: Artefact mimicking calcification caused by talcum powder is clearly evident in left hand image (arrows). The subsequent image on right, after removal of powder, is devoid of artefact. Similar artefacts may also arise from zinc powder on the skin.
Figure 18: Right CC image, illustrated on left, appears to demonstrate calcification (arrows) in body of breast. The right MLO image, shown on right with nipple in profile, is apparently devoid of calcifications. Calcifications are in fact located on the skin around nipple.

Although not unique to digital mammography and not strictly an artefact, poor collimation can result in large amounts of tissue being missed as illustrated in Figure 19.
Figure 19: An example of poor collimator adjustment. In this magnification view the collimator has not been adjusted by the service organization to allow the entire detector to be irradiated leaving a marked white border on the bottom and right margins of the image. Apart from being disconcerting for the radiologist interpreting the study, this allows an unacceptable amount of breast tissue to be missed, most seriously on the chest wall.

Finally, images must be checked before a case is closed in order to avoid mislabeling of images that cannot be corrected later. If the image processing for peripheral equalization is not performed well, then a “breast within a breast” appearance can be produced.
IV. FFDM QUALITY CONTROL TESTS

NOTES:

The following tests are designed to be performed using an excel spreadsheet for data collection. The majority of image acquisition information is initially collected in two tables (Table A – Raw Image Acquisition and Table B – Processed Image Acquisition). The information in these tables populates the various charts where the images are analyzed.

Except where explicitly indicated, images should be acquired in a “Raw”/”For Processing” mode, where any user-selectable post-processing options and/or image enhancements are turned off. This maintains a clearer relationship between pixel values and incident x-ray exposure to the detector.
1. **PROCEDURE: MAMMOGRAPHY UNIT ASSEMBLY EVALUATION**

**OBJECTIVE**

To ensure that all locks, detents, angulation indicators, and mechanical support devices for the X-ray tube and breast support assembly are operating properly, and that the DICOM image file headers are correctly populated.

**APPLICABILITY**

This procedure applies to all full-field digital mammography systems.

**TEST FREQUENCY**

Equipment evaluations, semi-annually

**REQUIRED TEST EQUIPMENT**

- thermometer
- 4 cm thick phantom, such as the site’s Digital Mammography Uniform Phantom (DMUP)
- set of scales or compression test tool
- lead, 2 mm stainless steel or other highly attenuating material

**TEST PROCEDURE STEPS**

1. Measure the temperature in the mammography acquisition room.

2. Verify that the freestanding dedicated mammography unit is mechanically stable under normal operating conditions.

3. Visually inspect the unit for loose parts, cracks in the compression paddles, compressor and bucky cleanliness and overall integrity.

4. Check that all hoses and cables are free from breaks, crimps or knots. Hoses and cables should not be under other heavy equipment.

5. Verify that all moving parts move smoothly, without undue friction; that cushions or bumpers appropriately limit the range of available motions; and that no obstructions hinder the full range of motions within these limits.

6. Set and test each lock and detent independently to ensure that mechanical motion is prevented when the lock or detent is set.

7. Verify that angulation indicators function correctly.

8. Verify that the image receptor holder assembly is free from wobble or vibration during normal operation.
9. Verify that it is possible to override the auto-decompression so that compression can be maintained (for procedures such as needle localizations) and its status displayed continuously (if auto-decompression is available).

10. Verify that compression can be manually released in the event of a power failure or automatic release failure. This verification can be done by reference to type testing data for the same model. (In the type testing, the power to the equipment would be turned off with a phantom under compression and then the manual compression control would be used to release the compression).

11. Verify that, in normal operation, the patient and operator are not exposed to sharp or rough edges or other hazards including electrical hazards.

12. Verify that all panel switches, indicator lights and meters are working properly. Controls, meters, lights and other indicators must be readily recognizable and clearly identifiable as to function. There must be some indication when the machine is energized and ready to produce x-rays (tube spun up) and when x-rays are being produced. The selected technique factor(s) must be visible to the operator before the patient is irradiated in manual mode, and in AEC mode, the kV, mAs, target and filter must be displayed immediately after the exposure.

13. Verify that the operator is protected by adequate radiation shielding during exposure. Ensure that the x-ray switch cannot easily be operated without standing behind the shielding. The switch must require continuous pressure by the operator to produce x-rays.

14. Verify that current and accurate technique charts for 50/50, dense and fatty breasts are posted and confirmed by consulting with the mammography technologist.

15. Using a set of scales or a compression test tool, verify that the maximum compression applied under powered drive is at least 15 daN (33 lbs) and less than 20 daN (45 lbs), and that the maximum compression that can be applied by the technologist is at least 15 daN (33 lbs).

16. Verify that the unit’s AEC or back-up timer terminates exposures before a maximum exposure of 2000 mAs is reached. This is most easily done by putting lead, 2 mm of stainless steel or other highly attenuating material in the beam to ensure the AEC aborts the exposure. An error message or reset light must indicate that the exposure has aborted to avoid exceeding the 2000 mAs limit. On most systems the exposure will be aborted with less than a 5 mAs exposure.

17. On any randomly selected patient image verify that displayed or printed images contain the correct institution name and address, unit number (if more than one at the site), patient name, patient ID number, technologist’s initials, projection, laterality and technique factors (kV, mAs, anode, filter), and that the time of image acquisition and the date are correct (Note that after software upgrades, the stored time zone or other data may have changed and be incorrect). This can be
accomplished by looking at the information included with the image on the review workstation or on printed films, if available or by looking at the contents of the DICOM header of an image with appropriate analysis software. Patient images must not be exported, except as anonymized images. Record that the values of displayed information are complete or note necessary changes on Chart 1-B.

18. Record the pass or fail of each inspection item on Chart 1.

**REQUIRED.** A permanent identification (ID) label or DICOM header which contains at least the following information: **facility name, facility location** (at a minimum the location shall include the **city, province and postal code**), **patient name (first and last)**, and **additional patient identification number** (e.g., medical record number or social security number; date of birth is less desirable), and the **date of the examination**.

---

**OBSP REQUIREMENTS:**

Mammographic image identification. Each mammographic image shall have the following information on it in a permanent, legible, and unambiguous manner and placed so as not to obscure anatomic structures:

(i) Name of patient and additional patient identifier.
(ii) Date of examination
(iii) View and laterality. This information should be placed on the image near the axilla. Standardized codes specified by the accreditation body shall be used to identify view and laterality.
(iv) Facility name and location. At a minimum, the location shall include the city, province, and postal code of the facility.
(v) Technologist identification
(vi) Mammography unit identification, if there is more than one unit at a facility.

---

**RECOMMENDED PERFORMANCE CRITERIA AND CORRECTIVE ACTION**

Room temperature should be in the range recommended by the manufacturer, never exceeding 30°C or going below 10°C, with tighter limits for patient comfort of 19°C – 25°C. If the radiographer indicates that the temperature sometimes falls outside of this range, a monitoring program should be established, to prevent premature failure of the equipment.

The digital mammography unit must be safely installed, and present no undue hazards.

Items that are hazardous, inoperative, or operate improperly should be repaired by appropriate service personnel.

<table>
<thead>
<tr>
<th>Manufacturer/System</th>
<th>Temperature Range</th>
<th>Humidity Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>GE Essential</td>
<td>15°C - 35°C</td>
<td>10% - 80%</td>
</tr>
</tbody>
</table>

OBSP Digital Mammography QC-Physicist-Rev 3.2-Final.doc

March 31 2014
<table>
<thead>
<tr>
<th>Equipment</th>
<th>Temperature Range</th>
<th>Humidity Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>GE DS</td>
<td>15°C - 35°C</td>
<td>40% - 75%</td>
</tr>
<tr>
<td>Hologic Selenia</td>
<td>10°C - 30°C</td>
<td>10% - 80%</td>
</tr>
<tr>
<td>IMS Giotto</td>
<td>15°C - 35°C</td>
<td>10% - 75%</td>
</tr>
<tr>
<td>Philips MammoDiagnost</td>
<td>10°C - 37°C</td>
<td>30% - 75%</td>
</tr>
<tr>
<td>Philips Microdose</td>
<td>10°C - 30°C</td>
<td>30% - 75%</td>
</tr>
<tr>
<td>Planmed Nuance</td>
<td>15°C - 28°C</td>
<td>25% - 80%</td>
</tr>
<tr>
<td>Siemens Inspiration</td>
<td>12°C - 37°C</td>
<td>30% - 75%</td>
</tr>
</tbody>
</table>

**TIMEFRAME FOR CORRECTIVE ACTION**

Immediately, before any further patients are imaged, for all items except items 2, 5, and 7. For these latter items corrective action must be taken within 30 days of the test date.
2. PROCEDURE: COMPRESSION FORCE AND THICKNESS ACCURACY

Adequate compression is essential for high-quality mammography. Compression reduces the thickness of tissue that must be penetrated by radiation, thereby reducing scattered radiation and increasing contrast, while reducing radiation exposure to the breast. Compression improves image sharpness by reducing the breast thickness, thereby minimizing focal spot blurring of structures in the image, and by minimizing patient motion. In addition, compression makes the thickness of the breast more uniform, resulting in more-uniform image densities and an image that may be easier to interpret. The displayed compressed breast thickness is often used to choose the technique factors so that it is important that this level of accuracy be achieved.

OBJECTIVE

To check that the mammography system provides an adequate compression in manual and automatic mode. To check the accuracy of the compression force indicator if present on the equipment. To check the accuracy (or deviation) of the compression thickness indicator.

APPLICABILITY

This procedure applies to all full-field digital mammography systems.

TEST FREQUENCY

Equipment evaluations, semi-annually

REQUIRED TEST EQUIPMENT

Slabs of PMMA used for AEC testing (to make thickness of 20, 45 and 70 mm)
Spacer material used for AEC testing (to make thicknesses of 53 and 90 mm)
Foam compression test tool
OR
Bathroom scales
Bath towels (cloths) or blocks of rubber foam

TEST PROCEDURE STEPS

Power Compression Mode

1. Place a bath towel on the Bucky and the platform scale over it. Centre the scale directly under the compression paddle (see Figure 20).

2. Place one or more towels (or block of rubber foam) on the scale in order to protect the compression paddle such that it does not obscure the reading on the scale
3. Activate the compression paddle so that it operates and stops at the maximum available powered force. This may require a second activation of the compression foot pedal.

4. Read the value of the compression force on both the scale and the machine readout and record this in Chart 1 – “Full Field Digital Mammographic Unit Assembly Evaluation”

5. Release the compression.

**Manual Mode**

1. Using the manual compression mode, move the compression paddle until it stops.

2. Read and record the compression force on the data collection sheet.

   **Note that provided the machine compression readout was found to be sufficiently accurate when evaluating the power compression mode, it can be used to assess the maximum available manual compression.**

3. Release the compression.

**Compression Thickness**

   **Note that the thicknesses used for this test are identical to those used for the AEC Evaluation (Test Procedure 4), and thus this portion of the test can be combined with acquiring the images used in AEC evaluation.**

1. Align the PMMA blocks (20, 45 and 70 mm) with the chest wall edge of the breast support platform.

2. When evaluating with the 45 mm thickness of PMMA add the 8mm spacer to achieve a total thickness of 53 mm. When evaluating the 70 mm thickness of PMMA add the 20mm spacer to achieve a total thickness of 90 mm.

3. In some systems, the breast thickness indicator is calibrated by the manufacturer, taking into account the tilt of the compression plate. In this case, the actual dimension of the PMMA slabs should allow the paddle to tilt during testing. Special care should be taken not to compress too much since when this tilting occurs, the greater the compression force, the higher the indication of PMMA thickness.

4. Apply a compression force used in the clinical setting (e.g.80 N). Record the force value. Once the applied force for this measurement has been established, the same force is used for all subsequent measurements.
5. Compare the displayed thickness value to the actual thickness of the slab (and spacer if applicable).

6. On systems where the radiographic factors (automatically selected by the system) depend on the compressed thickness, repeat the measurements in magnification mode.

**Note:** If using metric scales, one must convert from kg to N by applying the acceleration due to gravity. On earth, kilogram-mass = 9.81 newtons.

**Figure 20:** Positioning of bathroom scale to perform compression force measurement.

**RECOMMENDED PERFORMANCE CRITERIA AND CORRECTIVE ACTION**

1. The maximum compression force for powered compression should be no less than 150 N and no greater than 200 N.

2. Maximum manual compression force < 300 N.

3. Displayed value accuracy: ±20 N.

4. Acceptable: Displayed thickness within ±8 mm of slab thickness
   Achievable: Displayed thickness within ±5 mm of slab thickness.

**TIMEFRAME FOR CORRECTIVE ACTION**

If the force measurement is outside the tolerance, the problem should be corrected immediately, before any further patients are imaged. If the thickness indication is outside
of tolerance, the problem should be corrected at the next regular servicing.
3. PROCEDURE: TECHNIQUE CHART / AEC EVALUATION

OBJECTIVE

To evaluate the ability of the system to image a clinically expected range of breast thicknesses and to ensure that images of adequate penetration and acceptable signal difference–to-noise-ratio (SDNR) levels are produced.

To establish the baseline values to be used by the site for the weekly SDNR check.

To determine the imaging technique factors required for the estimation of mean glandular dose.

To establish the imaging technique and viewing parameters to be used by the site for their monthly full-field artefact check.

APPLICABILITY

This procedure applies to all full-field digital mammography systems.

TEST FREQUENCY

Equipment evaluations, semi-annually.

TEST PHANTOM REQUIREMENTS

Three slabs of PMMA: one that is 20 mm thick and two of 25 mm thickness. Dimensions should typically be at least 10 cm × 20 cm.

A contrast object – This could be a 1 mm thick, 25 mm diameter depression in the 20 mm PMMA slab (it must have a flat, smooth bottom) or a 1 mm thick, 25 mm diameter PMMA disc.

Appropriate spacers (e.g. Radiolucent U-shaped rigid expanded polystyrene of thicknesses as given in Table 4 to set compression paddle position). These spacers are required to simulate breast thicknesses for dosimetry purposes and to test the AEC (45 mm of PMMA plus a 8 mm spacer simulates a “standard” breast, 53 mm thick, while PMMA 70 mm thick plus a 20 mm thick spacer simulates a 90 mm thick “large” breast of typical composition [19]).

Table 4: Spacer thickness required to match PMMA thickness to a breast of equivalent thickness

<table>
<thead>
<tr>
<th>Breast type</th>
<th>Equivalent breast thickness (mm)</th>
<th>PMMA thickness (mm)</th>
<th>Spacer thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>thin</td>
<td>21</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>standard</td>
<td>53</td>
<td>45</td>
<td>8</td>
</tr>
<tr>
<td>thick</td>
<td>90</td>
<td>70</td>
<td>20</td>
</tr>
</tbody>
</table>
**Figure 21: Two layers of thickness tracking phantom with contrast disc.**

**TEST PROCEDURE STEPS**

1. Create a “patient” study with an appropriate name.

2. This image should be saved in the “for presentation” format to use to enter data on the technologist baselines sheet.

3. Stack the 20 and 25 mm PMMA slabs, with the contrast disc or square on their upper surface on the breast support such that the contrast object lies on the centreline of the breast support, approximately 30 mm from the chest wall edge as shown in Figure 21. Ensure that the front edge of the PMMA slab extends slightly (a few mm) beyond the chest-wall edge of the breast support. Use collimation that allows the full detector area to be exposed.

4. Lower the compression plate and apply the compression force typically used clinically (e.g. 80 N).

5. If the AEC detector location can be adjusted, it should be placed within 1 cm of the chest wall.

6. Choose the exposure mode used clinically. On initial commissioning, all available automatic modes should be tested. For systems that are not fully automatic, set the AEC or kV, target and filter to the appropriate technique for the equivalent breast thickness in TABLE 11.
7. Make one exposure, and record the kV, target, filter and mAs on Chart 5 –Breast Entrance Exposure and Mean Glandular Dose. These exposure factors are required to determine the incident air kerma, in Procedure 6, which in turn is used to calculate the mean glandular dose.

8. The values for the 45 mm test object should also be entered into Chart 9- Noise and Linearity where they are used to determine the reference technique.

9. Leaving the contrast disc or square in the same location, make exposures using the AEC, using 20 mm , 45 mm and 70 mm total thickness of PMMA. Each time, place the appropriate spacer above the uppermost slab (see Table 4).

10. Either display the images in “for processing” format on a workstation equipped with analytical tools (ROI, mean, standard deviation) or download the “for processing” images to a separate computer for analysis. Advice on how to download images can be obtained from the manufacturer or found on the website, http://humanhealth.iaea.org

11. View the unprocessed images taken at the three thicknesses with the image displayed so that the contrast object is clearly visible (see Figure 22).
Figure 22: ROIs in the image of a uniform test object with contrast disc used to calculate the signal difference to noise ratio.

12. According to the contrast object used, place a circular or square region of interest (ROI) approximately 0.8 cm$^2$ in area (~1 cm in diameter) over, and entirely contained within the contrast object area. Use the same size (or as close to as possible) ROI each time (for further information on choice of the ROI size, refer to Alsager et al 2008 [1]).

13. Measure the mean pixel value (MPV), recording it as A.

14. Choose an ROI located just beside the contrast object, and measure the background MPV, B, and the background standard deviation, C.

15. Enter results in Chart 2 and the “Radiographer Baselines and Summary” page (if applicable).
16. Calculate the signal difference to noise ratio (SDNR) as:

\[ \text{SDNR} = \frac{|A-B|}{C} \]

17. For a system equipped with multiple dose modes, at commissioning, the above procedure should be repeated for each of the applicable modes, recording the SDNR in each case.

18. For the 45 and 70 mm exposures, determine the exposure time either by direct measurement or by dividing the mAs required for the exposure by the mA from the manufacturer’s technical information for the system.

**Testing of density control (if applicable) and/or dose selection mode**

Some digital units have a variable “density control”. In digital mammography, the purpose of the density control is primarily to allow control of the image noise level. Small changes are not normally perceptible. It is desirable that use of the density control will allow the radiation dose to be increased by 25-100% from the “0” or “normal” position and similarly decreased by 25-50% in several steps.

1. Place a total thickness of 45 mm PMMA (plus the spacer) on the breast support as described above.

2. To test the +/- density control, if it exists, make exposures using the automatic exposure control. Use two density settings below the “0” or “normal” position, one at the “0” and two above, with each setting attempting to give about a ~25% variation in mAs. A total of 5 exposures is required for this test.

3. Record the density setting and the resulting mAs used to image the PMMA each time.

4. For DR systems, make exposures in all applicable dose modes and determine their effect on the exposure factors.

5. Record the dose mode setting and the resulting mAs used to image the PMMA each time.

6. It is not necessary to process the image after each exposure – the digital image itself will not be used. The objective is to ensure the density setting adjusts the mAs in a reasonable manner.

7. Provide a copy of the “Radiographer Baselines and Summary” page to the radiographer at the facility, to be used as a baseline for the Radiographer’s tests.

**DATA INTERPRETATION AND ANALYSIS**

1. The signal difference to noise ratio (SDNR) is calculated as:
SDNR = |A-B/C|

CALCULATION OF OPERATING POINTS AND LIMITS

The first image (of the DSB phantom, acquired in “for presentation” mode) is used to set the baseline for the technologist’s weekly SDNR.

1. Calculate the upper and lower mAs control limits. The mAs lower limit is 0.9 x target mAs. The mAs upper limit is 1.1 x target mAs.

2. Calculate the upper and lower ADU (signal) control limits. The ADU lower limit is 0.9 x target ADU. The ADU upper limit is 1.1 x target ADU.

3. Calculate the SDNR control limits. The SDNR lower limit is 0.90 x target SD NR. The upper limit is 1.1 x the target value.

4. Record the target values and upper and lower control limits on Technologists Baselines Worksheet.

RECOMMENDED PERFORMANCE CRITERIA AND CORRECTIVE ACTION

1. The SDNR values for images of 20, 45 and 70 mm of PMMA should exceed the acceptable values given in Table 5.

2. SDNR performance must be achieved within the dose limitations specified in Table 10.

3. The techniques chosen should not result in an exposure time greater than 5.0 s for 70 mm of PMMA and should be less than 2.5 s for a 45 mm PMMA slab. These time limits do not apply to scanning type systems.

For each thickness of PMMA, both acceptable and achievable SDNR values are provided in Table 5. These values must be regarded as provisional at this stage and further updates will be provided in future by reference to http://humanhealth.iaea.org Regardless of what the ultimate SDNR values are, it is expected that a DR system should be able to match the achievable SDNR using a dose that is well within the current dose tolerances provided in Table 10. In general, greater importance should be given to achieving adequate image quality rather than lowering the dose.

Caution should be exercised in interpreting the results of SDNR measurements. On any system it is expected that a higher SDNR corresponds to better image quality provided the image sharpness is unchanged. Thus an increase in radiation exposure will reduce quantum noise resulting in an increase in SDNR and better image quality if MTF is unchanged. However an increase in SDNR may be due to a deteriorating MTF which would result in an overall reduction in image quality. Thus SDNR is not on its own a reliable measure of image quality but is an easy to measure parameter that is a sensitive
indicator of changes that relate to image quality. Therefore any change in SDNR needs investigation to understand the cause.

**Table 5: Acceptable and achievable limits on SDNR used for AEC evaluation – 1mm thick PMMA contrast object**

<table>
<thead>
<tr>
<th>System</th>
<th>PMMA thickness (mm)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20</td>
<td>45</td>
<td>70</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Accept</td>
<td>Achiev</td>
<td>Accept</td>
<td>Achiev</td>
<td>Accept</td>
<td>Achiev</td>
<td></td>
</tr>
<tr>
<td>Fuji Amulet</td>
<td>2.1</td>
<td>3.4</td>
<td>1.8</td>
<td>2.9</td>
<td>1.5</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>GE 2000D</td>
<td>3.4</td>
<td>6.0</td>
<td>3.0</td>
<td>5.0</td>
<td>2.5</td>
<td>4.1</td>
<td></td>
</tr>
<tr>
<td>GE DS</td>
<td>3.4</td>
<td>5.6</td>
<td>2.7</td>
<td>5.0</td>
<td>1.7</td>
<td>2.2</td>
<td></td>
</tr>
<tr>
<td>GE Essential (FV On)</td>
<td>4.0</td>
<td>5.2</td>
<td>3.0</td>
<td>4.6</td>
<td>2.5</td>
<td>3.5</td>
<td></td>
</tr>
<tr>
<td>GE Essential (FV Off)</td>
<td>5.2</td>
<td>7.9</td>
<td>4.6</td>
<td>7.0</td>
<td>3.9</td>
<td>6.0</td>
<td></td>
</tr>
<tr>
<td>Hologic Dimensions</td>
<td>2.6</td>
<td>3.9</td>
<td>2.2</td>
<td>3.0</td>
<td>1.5</td>
<td>2.8</td>
<td></td>
</tr>
<tr>
<td>Hologic Selenia</td>
<td>2.6</td>
<td>3.9</td>
<td>2.2</td>
<td>3.0</td>
<td>1.0</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>IMS Giotto</td>
<td>2.9</td>
<td>4.6</td>
<td>2.6</td>
<td>4.0</td>
<td>2.1</td>
<td>3.4</td>
<td></td>
</tr>
<tr>
<td>Sectra D40</td>
<td>2.0</td>
<td>3.0</td>
<td>1.5</td>
<td>2.5</td>
<td>1.2</td>
<td>2.2</td>
<td></td>
</tr>
<tr>
<td>Philips Microdose</td>
<td>2.0</td>
<td>3.0</td>
<td>1.5</td>
<td>2.5</td>
<td>1.2</td>
<td>2.2</td>
<td></td>
</tr>
<tr>
<td>Siemens Novation DR</td>
<td>2.2</td>
<td>3.0</td>
<td>1.7</td>
<td>2.7</td>
<td>1.4</td>
<td>1.9</td>
<td></td>
</tr>
<tr>
<td>Siemens Inspiration</td>
<td>2.7</td>
<td>3.5</td>
<td>1.9</td>
<td>3.0</td>
<td>1.6</td>
<td>2.1</td>
<td></td>
</tr>
</tbody>
</table>

**Density Control**

1. The density control should allow the operator to make mAs adjustments as large as 25-100% upward from the “0” or “normal” position and 25%-50% downward.

**RECOMMENDATIONS FOR CORRECTIVE ACTION**

1. If the performance criteria for SDNR are not met, then the physicist should determine that the performance of the detector has not changed, using the methods described in Procedure 10: Noise and Linearity. If the detector is operating properly, the AEC should be adjusted or the technique chart should be revised as required.

2. If the density control does not provide the appropriate range of control, it should be adjusted.

**TIMEFRAME FOR CORRECTIVE ACTION**

For AEC evaluation, immediately, before any further patients are imaged. For density control, at the next regular servicing of equipment.
4. **PROCEDURE: ARTEFACT EVALUATION**

**OBJECTIVE**

To assess the degree and source of artefacts visualized in full-field digital mammograms or phantom images.

To ensure that the signal level and noise in the flat field image are uniform.

To establish the imaging technique and viewing parameters to be used by the site for their daily flat-field image and monthly full-field artefact check.

**APPLICABILITY**

This procedure applies to all full-field digital mammography systems.

**TEST FREQUENCY**

Semi-annually, after service to the X ray tube head, detector or modifications to the image acquisition or correction software.

**TEST EQUIPMENT REQUIREMENTS**

The uniform phantom OBSP DMUP used by the site for its daily and monthly full-field artefacts checks. See Figure 23.

A 25 mm phantom for magnification imaging.

The acquisition or radiologist’s workstation. Alternatively, images may be downloaded to another computer and analysed using image analysis software.

![Image of a uniform phantom suitable for artefact evaluation.](image-url)

**Figure 23:** Image of a uniform phantom suitable for artefact evaluation.
TEST PROCEDURE STEPS

1. Open a patient with the last name “Physics” and the first name “Artefacts”. The patient ID “9903UYYMMDD” may be used if it does not conflict with the hospital PACS or HIS/RIS systems.

2. Place the uniform phantom in the X ray field, either on the tabletop or suspended from the tube assembly, so that the front edge extends beyond the chest-wall edge of the breast support plate and also extends beyond each indicated edge of the image field. Leave the grid on for large-focal spot exposures and the most frequently used compression paddle in place for all images. Use collimation that allows the full detector area to be imaged.

3. Lower the compression paddle to be in contact with the test object or to a height of 45 mm above the breast support.

4. Use the exposure mode for a clinical image of a breast of equivalent thickness. This image should be saved in both the “for presentation” and “for processing” formats to use to enter data on the technologist baselines sheet.

5. Expose the image

6. Enter the imaging parameters on Table A. This will populate Chart 3, and the Technologist Baseline Chart.

7. Repeat steps 4-6 for all anode and filter combinations used in clinical practice, but only keeping the “for processing” format images. Use a manual (or AEC if possible) exposure technique that result in a reasonably exposed image. One image (at a typical clinical kV) is required for each given target/filter combination used clinically. Record the technique factors in Chart 3 for use by the radiographers in their monthly full-field artefact tests. For DR systems, the signal level in the raw images should be within 20% of the typical signal level in a raw image acquired using the AEC. Install the magnification stand (if used clinically).

8. Place the thinner test object (25 mm equivalent uniform phantom) on the magnification stand.

9. Select the manual or AEC mode used clinically for magnification imaging of an average breast.

10. Expose the image.

11. Enter the imaging parameters on Table A.
12. Repeat steps 9-13 for other magnification stand positions (magnification factors) and clinically relevant anode-filter combinations. It is not necessary to exhaustively image all possible permutations of magnification stand positions and target/filter combinations, but each magnification stand position should be used at least once, and the most commonly used target/filter combinations should be tested at least once with the magnification stand.

DATA INTERPRETATION AND ANALYSIS.

Artefacts may include: dust or dirt, “ghost” images left over from repeated test or clinical exposures, blotchiness due to thickness variations of the filter, dirt or corrosion on the filter, stitching artefacts, clipping/electronic noise, spatial non-uniformities, artefacts, plus or minus signal variations, flat-fielding artefacts, grid lines, streaking in the horizontal or vertical directions, bad pixels, and other equipment-induced artefacts. Artefacts are also caused by dirt or debris in the tube port or on the underside of the breast support plate or grid. Some examples of artefacts associated with digital mammography systems are illustrated in Section III.

1. Examine the image on a workstation.

2. Select a window width (WW) and window level (WL) that allows artefact severity assessment, without accentuating the noise excessively. Adjust the window width to match that selected for evaluating the ghosting image and adjust the window level to give a mid-gray.

3. If patient images are interpreted on hard-copy, print the images using the window width and level settings established in step 2. View the image on a mammographic quality viewbox. If the printed image is not suitable (not enough or too little contrast, too light or too dark) for artefact evaluation, adjust the window width and level settings slightly and try again.

4. Record the window width and level settings used on Chart 3.

5. Examine the images of the uniform phantom(s) carefully for artefacts. These may include: dust or dirt, “ghost” images left over from repeated test or clinical exposures, filter blotchiness, stitching artefacts, clipping/electronic noise, spatial non-uniformities, film handling artefacts, plus or minus signal variations, processing artefacts, grid lines, streaking in the horizontal or vertical directions, bad pixels, and other equipment-induced artefacts. Record any visible artefacts on Chart 3.

6. The image should be examined for flat field uniformity to ensure that the image does not have non-uniformities across the field of view. Review the images for all clinically used target/filter combinations.

7. If any artefacts or non-uniformities are present, rotate the phantom 90° and repeat the exposure and acquisition procedure. Any artefacts or non-uniformities that
keep a fixed orientation relative to the image receptor in both images and are deemed significant probably require a re-calibration of the gain file specific to the target/filter combination in question.

8. If the artefact or non-uniformity remains, service by a qualified service engineer should be obtained and the problem fixed.

9. Display the uniformity image with a zoom factor that displays full resolution (1:1 pixel mapping). Reduce the WW until the noise pattern becomes apparent. Pan over the entire image, examining the image for variations in the amount of noise and in its texture from place to place in the image.

10. Ensure that some of the thickness tracking images are also examined to ensure the flat-fielding algorithm works well across the range of 2-9 cm, and not just for the thickness of the site’s uniform phantom.

RECOMMENDED PERFORMANCE CRITERIA AND CORRECTIVE ACTION

1. There should be no visible dead pixels, missing lines or missing columns of data.

2. There should be no visually distracting structured noise patterns in a uniform phantom image.

3. There should be no regions of discernibly different density on an unprocessed image of a uniform phantom when viewed on radiologist workstation with a window width setting and a window level setting such that a majority of the image is mid-gray. Choosing an appropriate window-width can be done by examining the image(s) taken of the CAR mammography accreditation phantom for the ghosting test (Procedure 7). Window-width should be selected to best visualize the anatomic test-objects (fibres, specks and masses) without exaggerating image noise.

4. There should be no unexpected variation in apparent texture or magnitude of the noise across the uniform image. If the place-to-place variation changes over time, areas where the noise appears to be less may indicate degradation in the detector causing a loss of sharpness. Increases in noise may indicate other detector problems. Document such problems by measuring the local SNR, [(pixel value-offset)/standard deviation] in ROIs of about 100 mm² or less, located in an area of “normal” noise level and compare to the area(s) where noise levels are observed to have changed.

5. If dead pixels or other unacceptable artefacts are noted, or significant non-uniformity is present, the service person should be contacted to investigate and correct the problem.
TIMEFRAME FOR CORRECTIVE ACTION

For severe artefacts, immediately, before any further patients are imaged. For minor artefacts, at the next routine servicing of equipment.
5. PROCEDURE: BREAST ENTRANCE EXPOSURE AND BEAM QUALITY ASSESSMENT (HVL)

OBJECTIVE

To measure the half-value layer and to confirm that the total filtration of the X ray beam is in agreement with the minimum requirements of the national and international standards [2,4,27,61,110].

To measure the typical entrance exposure rates (mR/mAs) or air kerma of the system for clinically used techniques.

To ensure that the x-ray beam quality is consistent with the target, filter and kV selected.

To enable the calculation of mean glandular dose.

To verify the reproducibility of the x-ray generator.

APPLICABILITY

This procedure applies to all full-field digital mammography systems.

TEST FREQUENCY

Equipment evaluations, semi-annually

REQUIRED TEST EQUIPMENT

Ionization chamber and electrometer calibrated at mammographic x-ray beam energies (the calibration factor should be constant to within ±1% over the HVL range from 0.2 to 0.6 mm Al). A chamber which is not sensitive to backscatter is preferred, otherwise a correction should be made for backscatter.

Sheets of 99.9% pure aluminum (type 1145 aluminum alloy) of length and width sufficient to cover the ionization chamber fully. The stated thicknesses should be accurate to within ±1%. The total thickness of all the aluminum sheets should be at least 0.6 mm. At least one sheet should be 0.1 mm thick or less. One possibility is 6 sheets, all 0.1 mm thick, another possibility is the following combination of thicknesses: 0.05 mm (2 sheets), 0.1 mm (1 sheet) and 0.2 mm (2 sheets)

Measuring tape

Metal plate to shield the detector from X rays (e.g. 1 mm steel, 5 mm Al or > 0.1 mm Pb) and large enough to cover the active area of the detector.

NOTE: The use of type 1100 aluminum alloy for HVL measurement can give (depending on specific samples) HVL values up to 7.5% lower than those measured using type 1145 aluminum. If type 1100 aluminum is used, results should be corrected to agree with those obtained using type 1145 aluminum.
TEST PROCEDURE STEPS

1. Create a patient with last name “Physics” and first name “Junk”. The patient ID “9904UYMMDD” may be used. These images will not be viewed or saved. This same patient study will be used for procedure 8.

2. Place the metal shielding on the breast support table to protect the detector from excessive radiation exposure that could cause artefacts.

3. Select the manual mode of operation, and the target/filter/kV combinations selected by the AEC for 20, 45 and 70 mm thicknesses of PMMA (see Procedure 3) and record on Chart 4.

4. Place the dosimeter at a height of 45 mm over the breast support, laterally centred and 40 mm from the chest wall edge, so that the sensitive volume of the chamber remains completely within the radiation field.

5. For scanning systems (i.e. Philips) ensure that the dosimeter is set to integrating mode rather than pulse mode.

6. Place the compression paddle approximately halfway between the x-ray target and the dosimeter.

7. Carry out an exposure and record the reading on Chart 4.

8. Place 0.3 mm of aluminium (or 0.4 mm, depending on the target/filter/kV combination that has been selected) on the compression paddle above the aperture, totally covering the active volume of the chamber, and make an exposure with the same parameters. Check that the reading is higher than half of the reading without filter. If it is not, use a thinner aluminium thickness.

9. Add 0.1 mm (or .025mm for more precision) of Al and repeat the previous step. Check that the reading is smaller than half of the reading without filter. Otherwise, add more Al until the reading falls below half of the reading without filter.

10. Remove all the filters and repeat the exposure again. Take note of the reading.

11. Repeat this procedure for the other selected target/filter/kV combinations.

12. Record the temperature and barometric pressure, so any necessary corrections can be applied to the measurements.

DATA ANALYSIS AND INTERPRETATION

1. The HVL is calculated in the spreadsheet by logarithmic interpolation of the aluminum thickness of the points just below and just above 50% of the zero thickness exposure.
2. Alternately calculate the value of the HVL, based on the following expression:

\[
HVL = \frac{t_2 \ln \left( \frac{2M_1}{M_0} \right) - t_1 \ln \left( \frac{2M_2}{M_0} \right)}{\ln \left( \frac{M_1}{M_2} \right)}
\]

where
t1 and t2 are the thicknesses (in mm) of the filters used,
M0 is the average value of readings 6 and 9 measured without any added filter.
M1 and M2 are the readings measured in steps 7 and 8 that are just above and just below 50% of M0

3. Note the calculated HVL on Chart 4.

RECOMMENDED PERFORMANCE CRITERIA AND CORRECTIVE ACTION

Acceptable: kV/100 + 0.03 ≤ HVL ≤ kV/100 + C  where
C = 0.12 for Mo/Mo,
0.19 for Mo/Rh,
0.22 for Rh/Rh,
0.30 for W/Rh,
0.36 for W/Rh, (Planmed)
0.32 for W/Ag,
0.46 for W/Ag, (Planmed)
0.25 for W/Al

and kV is the measured value for the nominal kV selected.

Note the maximum expected HVL values for the Lorad Selenia Dimensions with the silver filter are given in Table 6 below.

Table 6: Maximum acceptable half-value layer values for Lorad Selenia Dimensions with Ag filtration.

<table>
<thead>
<tr>
<th>kV</th>
<th>Maximum HVL (mm Al)</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>0.646</td>
</tr>
<tr>
<td>32</td>
<td>0.698</td>
</tr>
<tr>
<td>36</td>
<td>0.732</td>
</tr>
<tr>
<td>39</td>
<td>0.759</td>
</tr>
</tbody>
</table>

Record on Chart 4 if the value of the HVL is acceptable. If this tolerance is met, it is generally the case that regulatory requirements for total beam filtration without compression paddle will also be satisfied.

If the measured HVL is below these limits at any kVp setting, service personnel should be contacted to check whether appropriate filtration is in place, or if the kVp has changed.
Excessive HVL should prompt a check by service personnel to assure that the x-ray tube has an appropriate (beryllium) window, that aluminum fitted to tube port for shipping is removed, that filtration and mirror are correctly installed and that the mirror motor is operational if it exists.

If the HVL is outside the recommended limits it may be helpful to verify that the kV output of the system is accurate. On scanning systems the desired method of verifying kV is to have a service person connect a volt-meter to the generator. On full-field (non-scanning) systems a calibrated non-invasive kV meter may be used. Note that many non-invasive kV meters do not work well with tungsten (W) anodes.

Also, at any given target, filter and kV combination, the difference in radiation output (mR) between two repeated exposures shall be no more than 2% of the measured output.

**TIMEFRAME FOR CORRECTIVE ACTION**

Within 30 days of the test date.
6. PROCEDURE: AVERAGE GLANDULAR DOSE

OBJECTIVE

Estimate the mean glandular dose (DG) for breasts represented by PMMA thicknesses of 20 mm, 45 mm and 70 mm. Reference: [4, 19, 27, 114, 115]

APPLICABILITY

This procedure applies to all full-field digital mammography systems.

TEST FREQUENCY

Equipment evaluations, semi-annually

TEST PROCEDURE STEPS

1. Determine the distance, $d_T$, from the focus of the X ray tube to the breast support table and record in Chart 5 – Breast Entrance Exposure and Mean Glandular Dose. This can be done using the manufacturer’s specifications or by measurement if necessary.

2. The parameters for imaging the DMUP phantom are recorded in Table A-Raw Image Acquisition using the AEC setting or technique used clinically for a 5.3 cm breast composed of 50% fatty and 50% fibroglandular tissue.

3. Other techniques used for each of the images from Chart 2 have air kerma rates on Chart 5.

DATA INTERPRETATION AND ANALYSIS

1. Multiply the exposure reading from the dosimeter by any correction factors required (Air pressure, temperature, HVL). The equation for correcting a dosimeter for different temperature and pressure conditions is given below:

   $$k_{TP} = \frac{(273.2 + T)}{(273.2 + T_0)} \times \frac{P_0}{P}.$$  

   where $T_0$ and $P_0$ are the values of pressure and temperature at which the dosimeter is calibrated (if applicable).

2. The mR/mAs for each measurement taken is shown on Chart 5.

3. Correct the incident air kerma value to the location of the entrance surface as follows:
\[ K_{i,t} = K_{i,45} \left( \frac{d_T - 45}{d_T - t} \right)^2 \]

where \( t \) is the phantom thickness in mm.

4. The mean glandular dose (\( D_G \)) is obtained from the incident kerma in air and relevant conversion coefficients using the following formula:

\[ D_G = g_t \ c_t \ s \ K_{i,t} \]

where 

- \( K_{i,t} \) is the entrance air kerma at the surface of the slab of PMMA (20, 45 and 75 mm thick), used to simulate the standard breasts with a thickness of \( t \) mm, measured without backscatter (see Procedure 5).
- \( g_t \) is the factor that converts from air kerma to mean glandular dose for a breast of composition 50% fibroglandular/50% fat with a thickness of \( t \) mm,
- \( c_t \) is the conversion factor which allows for the glandularity of standard breast of thickness \( t \) mm-thick, and
- \( s \) is the s-factor which gives a correction that depends on the target/filter combination.

   a. Use the product of the \( g \)- and \( c \)-factors, which are dependent on the HVL of the spectra used, as provided in Table 7. The HVL value is obtained following the method described in Procedure 5.

   b. Apply the values of the s-factor for relevant target/filter combination provided in Table 8 or Table 9.

   c. Record the values of \( g \), \( c \), \( s \), HVL and \( D_G \) on Chart 5

**Table 7:** Product of conversion factors “\( g \)” and “\( c \)” for calculating \( D_G \) for the standard breasts from measurements with different thicknesses of PMMA phantom

<table>
<thead>
<tr>
<th>PMMA thickness (mm)</th>
<th>Equivalent breast thickness (mm)</th>
<th>Fibroglandular proportion of equivalent breast</th>
<th>product of ( g ) and ( c )-factors</th>
<th>HVL (mm Al)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>21</td>
<td>97</td>
<td>0.336, 0.377, 0.415, 0.450, 0.482, 0.513, 0.539</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>32</td>
<td>67</td>
<td>0.245, 0.277, 0.308, 0.338, 0.368, 0.399, 0.427</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>45</td>
<td>41</td>
<td>0.191, 0.217, 0.241, 0.268, 0.296, 0.322, 0.351</td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>53</td>
<td>29</td>
<td>0.172, 0.196, 0.218, 0.242, 0.269, 0.297, 0.321</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>60</td>
<td>20</td>
<td>0.157, 0.179, 0.198, 0.221, 0.245, 0.269, 0.296</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>75</td>
<td>9</td>
<td>0.133, 0.151, 0.168, 0.187, 0.203, 0.230, 0.253</td>
<td></td>
</tr>
<tr>
<td>70</td>
<td>90</td>
<td>4</td>
<td>0.112, 0.127, 0.142, 0.157, 0.173, 0.194, 0.215</td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>103</td>
<td>3</td>
<td>0.097, 0.110, 0.124, 0.136, 0.150, 0.169, 0.188</td>
<td></td>
</tr>
</tbody>
</table>
### Table 8: “S” factors for Target/Filter combinations

<table>
<thead>
<tr>
<th>Target/filter combination</th>
<th>Filter thickness</th>
<th>s-factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mo/Mo</td>
<td>30</td>
<td>1.000</td>
</tr>
<tr>
<td>Mo/Rh</td>
<td>25</td>
<td>1.017</td>
</tr>
<tr>
<td>Rh/Rh</td>
<td>25</td>
<td>1.061</td>
</tr>
<tr>
<td>Rh/Al</td>
<td></td>
<td>1.044</td>
</tr>
<tr>
<td>W/Rh</td>
<td>50-60</td>
<td>1.042</td>
</tr>
<tr>
<td>W/Ag</td>
<td>50-75</td>
<td>1.042</td>
</tr>
</tbody>
</table>

### Table 9: “S” factors for W target filtered by 0.5 mm Al [20]

<table>
<thead>
<tr>
<th>PMMA Thickness (mm)</th>
<th>Equivalent Breast Thickness (mm)</th>
<th>s-Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>21</td>
<td>1.075</td>
</tr>
<tr>
<td>30</td>
<td>32</td>
<td>1.104</td>
</tr>
<tr>
<td>40</td>
<td>45</td>
<td>1.134</td>
</tr>
<tr>
<td>45</td>
<td>53</td>
<td>1.149</td>
</tr>
<tr>
<td>50</td>
<td>60</td>
<td>1.160</td>
</tr>
<tr>
<td>60</td>
<td>75</td>
<td>1.181</td>
</tr>
<tr>
<td>70</td>
<td>90</td>
<td>1.198</td>
</tr>
<tr>
<td>80</td>
<td>103</td>
<td>1.208</td>
</tr>
</tbody>
</table>

**NOTE:** The conversion factor and the average glandular dose change substantially for other breast thicknesses; these factors apply only to a 4.2-cm compressed breast thickness. Conversion factors for other breast or phantom thicknesses can be found in papers by Dance and by Wu et al. [18-20,114-115]

**RECOMMENDED PERFORMANCE CRITERIA AND CORRECTIVE ACTION**

The mR/mAs for each target-filter-kV combination should be within the recommended range for that system type, as listed in Table 11.

The average glandular dose to a standard breast (45 mm PMMA) should not exceed 3 mGy (0.3 rads) per view.

If the values exceed these levels, action should be taken to evaluate and eliminate the cause of excessive dose.

If the AGD determined by the x-ray unit is displayed for an image, or reported in the DICOM header, that value should match the physicist calculated value to within 20%.

Observe the variation of $D_G$ with time and, if the limits are exceeded, investigate the possible causes and take the necessary corrective measures.
It is recommended that the mean glandular dose also be estimated from actual patient exposures periodically and values compared to diagnostic reference levels that have been established at the local or national level [19,59,60,114,115].

Table 10: Acceptable and achievable limits for $D_G$ to equivalent breasts in mGy

<table>
<thead>
<tr>
<th>Thickness of PMMA (mm)</th>
<th>Thickness of equivalent breast (mm)</th>
<th>Acceptable level for $D_G$ (mGy)</th>
<th>Achievable level for $D_G$ (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>21</td>
<td>1.1</td>
<td>0.6</td>
</tr>
<tr>
<td>30</td>
<td>32</td>
<td>1.5</td>
<td>1.0</td>
</tr>
<tr>
<td>40</td>
<td>45</td>
<td>2.0</td>
<td>1.6</td>
</tr>
<tr>
<td>45</td>
<td>53</td>
<td>2.5</td>
<td>2.0</td>
</tr>
<tr>
<td>50</td>
<td>60</td>
<td>3.0</td>
<td>2.4</td>
</tr>
<tr>
<td>60</td>
<td>75</td>
<td>4.5</td>
<td>3.6</td>
</tr>
<tr>
<td>70</td>
<td>90</td>
<td>6.5</td>
<td>5.1</td>
</tr>
</tbody>
</table>

Table 11: Typical Tube Output Ranges for different machines and target-filter combinations

<table>
<thead>
<tr>
<th>System</th>
<th>Target/Filter</th>
<th>kV</th>
<th>mR/mAs Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>GE 2000D</td>
<td>Mo/Mo</td>
<td>27</td>
<td>9.3-12.3</td>
</tr>
<tr>
<td>GE 2000D</td>
<td>Mo/Rh</td>
<td>28</td>
<td>8.3-11.5</td>
</tr>
<tr>
<td>GE 2000D</td>
<td>Rh/Rh</td>
<td>32</td>
<td>12.0-16.4</td>
</tr>
<tr>
<td>GE DS</td>
<td>Mo/Mo</td>
<td>26</td>
<td>7.7-11.4</td>
</tr>
<tr>
<td>GE DS</td>
<td>Mo/Rh</td>
<td>28</td>
<td>8.5-11.5</td>
</tr>
<tr>
<td>GE DS</td>
<td>Rh/RH</td>
<td>29</td>
<td>8.6-12.4</td>
</tr>
<tr>
<td>GE Essential</td>
<td>Mo/Mo</td>
<td>26</td>
<td>8.2-11.4</td>
</tr>
<tr>
<td>GE Essential</td>
<td>Mo/Rh</td>
<td>27</td>
<td>7.6-10.5</td>
</tr>
<tr>
<td>GE Essential</td>
<td>Rh/Rh</td>
<td>29</td>
<td>8.0-12.8</td>
</tr>
<tr>
<td>Hologic Dimensions</td>
<td>W/Ag</td>
<td>33</td>
<td>6.2-8.7</td>
</tr>
<tr>
<td>Hologic Dimensions</td>
<td>W/Rh</td>
<td>29</td>
<td>3.4-5.5</td>
</tr>
<tr>
<td>Hologic Selenia</td>
<td>Mo/Mo</td>
<td>28</td>
<td>10.0-16.4</td>
</tr>
<tr>
<td>Hologic Selenia</td>
<td>Mo/Rh</td>
<td>34</td>
<td>15.3-17.7</td>
</tr>
<tr>
<td>Hologic Selenia</td>
<td>W/Ag</td>
<td>28</td>
<td>3.5-5.9</td>
</tr>
<tr>
<td>Hologic Selenia</td>
<td>W/Rh</td>
<td>28</td>
<td>3.8-5.1</td>
</tr>
<tr>
<td>IMS Giotto</td>
<td>W/Ag</td>
<td>33</td>
<td>8.4-11.2</td>
</tr>
<tr>
<td>IMS Giotto</td>
<td>W/Rh</td>
<td>24</td>
<td>2.7-4.3</td>
</tr>
<tr>
<td>IMS Giotto</td>
<td>W/Rh</td>
<td>30</td>
<td>5.3-7.6</td>
</tr>
<tr>
<td>Philips Microdose</td>
<td>W/Al</td>
<td>32</td>
<td>18.2-24.2</td>
</tr>
<tr>
<td>Planmed Nuance Excel</td>
<td>W/Rh</td>
<td>29</td>
<td>4.3-4.8</td>
</tr>
<tr>
<td>Siemens Inspiration</td>
<td>Mo/Mo</td>
<td>26</td>
<td>8.7-12.9</td>
</tr>
<tr>
<td>Siemens Inspiration</td>
<td>Mo/Rh</td>
<td>28</td>
<td>8.6-11.0</td>
</tr>
<tr>
<td>Siemens Inspiration</td>
<td>W/Rh</td>
<td>28</td>
<td>3.5-4.6</td>
</tr>
<tr>
<td>Siemens Novation</td>
<td>Mo/Mo</td>
<td>27</td>
<td>10.4-13.9</td>
</tr>
</tbody>
</table>
Siemens Novation  Mo/Rh  27  8.5-9.8
Siemens Novation  W/Rh  27  3.0-4.3

TIMEFRAME FOR CORRECTIVE ACTION

Immediately, before any further patients are imaged.

**OBSP REQUIREMENTS:**

Dosimetry. The average glandular dose delivered during a single cranio-caudal view of a phantom simulating a standard breast shall not exceed 3.0 mGy (0.3 rad) per exposure. The dose shall be determined with technique factors and conditions used clinically for a standard breast.

If the results fall outside the action limits, the source of the problem shall be identified and corrective actions shall be taken before any further examinations are performed or any images are processed using the component of the mammography system that failed the test.
7. PROCEDURE: EVALUATION OF GHOSTING

In this measurement, ghosting (sensitivity variation) or lag (residual signal) from a previous exposure is induced in a manner similar to clinical operation, and the results are quantified. For simplicity, both phenomena will be referred to in this document as “ghosting”. Both qualitative and quantitative (preferred) evaluations may be undertaken depending on the capability of the acquisition workstation. Here, a quantitative method for assessing ghosting and an alternative qualitative technique are described.

OBJECTIVE

To evaluate the severity of any artefact due to recent previous exposure to the detector in all systems except photon counting systems.

APPLICABILITY

All flat panel detectors (phosphor and direct conversion detectors)

TEST FREQUENCY

Semi-annually, equipment evaluations (new unit, replacement of the detector).

REQUIRED TEST EQUIPMENT

CAR accreditation phantom
Timer (watch, stopwatch, etc.)

TEST PROCEDURE STEPS

Read through these steps and understand them before starting this test. It is important that the elapsed time between acquisition of the initial image (step 4) and the ghost measurement image (step 5) be either 1 minute, or the shortest time possible that the mammography unit allows, whichever is greater, as this will replicate the clinical situation.

1. Create a patient with last name “Physics” and first name “Ghosting”. Patient ID “9907UYYMMDD” may be used.

2. Place the CAR accreditation phantom on the right half of the breast support plate with the edge placed at the middle of the table, running from chest wall to the anterior edge such that approximately one half of the breast imaging area is covered. See Figure 24a.
3. Lower the paddle so that it is in contact with the phantom. Using the top of the compression paddle (or printed AEC markers) as a reference, Note where the edge of the phantom crosses the detector.

4. Acquire an image under manual exposure, using typical clinical exposure factors for the average breast. This is the “ghost creation” image

5. Reposition the phantom on the detector so that the middle of the phantom is centered on the location of the edge of the uniform attenuator in the ghost creation image (see Figure 24b).

6. One minute after the time that the first image was acquired, or as soon as the unit allows another exposure if that is longer, acquire another image at the same manual technique. This is the ghost measurement image.

7. If “for presentation” (processed) images are not automatically provided, repeat step 7 with the processing turned on.

8. View the ghost measurement image (unprocessed version if possible). Use the region of interest tool (ROI, area~ 4 cm²) to make 3 measurements in 2 ROIs in the ghost measurement image at the locations described below:

   a) A : the mean pixel value in the background of the phantom on the side where no attenuator was present in the first image. In Figure 24b, the centre of the ROI should be ~ 20 mm to the left of the line marked “D”.

   b) B : the mean pixel value in the background of the phantom on the side where the uniform attenuator was present in the first image. Here, the centre of the ROI should be ~ 20 mm to the right of the line marked “D”.

   c) C : the standard deviation (SD) in ROI B.

9. Record the results on Chart 6.
Figure 24: Setup for (a) ghost creation image and (b) ghost measurement image.

DATA INTERPRETATION AND ANALYSIS

1. Calculate the ghost image SDNR using the equation:

   The ghost image SDNR = \left| \frac{A - B}{C} \right|

2. View the “for processing” version of the ghost measurement image on the radiologist’s review workstation.

3. Use a narrow window width (without exaggerating image noise) and appropriate window level. Inspect the central part of the image where the boundary between the two areas of the exposure lies. (OBSP using phantom- Adjust the window width and window level to clearly see the anatomic test objects without exaggerating image noise.) Record the window-width and window level on Chart 6.

4. Record the presence or absence of any visually observable ghost image on Chart 6.

RECOMMENDED PERFORMANCE CRITERIA AND CORRECTIVE ACTION

If the absolute value of the ghost image SDNR is more than 2.0, the service person should be contacted.

When viewing the ghost measurement image with a typical clinically used window setting, there should be no visible indication of the location of the phantom in the ghost creation image.
TIMEFRAME FOR CORRECTIVE ACTION.

Immediately.
8. PROCEDURE: COLLIMATION AND LIGHT FIELD BRIGHTNESS ASSESSMENT

Proper alignment of the edge of the compression paddle with the chest wall edge of the image-receptor holder assembly is necessary for proper positioning and compression of the breast. If the edge of the compression paddle extends too far beyond the image receptor edge, the patient’s chest is pushed away from the image receptor and some breast tissue will not be recorded on the image. If the edge of the compression paddle does not extend far enough, the breast tissue will not be properly pulled away from the chest wall and compressed for visualization in the image, and a shadow of the vertical edge of the compression paddle will be visible in the image, possibly obscuring clinical information.

It is important to include as much of the breast tissue as possible in the mammogram to avoid missing the detection of a cancer. Of necessity, there is some inactive region at the chest wall edge of the detector where breast tissue is excluded.

OBJECTIVES

To determine the amount of breast tissue at the chest wall that is excluded from the image because of the imaging geometry or detector design.

To ensure that the collimator allows for full coverage of the image receptor by the X ray field but does not allow radiation beyond the edges of the beam stop\(^1\) except at the chest wall and that the chest wall edge of the compression paddle aligns with the chest wall edge of the image receptor.

To ensure that the light field correctly indicates the active area of the detector.

To ensure the light field is bright enough to see the edges of the detector when positioning a patient.

APPLICABILITY

All full-field digital mammography systems.

TEST FREQUENCY

Semi-annually, Equipment evaluations (new units, service to x-ray tube or collimator).

\(^1\) “Beam stop” refers to the material below the image receptor that provides the effective barrier for the primary X ray beam. Normally, this is the caudal surface of the breast support table.
REQUIRED TEST EQUIPMENT

Five radiographic rulers (with 5 mm markings or finer and the “0” point at the halfway point of the ruler) or four radiographic ruler and a coin.
Five phosphorescent screen pieces each approximately 20 mm × 50 mm.
Opaque material that is wide enough to cover the phosphorescent strips inside the acceptable zone, such as metal foil.
Slabs of PMMA totaling 45 mm in thickness.
Tabletop (not mag-stand) image of the DMPA Phantom acquired in Procedure 9.
Illuminance meter (calibrated in Lux).

TEST PROCEDURE STEPS

If screen-film cassettes are used for this test, follow the method outlined in the document: Mammography Quality Control Manual [4].

1. Create a patient with last name “Physics” and first name “Collim”. The patient ID number 9908UYYMMDD may be used.

2. Tape four phosphorescent strips to the breast support, one on each edge, so that they overlap the edge of the breast support. The long dimension should be perpendicular to the edge of the breast support (see Figure 25).

3. Tape a fifth phosphorescent strip in the middle of the X ray field on the breast support. This strip will provide a check that you can perceive the light generated by primary X ray interaction with the phosphor.

4. Cover that part of the phosphorescent strips on the left, right and anterior edges that are actually on the breast support with metal foils. The fourth foil should cover the phosphorescent strip on the chest wall edge up to a distance of 5 mm beyond the breast support. The pieces of phosphorescent screen are placed in a manner, such that if the X ray field alignment is in compliance, the screens will not glow.

5. Ensure you have a clear view of the breast support from the control console and darken the room, so that you can watch the markers to see if there is any primary radiation beyond the breast support, and verify that the phosphorescent strip in the middle of the field glows. The unit may be angulated so that the phosphorescent screens are more easily visible from behind the X ray shield at the operator’s console.

6. Take an exposure under manual control at 28 kV and typically 100 mAs.

7. Record whether the phosphorescent screens glowed or not on Chart 7. If any of the phosphor screens glow, this implies that the radiation field extends beyond the edge of the active area by more than the limit. If necessary, make multiple
exposures to allow adequate time to observe each of the phosphor screens. Note that the digital images from these exposures are not needed for further analysis.

**Figure 25:** Suggested layout for rulers and phosphorescent screen markers used to evaluate X-ray field alignment and missing tissue. Compression paddle with radiographic ruler attached and 5th phosphorescent screen are not shown for clarity. Details are not drawn to scale.

8. Place slabs of PMMA of total thickness, 45 mm on the breast support with one edge aligned flush with the chest wall edge of the tabletop.

9. Place a radiographic ruler on the PMMA perpendicular to the chest wall so that the “0” marker is aligned with the edge of the PMMA. This will allow determination of the “missing tissue”. Alternatively, if using the OBSP Digital Mammography phantom, the MTF Overlay contains missed tissue rulers.

10. Tape a radiographic ruler to the underside of the compression paddle, with the zero line parallel to and aligned with the patient contact edge of the paddle at the chest wall, or tape a coin to the underside of the paddle with one edge of the coin tangent to the front edge of the paddle. Make sure that this ruler (or coin) does not overlap with the one on the PMMA. This ruler will provide the quantitative measurement of the position of the compression paddle edge with respect to the image receptor.

11. Position four radiographic rulers with their zero markings at the edges of the light field (or other indication of active image area). These will assess the congruence of the light field (or active area markings) and the actual region imaged.
12. Lower the compression paddle to make light contact with the PMMA.

13. Make an exposure using a manual technique, matching the kV, mAs, target and filter used to image the standard breast.

14. Repeat steps 2 through 13 for each image receptor size. If the unit has multiple positions for the small paddle that result in different collimator blade positions (i.e. left and right, to allow better positioning for MLO views), these should be evaluated.

15. Repeat with the magnification table if applicable.

16. Measure the background brightness on the breast support plate by placing the meter on the breast support plate facing the tubeport and waiting for the positioning light to turn off. Record the background brightness in Lux on Chart 7.

17. Measure the brightness of the light field for both small and large detector sizes by placing the meter on the breast support plate facing the light source and turning the light on. Record the amount on Chart 7.
Figure 26: Portion of Digital Mammography Physics Accreditation (DMPA) phantom showing missed tissue ruler. This ruler shows just less than 4mm of missed tissue.

DATA INTERPRETATION AND ANALYSIS

1. Examine the processed version of the digital image and measure the distances from the light-field or active area markings to the active edges of the detector.

Occasionally image processing algorithms end up cropping the edges of the image by \( \frac{1}{2} \) the processing kernel size. Therefore it is preferable to examine the processed (for presentation) version of the image for collimation and missed tissue.

2. Record the results on Chart 7 under “Light Field- Detector Congruence”.

3. Examine the digital image and measure the distance from the chest wall edge of the compression plate (“0” mark on the ruler or edge of coin) to the active edge of the detector using the ruler taped to the compression paddle.
4. Enter results on Chart 7 under “Alignment of chest wall edges of compression paddle and image receptor”.

5. Examine this digital image and determine the distance from the “0” mark on the ruler on the PMMA to the edge of the active detector. This is a measure of the “missing tissue”. Alternatively display the image of the DMPA phantom acquired using normal patient imaging technique. Adjust the window width and window level so that the missing tissue ruler is clearly visible (see Figure 26).

6. Record the amount of missing tissue on Chart 7 under “Missed Tissue (DMPA Phantom”).

7. If any of the phosphor screens attached to the rulers glow, this implies that the radiation field extends beyond the edge of the beamstop. If necessary, make multiple exposures to allow adequate time to observe each of the phosphor screens.

8. Calculate the difference between the light intensity on the breast support plate with the positioning light turned on and off.

RECOMMENDED PERFORMANCE CRITERIA AND CORRECTIVE ACTION

1. Coincidence between active detector edge and light field/active area markings: The markings should be within 10 mm of the detector edges in all directions.

2. Missing tissue at the chest wall: Achievable: ≤ 5 mm Acceptable: ≤ 7 mm

3. Coincidence between active detector edge and radiation field: Achievable; the beam completely irradiates the active area of the detector but does not extend beyond the breast support. Acceptable; the beam completely irradiates the active area of the detector and does not extend beyond the breast support except at the chest wall where it can extend beyond the breast support to a maximum of 5 mm.

4. The patient-contact chest wall edge of the compression paddle should not extend beyond the chest wall edge of the image receptor by more than 5 mm, and the chest wall edge of the paddle must not be visible in the image.

5. The positioning light field intensity must be at least 160 lux above the background light level.

6. If any of the above criteria are not met then service support is required.

TIMEFRAME FOR CORRECTIVE ACTION

Within 30 days of the test date
9. **PROCEDURE: EVALUATION OF SYSTEM RESOLUTION/MODULATION TRANSFER FUNCTION (MTF)**

In digital mammography the major system-related physical factor affecting spatial resolution is the signal blurring within the detector and the integration of signal over the area of the del to form a single reading. This can be assessed by calculating the MTF from the spreading of signal in the image of a sharp, high-contrast edge. If a square object is imaged, the edges in both the horizontal and vertical directions can be measured and evaluation can be performed for both the signal-rising and signal-falling conditions. Slanting the edge slightly allows determination of the “pre-sampled” MTF—i.e. the MTF that would exist before sampling to form the digital image [17,25,31,32]. The method presented here is a field measurement of “effective system resolution at the top surface of the breast” rather than a rigorous laboratory test. This incorporates the effects due to the focal spot as well as those due to detector characteristics.

**OBJECTIVE**

To determine the effective resolution for the entire imaging system including effects from geometric (focal spot) blurring and the detector and allow determination of limiting resolution (MTF).

**APPLICABILITY**

This procedure applies to all full-field digital mammography systems. There are two methods for measuring effective resolution: Method A, an actual measurement of system MTF for those with access to the software; and Method B, an interim method, which is the test specified in the manufacturer’s quality control program.

**TEST FREQUENCY**

Equipment evaluation, after service to detector, tube or bucky, semi-annually.

**METHOD A – MTF DETERMINATION**

**REQUIRED TEST EQUIPMENT**

- CAR DSB Phantom with overlay
- MTF test tool: A square of metal foil with very straight edges of size 20 mm to 50 mm on a side. The test object may be made of a variety of materials such as copper (70 µm thick), stainless steel [62], brass backing with tungsten or lead [12], or niobium (20 - 30 µm thick) [68]. Ideally, whatever the material used, the thickness of this foil will provide measurable X ray transmission at mammographic energies so that a reliable signal is obtained beneath the foil.
- slabs of PMMA totaling 25 mm and 45 mm to support the MTF test tool. Alternatively, the square can be permanently mounted on a larger (100 mm × 100 mm) 1.5-2 mm thick aluminum plate, angled slightly with respect to the edge of the sheet.
MTF software. See website http://humanhealth.iaea.org

Figure 27: Radiograph of MTF overlay placed on top of 45 mm of PMMA

TEST PROCEDURE STEPS

1. Position the DSB phantom on the breast support plate or place the MTF tool 45 mm above the breast support table such that the square is angled slightly (2-5°)
with respect to the chest wall edge of the breast support table. Use of a pre-mounted square achieves this automatically.

2. Make an exposure using manual factors similar to those used for a clinical image of the average breast. Choose factors such that there are no pixel values in the uniform regions of the phantom or MTF square that reach the maximum pixel value for the system or fall to the minimum value.

3. Acquire images for other clinically used anodes with clinically relevant kV and mAs selections.

4. Install the magnification stand at the most commonly used position for the site.

5. Position the 25 mm slab of the FFDM phantom on the magnification stand or place the MTF tool 25 mm above the breast support table such that the square is angled slightly (2-5°) with respect to the chest wall edge of the breast support table.

6. Acquire images for the clinically used anodes at appropriate kV and mAs selections.

DATA INTERPRETATION AND ANALYSIS

1. Download the “for processing” image onto the computer on which the MTF software is available. Run the software according to its provider’s directions to calculate the MTF from the “for processing” image. It is desirable to obtain MTFs on both the rising edge and the falling edge of the edge-spread data. It is important to ensure that large enough sample regions are used in order to ensure that the MTF calculation is accurate, and not noisy.

2. Record the spatial frequencies at which the MTF has fallen to 50 % and 20 % in the x and y directions on Chart 8.

3. Record the MTF value at 2.5, 5 and 7.5 cycles/mm on Chart 8.

RECOMMENDED PERFORMANCE CRITERIA AND CORRECTIVE ACTION

1. The MTF should at least be equal to the manufacturer’s specified values.

2. The spatial frequencies at which the MTF has fallen to 50 % and 20 % should not be less than the values specified for that model of digital mammography equipment in Table 12.

3. The MTF at 2.5, 5 and 7.5 cycles/mm should not change more than 10 % from the value established at commissioning of the equipment or from the established acceptable range for that particular unit.
4. If it is suspected that the spatial resolution is varying excessively from place to place in the image (e.g. due to detector deterioration) then the MTF should be measured at different locations in the image and evaluated.

5. A variation in noise from place to place in the image (See Procedure 10, Noise and Linearity) can be an indicator of changes in local MTF [69].

6. If any of criteria 1, 2 or 3 above are not met consult the manufacturer’s service representative.

**TIMEFRAME FOR CORRECTIVE ACTION**

Immediately, before any further patients are imaged.

**METHOD B – LIMITING SPATIAL RESOLUTION**

If it is not possible to perform the MTF measurement, a less suitable alternative is to measure the limiting spatial resolution in a manner similar to that done for screen-film mammography.

**REQUIRED TEST EQUIPMENT**

Star or bar resolution pattern covering at least the range 5-12 lp/mm
PMMA slabs
Magnifier lens (4-5 ×).

**TEST PROCEDURE STEPS**

1. Place the resolution pattern centrally on top of 45 mm of PMMA, 10 mm from the chest wall with the bars oriented at approximately but not exactly 90° with respect to the chest wall edge of the breast support table. The slight rotation of a few degrees is intended to avoid moiré effects.

2. Ensure that any image processing and detector correction algorithms (except for flat field correction) are turned off.

3. Confirm that the AEC sensor is not under the resolution pattern. Image the pattern using the technical factors (kV, grid, target, filter,) clinically used for a compressed breast of 45 mm.

Repeat the measurement with the bars oriented at near 0° (but not exactly). For convenience, the two measurements can be done simultaneously if the appropriate bar or star pattern is available.

**DATA INTERPRETATION AND ANALYSIS**

1. View the image on the monitor of the available workstation with at least 1:1 zoom factor. If hardcopy is normally used with the system, the image could be viewed on
the printed film with the aid of the magnifying lens. Note the number of line groups that can be observed clearly, starting with the most easily resolved.

2. Note the result on Chart 8.

3. The limiting spatial resolution in line-pair/mm should not fall below the values listed under the 20% column in Table 12.

4. The limiting spatial resolution should not decrease in time by more than 10% from the baseline value.

5. If variations in the resolution are observed, the cause should be identified (e.g. detector damage, change of size of the focal spot). If necessary, consult the manufacturer’s service representative for assistance in resolving the problem.

6. If the resolution of an image viewed on hardcopy film does not meet the spatial resolution requirement, ensure that the problem is not caused by the laser printing

**TIMEFRAME FOR CORRECTIVE ACTION**

Immediately, before any further patients are imaged.

**Table 12:** Acceptable frequencies at which the MTF falls to 50% and 20%. Where two numbers are given, the first is for the direction perpendicular to the chest wall, and the second is for the direction parallel to the chest wall.

<table>
<thead>
<tr>
<th>System</th>
<th>Contact mode</th>
<th>50 % (c/mm)</th>
<th>20 % (c/mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuji Amulet</td>
<td>4.5</td>
<td>7.5/4.5</td>
<td></td>
</tr>
<tr>
<td>GE 2000D</td>
<td>2.5</td>
<td>5.0</td>
<td></td>
</tr>
<tr>
<td>GE DS</td>
<td>3.5</td>
<td>5.5</td>
<td></td>
</tr>
<tr>
<td>GE Essential (FV On)</td>
<td>2.5</td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td>GE Essential (FV Off)</td>
<td>1.7</td>
<td>3.7</td>
<td></td>
</tr>
<tr>
<td>Hologic Dimensions</td>
<td>3.5</td>
<td>7.5</td>
<td></td>
</tr>
<tr>
<td>Hologic Selenia</td>
<td>3.5</td>
<td>7.5</td>
<td></td>
</tr>
<tr>
<td>IMS Giotto</td>
<td>3.3/3.0</td>
<td>6.0</td>
<td></td>
</tr>
<tr>
<td>Philips Microdose</td>
<td>3.0</td>
<td>4.6</td>
<td></td>
</tr>
<tr>
<td>Philips PCREleva</td>
<td>5.0</td>
<td>9.0/8.0</td>
<td></td>
</tr>
<tr>
<td>Planned Nuance</td>
<td>3.5</td>
<td>6.0</td>
<td></td>
</tr>
<tr>
<td>Siemens Inspiration</td>
<td>4.0</td>
<td>7.5</td>
<td></td>
</tr>
<tr>
<td>Siemens Novation DR</td>
<td>4.5</td>
<td>9.0/8.0</td>
<td></td>
</tr>
</tbody>
</table>
10. PROCEDURE: NOISE AND LINEARITY

OBJECTIVE

To evaluate the spatial and electronic noise characteristics of the entire imaging chain.

To establish baselines for the response and noise characteristics of the image acquisition system under standard radiation exposure conditions. The data sheet produced should be kept as a reference to be compared against future measurements.

APPLICABILITY

This procedure applies to all full-field digital mammography systems.

TEST FREQUENCY

Equipment evaluation, after service, semi-annually

REQUIRED TEST EQUIPMENT

2 sheets of aluminum measuring 1.3 mm thick OR
Slab of PMMA with total thickness 40 mm of sufficient size to cover the entire detector (DMUP phantom).
The PMMA contrast object used for SDNR measurements
Acquisition or radiologist’s workstation with ROI capability or QC software for image analysis. Alternatively, images may be downloaded to another computer and analyzed using image analysis software.

TEST PROCEDURE STEPS

NOTE: These tests should be performed on flat-fielded, but un-enhanced (raw, i.e. without peripheral or resolution enhancement) images.

1. Create the patient study with last name “Physics” and first name “NL”. The patient ID number 9910UYYMMDD can be used.

2. Place phantom on the tabletop so that the front edge is aligned with the chest-wall edge of the breast support. Use collimation that allows the full detector area to be exposed.

3. For the aluminum sheet (2.6 mm), place the 3.8 mm spacer post near the edge of the image area away from the chest wall to make it 4 cm equivalent.

4. Place the contrast object on the upper surface of the Aluminum or PMMA in the location shown in the image in Figure 28.

5. Lower the compression plate in contact with the spacer post or PMMA.
6. In manual mode (with the radiographic grid in place), obtain an image with the same target/filter and kV selected by the AEC for 45 mm of PMMA without the spacer material in the AEC evaluation (Test Procedure 3). Select the closest mAs value available for manual exposure. This is mAs\textsubscript{ref}.

7. Also obtain images with three additional mAs values that cover the largest practical range that spans the range of reasonable mAs settings, e.g. values that are 1/8, 1/2, and 4 times as large as mAs\textsubscript{ref}. Once selected, these settings should be used for all future tests. These images will be used to characterize the detector response. For ease of analysis, ensure that the laterality (Left or Right breast) chosen for all images are the same, so the chest wall edge will appear on the same side on the monitor in all images.

8. For each of the images, with the image displayed so that the contrast object is clearly visible, place ROIs of approximately 80 mm\(^2\) (~10 mm in diameter) in the locations indicated in Figure 28. None of ROIs should be closer than 4mm from an edge of the detector. ROI\#6 should be over and entirely contained within the contrast object.

9. Record the mean pixel value (MPV) of ROI\#6 and label this value “A” - it will be used to calculate the SDNR.

10. Record the MPV and standard deviation of ROI\#5 as used above as B and C.

11. Calculate the signal difference to noise ratio (SDNR) as: SDNR = |A-B|/C

12. For linear systems plot the values of MPV (parameter B), the variance (C\(^2\)) and SDNR versus mAs. Perform a linear fit to the data and obtain the slope, intercept and correlation coefficients (R\(^2\)). For logarithmic systems, it may be necessary to plot the MPV and variance against 1/mAs to obtain a straight line.

13. Some manufacturers intentionally add a pixel value offset to their image data. This value (parameter B\(_o\)) should be obtained from the manufacture’s technical documentation. Alternatively, the intercept obtained in Step 13 can be used as B\(_o\).

14. Calculate the value of (B-B\(_o\))/mAs for all values of the mAs and also the average value of this quantity.
Figure 28: Locations of ROIs for noise and linearity analysis.

DATA INTERPRETATION AND ANALYSIS

1. **Detector Linearity**: The mean pixel value/mAs versus mAs is plotted for the center ROI (Chart 9-B, Signal Linearity), after correcting for any pixel value offset.

2. **Raw Noise**: The variance vs. mAs for the different ROI in the images taken at the kV used for imaging the accreditation phantom is plotted (Chart 9-B, Noise Linearity). For CR systems, which are logarithmically scaled, the variance is plotted versus the reciprocal of the entrance exposure. The regression coefficient ($R^2$) for a linear fit to the data is calculated.

3. **Signal to Noise Ratio (SNR)**: The signal is divided by the SD ($\sigma$) and recorded on Chart 9-A.

SUGGESTED PERFORMANCE CRITERIA AND CORRECTIVE ACTION

Table 13: Detector response and noise tolerances

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Acceptable tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPV (B-B_o)</td>
<td>$\Delta(B-B_o) \leq 10%$</td>
</tr>
<tr>
<td>Standard deviation (C)</td>
<td>$\Delta C \leq 5%$</td>
</tr>
<tr>
<td>SDNR</td>
<td>$\Delta SDNR \leq 5%$</td>
</tr>
</tbody>
</table>

In addition to the tolerances specified in Table 13:

1. **Detector Linearity**: The plot of pixel value/mAs versus mAs should be flat. All (ADU – Pixel Value Offset)/mAs values plotted should be within 10% of the mean ADU/mAs at the kV used for imaging the digital standard breast phantom. The plot of MPV (B) and variance ($C^2$) versus mAs should be linear with $R^2 \geq 0.95$. All values of $(B-B_o)/mAs$ should be within 10% of the mean value of this ratio.

2. For systems with flat-fielding corrections if any ROI mean pixel value differs by more than 10% from the middle (#1) location, then the source of the signal non-uniformity should be identified and corrected.
3. For systems with flat-fielding corrections if the SNR in other ROIs differs by more than $\pm 20\%$ from the middle (#1) location then the source of SNR non-uniformity should be identified and corrected.

4. If the SDNR changes by more than $\pm 5\%$ from the previous SDNR measurement made at the same location with the same uniform phantom and target, filter, kV and mAs selection, then the source of temporal change in SDNR should be identified and corrected.

**TIMEFRAME FOR CORRECTIVE ACTION**

Within 30 days of the test date.
11. PROCEDURE: SPATIAL LINEARITY AND GEOMETRIC DISTORTION OF THE DETECTOR

OBJECTIVE

To determine the absolute image magnification and the fidelity with which straight lines are captured.

APPLICABILITY

This procedure applies to all full-field digital mammography systems.

TEST FREQUENCY

Semi-annually for systems with moving parts (e.g. slot-scan) and after detector replacement.

TEST PHANTOM REQUIREMENTS

Geometric Distortion Test Tool with parallel lines at 20 mm spacing, lines angled at 45 degrees to the edges of the board.

Figure 29: Geometric distortion test tool

TEST PROCEDURE STEPS

Acquisition of these images can be combined with Procedure 8 – Collimation Assessment

1. If more than one image size is available, select the largest one and install the appropriate compression paddle.
2. Place the Geometric Distortion Test Tool on the breast support plate, approximately centered left to right.

3. Create a patient with last name “Physics” and first name “Distortion”. The patient ID number 9910UYYMMDD may be used.

4. Make an exposure using the technique for the standard breast.

5. Record the target/filtration, kV setting, mAs setting, and grid use on Table A, to populate Chart 10.

6. Make a second exposure with the distortion test tool on the magnification table.

DATA INTERPRETATION AND ANALYSIS

1. At a workstation equipped with image analysis tools, including distance measurement, display the images of the distortion phantom, using appropriate window-width and window-level settings. The background of the phantom should be a mid-grey, with the lines clearly visible.

2. Examine the image for uniformity of sharpness across the image and for any distortion in the regular pattern.

3. Using image roam and zoom controls, examine the pattern to ensure that all lines are smooth and straight.

4. Adjust the zoom to achieve a 1:1 display, calculate the effective detector element (del) size referred to the breast support table by measuring the horizontal and vertical distances in pixels between reference points of known spacing in the pattern. Record the results on Chart 10.

5. Multiply the effective del size by the numbers of rows and columns in the image matrix in order to calculate the width and length of the image referenced to the breast support table. Record the results on Chart 10.

SUGGESTED PERFORMANCE CRITERIA AND CORRECTIVE ACTION

1. The image size (in cm) should be within 10% of the manufacturer’s stated nominal image size.

2. The effective del width and length (x and y) dimensions should be within 5% of each other.

3. There should be less than 2% deviation from a straight line over a 100 mm length in the centre of the field (i.e. the line should not deviate from its true path by more than 2 mm over 100 mm). Note that on systems with a curved breast support plate the lines will appear distorted/curved. This is normal.
4. If there is any significant resolution non-uniformity or pattern distortion, rotate the image on the monitor 90°. If the resolution non-uniformity or distortion persists there is a detector problem, otherwise there may be a software or monitor problem. Seek service from a qualified service engineer to have the problem corrected.

**Note:** The design of some scanning systems (e.g. curved breast support plate) may introduce a geometric distortion. In this case, the amount of distortion should be characterized at machine commissioning. Thereafter, the test should measure whether the distortion has changed over time. Note that distortions can influence the accuracy of needle placement in the breast and this factor should be kept in mind.

**TIMEFRAME FOR CORRECTIVE ACTION**

Immediately, before any further patients are imaged.
12. PROCEDURE: MONITOR DISPLAY QUALITY

OBJECTIVE

To ensure that digital softcopy review workstation and acquisition station monitors have acceptably low artefact levels, with minimal geometric distortion, good contrast and good luminance uniformity.

APPLICABILITY

This procedure should be performed on all primary medical display devices used to interpret digital mammograms (radiologist’s workstations).

This procedure (except steps 14-17) should also be performed on the secondary display devices which include the monitor attached to the acquisition workstation that is used to verify patient image quality and/or the monitor(s) used to manipulate and print the images (technologist’s workstations).

If the interpreting physicians provide final interpretations from hardcopy only, the tests need only be performed on the secondary display devices.

Test images which mimic the images that are 1) produced by each model of digital mammography unit in the facility, or 2) might be interpreted at that workstation are required to be used.

TEST FREQUENCY

Equipment evaluations, semi-annually

REQUIRED TEST EQUIPMENT

Unit specific TG18-QC comprehensive display quality pattern with DICOM header and image format identical to that produced by the acquisition system. Installation of images is described in the next section. Images are available from www.sunnybrook.utoronto.ca/~yaffegrp/OBSP/Physicist/Physicist_Tools/Patients/(directories CD1TG18 and CD2TG18).

Unit specific images of the TG18-UNL20 and TG18-UNL 80 luminance uniformity patterns. Images are available from www.sunnybrook.utoronto.ca/~yaffegrp/OBSP/Physicist/Physicist_Tools/Patients/LNandUNL.

Luminance meter (photometer) able to measure luminance between 0.5 and 1000 cd/m² with better than 5% accuracy with a precision of at least 10⁻², complying with the CIE standard photopic spectral response to within 3%. If the monitors are LCD technology and the photometer is a near-range contact design (not telescopic), the

---

2 These are uniformly grey images with brightness set at 20% and 80% of maximum brightness
acceptance angle must be less than 5 degrees. The photometer should not be the one attached to the graphics board on the workstation and used to calibrate the monitors – this is to be an independent check of the system (the attached probe could be dirty or out of calibration).

PROCEDURE

![This is to be performed for each display station used for diagnosis and a separate Chart 11-B should be filled out for each review workstation monitor and acquisition system combination used. In addition, the monitor attached to the acquisition system that is used to verify patient image quality should be tested with the appropriate acquisition system image type and a Chart 11-A should be completed. Any monitors used to manipulate and print the images should be tested with all image types that will be displayed on that monitor.]

1. Set the room lighting as used for image viewing.

2. On each display to be tested, display the specific TG18-QC pattern provided for the acquisition system. Set the window-level to half of maximum and the window-width to full-scale.

3. Check that there is no evidence of smearing or bleeding noticeable in the black-to-white and white to black transition areas.

4. Inspect the image for any other artefacts, such as temporal variations or replicated edges.

5. Inspect the gray-scale ramps (F in Figure 31) to ensure they are smooth and continuous, without noticeable terracing or discontinuities.

6. Visually check that the lines dividing the test pattern into squares are crisp and straight, that the pattern is centered in the active image area of the monitor, and that the squares are indeed square (correct aspect ratio), with right-angled corners.

7. Verify that the 16 gray-level patches labeled 2 through 17 are distinguishable from one another, and that the low-contrast corners in each patch are visible.

8. Examine the text areas (G) below the central region of the pattern (only required for primary display devices/radiologist’s workstations). Letters spelling “QUALITY CONTROL” are printed in progressively fainter text over dark, mid-gray and white backgrounds. Record the number of letters visible over each background on Chart 11-A “Acquisition Monitor Display Quality” or Chart 11-B Review Monitor Display Quality” as applicable.

9. Verify that the 0%-5% contrast box (A) is clearly discernible.

10. Verify that the 95%-100% contrast box (B) is clearly discernible.
11. For primary displays, adjust the zoom level to 1:1 (1 pixel in the image is 1 pixel on the monitor) and use the magnifying lens to verify that the finest (Nyquist) vertical and horizontal high-contrast bars in the line-pairs patterns (C) are visible in all four corners and record status on **Chart 11-B**.

12. If the display system uses two monitors, repeat steps 2 through 11 on the other monitor and ensure that both monitors look the same.

13. If the monitor is a primary display device, display the TG18-UNL20 image.

14. Measure and record the luminance in the five squares indicated (top left, top right, middle, bottom left and bottom right) in Figure 30.

![Figure 30](image)

**Figure 30:** Using the photometer to measure monitor luminance with the TG18-UNL10 and UNL80 test patterns

15. Inspect the image for artefacts such as dead or bright pixels (LCD monitors only), scratches and other brightness non-uniformities.

16. Repeat steps 14 through 15 with the TG18-UNL80 image.
Figure 31: Modified TG18-QC test pattern with test objects indicated. A – 0-5% contrast square, B – 95-100% contrast square, C – horizontal and vertical line pairs, D – squares going from black to white, E – 5 cm line, F grey-scale ramp, G “QUALITY CONTROL” subjective test.

SUGGESTED PERFORMANCE CRITERIA AND CORRECTIVE ACTION

**TG18-QC test pattern image**

1. There should be no smearing or artefacts noticeable. The gray-scale ramps should appear smooth and continuous, without terracing or discontinuities. This might
include diagonal lines, flicker, blotches, non-uniform grey scale ramps, straight lines that appear curved in the image and inappropriate bright or dark pixels.

2. Lines should appear straight, and the boxes should be square. The pattern should be centered in the active display area.

3. All 16 luminance patches should be distinct from each other in shade and the low-contrast targets should be visible in the image.

4. At least 11 the letters “QUALITY CONT” should be visible in each of the three regions of the TG18-QC image on the primary display devices (radiologist’s workstations).

5. The 5% contrast squares in the image should be visible in both the dark (0-5%) and light (95-100%) squares (areas F).

6. For primary display devices, the finest (Nyquist) vertical and horizontal high-contrast bars in the patterns should be visible in all four corners and at the centre.

7. The images on paired primary display monitors (i.e radiologist’s workstations) should appear to be visually identical (the same brightness and contrast).

**TG18-UNL test pattern images**

1. The maximum and minimum luminance measurements made on the TG18-UNL20 image should be within 30% of their mean.

2. The maximum and minimum luminance measurements made on the TG18-UNL80 image should be within 30% of their mean.

3. There should be no excessively bright or dark regions, scratches or bright or dark pixels noticeable when viewing the TG18-UNL20 or TG18-UNL80 image.

**Recommendations and corrective actions**

1. If any of the following problems occur with the TG18-QC pattern:
   - noticeable artefacts are present
   - lines appear curved or ragged
   - squares are not square
   - grey scale ramps are not smooth or continuous
   - the letters “Quality Cont” are not visible against the respective backgrounds of dark, mid-grey and light grey
   - not all 16 luminance squares or low contrast targets are discernible
   - the horizontal and vertical high-contrast finest line-pair patterns cannot be resolved
   - paired monitors have visually different appearances
• the difference between the maximum and minimum luminance measurements made on the TG18-UNL10 image are not within 30% of their mean, or
• The difference between the maximum and minimum luminance measurements made on the TG18-UNL80 image are not within 30% of their mean or
• There are bright or dark regions, scratches, and/or bright or dark pixels noticeable when viewing the TG18-UNL10 or TG18-UNL80 image, then the monitors need to be serviced and recalibrated by qualified service personnel

TIMEFRAME FOR CORRECTIVE ACTION

Immediately, before any further patient images are read. If the monitor being evaluated is on a review workstation, acquisition does not need to be stopped, unless repair cannot be achieved within four working days and no other approved review workstations are available for image interpretation.

NOTE: Failure of a review workstation monitor test does not mean that patient image acquisition must cease, only that interpretation of patient images using that monitor must cease until the problem is corrected.

Failure of the acquisition station monitor requires the cessation of patient imaging; unless the review workstation is located close enough to the acquisition station, so that each image can be checked before the next is taken.

INSTALLING TEST IMAGES

1. Install the test images on the primary and secondary display devices.

2. If the device can read DICOM media CDs, simply place the appropriate test image CD in the drive and import the appropriate patients.

3. If the device cannot read DICOM media, work with the hospital PACS people to “C-MOVE” the images to the appropriate DICOM servers.

NOTE: The measurement procedures described here are a modified sub-set of those recommended by the American Association of Physicists in Medicine’s Task Group 18 (AAPM TG18). Additional measurements are described in the AAPM TG18 standard that the medical physicist may wish to include.
13. PROCEDURE: ASSESSMENT OF REVIEW WORKSTATION MEASUREMENT TOOLS AND DISPLAY SCALING

OBJECTIVE

To ensure that the software used to display and report the digital mammograms can provide accurate measurements of lesion size.

To ensure that images of the same breast acquired from different detectors can be displayed at a similar size on the monitors for easy comparison with prior examinations.

APPLICABILITY

All units

TEST FREQUENCY

Equipment Evaluations, after changes to the display software.

REQUIRED TEST EQUIPMENT

Unit specific TG18-QC comprehensive display quality pattern with DICOM header and image format identical to that produced by the acquisition system. Installation of images is described in the next section. Images are available from

www.sunnybrook.utoronto.ca/~yaffegrp/OBSP/Physicist/Physicist_Tools/Pat terns/ (directories CD1TG18 and CD2TG18).

MTF images from Procedure 8.

Pixel size display test image set, available from

www.sunnybrook.utoronto.ca/~yaffegrp/OBSP/Physicist/Physicist_Tools/Pat terns/LNandUNL/ Pixel size display test image set, available from

www.sunnybrook.utoronto.ca/~yaffegrp/OBSP/Physicist/Physicist_Tools/Pat terns/LNandUNL/ Matrix size display test image set, available from

www.sunnybrook.utoronto.ca/~yaffegrp/OBSP/Physicist/Physicist_Tools/Pat terns/LNandUNL/

PROCEDURE

1. Set the room lighting as used for image viewing.

2. On each display to be tested, display the specific TG18-QC pattern provided for the acquisition system. Set the window-level to half of maximum and the window-width to full-scale.

3. For primary displays, measure the lengths of the horizontal and vertical 5 cm rulers using the display software’s measurement tool and record the lengths in mm.

4. Load the MTF images taken on the acquisition workstation (one contact and one magnified).
5. Measure the physical size of the square or resolution pattern on the phantom along one edge in both vertical and horizontal directions, and enter these values on **Chart 12**.

6. Using the annotation tool, measure the size of the square or resolution pattern in the same locations for both contact and magnification images, and enter these values on **Chart 12**. This only needs to be done on one monitor, but needs to be done on each separate workstation.

7. Display the Pixel Size Test Study (Patient Name AAPM Test^QC^Sizing, image date 20091218).

8. Compare the size of the left and right CC images. Record if they appear similar sizes or not on **Chart 12**.

9. Display the Matrix Size Test Study (Patient Name AAPM Test^QC^Sizing, image date 20110413).

10. Compare the size of the left and right CC images. Record if they appear similar sizes on not on **Chart 12**.

**SUGGESTED PERFORMANCE CRITERIA AND CORRECTIVE ACTION**

1. The length of the 50 mm line measured by the radiologist’s review workstation software should be between 47.5 mm and 52.5 mm, in both the horizontal and vertical directions.

2. The Annotation tool should indicate the test object sizes to within 10% of true size in both table-top and magnification stand images. Since the MTF tool is not on the exact plane calibrated by the manufacturer, an adjustment to that plane may need to be made.

3. The right and left CC images in the pixel test study should display as the same size.

4. The right and left CC images in the matrix test study should display as the same size.

**TIMEFRAME FOR CORRECTIVE ACTION**

Within 30 days.
14. **PROCEDURE: MONITOR LUMINANCE RESPONSE AND VIEWING CONDITIONS**

The accuracy of the diagnosis and the efficiency of the radiologist are influenced by the conditions under which the mammograms are viewed. Viewing conditions may affect the diagnostic potential of even the best quality mammograms. These conditions are determined by the luminance and calibration of the monitors used for softcopy interpretation, the luminance of the view-boxes used for hardcopy interpretation, the ambient room illumination or the amount of light falling on the monitor and/or view-box surface, and good masking of films on the view-box.

Contrast is extremely important in the mammography image and is degraded by extraneous light. Consequently, monitors and view-boxes should be positioned to avoid light from windows, other monitors or view-boxes, and other sources of bright light, either direct or reflected. General lighting in the room should be at a low level and diffuse.

Ambient room lighting is as important as monitor and view-box luminance for the radiographic reading environment. Ambient illumination should be low to improve image contrast and low-contrast object detectability. Glare falling upon the monitor face and being reflected into the eyes of the radiologist should be as low as possible. In the past, it has been recommended that the ambient room illumination be no greater than 10 lux and ideally less than 5 lux. Currently, it is considered that levels between 20 and 40 lux are more reasonable [116]. Furthermore, recently, it has been suggested that there is a benefit in terms of reduced eyestrain if room lighting levels are somewhat higher and room finishes are chosen such that light reflected from the walls of the room in the radiologist’s line of sight be similar to the average brightness emanating from the monitors when a grey image (~ 30% of full image brightness) is displayed. However, again it must be ensured that as little of this light as possible falls upon and is reflected from the monitor face. Under such conditions ambient room lighting up to 75 to 100 lux may be acceptable. It should be confirmed that the luminance of light reflected off the monitor screen toward the eyes of the radiologist due to ambient light (e.g., tested with the monitor turned off) is considerably less than 1/250 of the maximum luminance provided by full image brightness. This ensures that the reflection of ambient light does not have an appreciable effect on the contrast ratio of the display.

Radiologists should experiment with the lighting conditions while viewing the TG18 QC test patterns and also while viewing clinical mammograms. Once the illumination conditions for reading have been established they should be maintained constant and monitors should be set up for those conditions [85].

Illuminance is measured by placing the detector-filter-diffuser combination at the view-box or monitor surface, pointed away from and parallel to the surface. These measurements can be influenced by the individual making the measurement, especially if one stands between a source of light and the detector-filter-diffuser combination, or wears reflective clothing.
Some vendors provide software packages and procedures for evaluation of monitor performance. Such packages may be convenient for carrying out the assessment and tracking of display performance. If such packages are used, however, it should be ensured that all of the functionality discussed below is assessed.

OBJECTIVE

To ensure that digital softcopy review workstation monitors are of adequate brightness and contrast, that the luminance response is perceptually linear and that the brightness and contrast of multiple monitors match one another such that images are displayed and printed consistently. These tests also ensure that monitors meet the DICOM grey-scale display function (GDSF) to enable the display of mammograms produced by any digital mammography unit adhering to the DICOM grey-scale standard for presentation.

To ensure that monitors meet the DICOM gray-scale standard to enable the display of mammograms produced by any digital mammography unit adhering to the DICOM gray-scale standard for presentation.

APPLICABILITY

This procedure should be performed on all primary medical display devices used to interpret digital mammograms.

TEST FREQUENCY

All systems with softcopy reading: Equipment evaluations and when display monitors are serviced or changes or upgrades are made to the image display software, semi-annually.

REQUIRED TEST EQUIPMENT

Illuminance meter able to measure illuminance between 1-500 lux (lm/m$^2$) with better than 5% accuracy, complying with the CIE standard photopic response to within 3%. Luminance meter (photometer) able to measure luminance between 0.5 and 1000 cd/m$^2$ with better than 5% accuracy with a precision of at least 10-2, complying with the CIE standard photopic spectral response to within 3%. If the monitors are LCD technology and the photometer is a near-range contact design (not telescopic), the acceptance angle must be less than 5 degrees. The photometer should not be the one attached to the graphics board on the workstation and used to calibrate the monitors – this is to be an independent check of the system (the attached probe could be dirty or out of calibration).

TG18-LN image set with DICOM header exactly matching the modality produced by the Acquisition system (provided)

Note: The unit candela per square meter is sometimes referred to as the “nit”.

Note: The unit candela per square meter is sometimes referred to as the “nit”.

Note: The unit candela per square meter is sometimes referred to as the “nit”.

Note: The unit candela per square meter is sometimes referred to as the “nit”.

Note: The unit candela per square meter is sometimes referred to as the “nit”.
PROCEDURE

This is to be performed for each display station used for diagnosis and a separate Chart 13 should be filled out for each workstation.

1. Set the room lighting as used for viewing of mammograms.

Ambient room lighting is almost as important as the monitor and view-box luminance when optimizing the radiographic reading environment. It is especially important that any sources of glare that will reflect from the image displays be minimized. This can be accomplished by a combination of low illuminance in the room and/or ensuring that as little of the room light as possible is reflected from the monitor screen onto the eyes of the radiologist. Note that these measurements can be influenced by the individual making the measurement, especially if one stands between a source of light and the detector-filter-diffuser combination, or wears reflective clothing.

2. Display the first TG18-LN pattern provided for your system (patient name “AAPM Test Patterns, Series “TG18-LN”).

3. Set the window-level to half of maximum and the window-width to full-scale. Ensure the image is scaled to fill the monitor (1 image per monitor).

4. If the photometer used is the telescopic type, point the sensitive region of the meter at the center of the square. If the photometer used is the near-range contact type, place the sensitive region against the monitor in the center of the square (Figure 32). Measure the intensity of the square. Record this value on Chart 13-A and compare to previous measurements.

5. Repeat steps 2-4 for each luminance level.

6. Measure the amount of ambient light falling on the monitor face with the illuminance meter. If the ambient light measured has changed from the baseline value established for the reading room by more than 10 lux, adjust the lighting until the ambient light level is within tolerance. Record the viewing conditions that result in sufficiently low ambient light levels on Chart 14- and leave a copy on site to be posted in the room.

7. If the photometer used is the near-range contact type (not telescopic) the ambient luminance must be measured. With the monitor turned off, hold the photometer a distance from the monitor such that the acceptance angle includes the majority of the monitor face but excludes the monitor surroundings. This distance will vary depending on the photometer design and monitor dimensions. Care must be taken to ensure that the measurement is not affected by direct luminance sources outside the monitor face. Record the luminance reflected from the monitor face on Chart 13-A. Alternately, if the diffuse reflection coefficient of the monitor is known, calculate the ambient luminance by multiplying the illuminance measured...
in step 6 by the reflection coefficient. Typical reflection coefficients for some common monitor models are given in Table 14.

8. The automated spreadsheet in Chart 13-B will calculate and plot the test results and indicate whether performance is compliant with the grey-scale display function.

9. The ratio of the maximum luminance to the minimum luminance including contribution from ambient lighting (contrast ratio) is also calculated by Chart 13-B.

10. Repeat steps 2 through 7 for the other monitor if this is a two-monitor workstation.

<table>
<thead>
<tr>
<th>Monitor Make and Model</th>
<th>Typical Reflection Coefficient ((cd/m²)/lux or sr⁻¹).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barco MDMG-5221</td>
<td>0.011</td>
</tr>
<tr>
<td>Barco MFGD 5621HD</td>
<td>0.013</td>
</tr>
<tr>
<td>Barco MDNG-5121</td>
<td>0.014</td>
</tr>
<tr>
<td>Barco MDNG-6121</td>
<td>0.012</td>
</tr>
<tr>
<td>Barco MDCG-10130</td>
<td>0.010</td>
</tr>
</tbody>
</table>
Figure 32: Using the photometer to measure monitor luminance

SUGGESTED PERFORMANCE CRITERIA AND CORRECTIVE ACTION

1. If the monitor luminance response is unacceptable, the monitor should be recalibrated. If recalibration does not correct the problem, the monitor may need servicing or replacement.

2. If the difference of maximum luminance between paired monitors is not ≤10% then recalibration is required.

3. If the ambient light level is non-compliant and especially if there is noticeable glare reflected off the display, then a re-design of the viewing area needs to be undertaken.
Table 15: Tolerances on primary display monitor performance.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Acceptable</th>
<th>Achievable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum luminance difference between paired monitors</td>
<td>≤10%</td>
<td>≤5%</td>
</tr>
<tr>
<td>The contrast ratio (ratio between white target luminance and black target luminance including ambient light)</td>
<td>≥250:1</td>
<td></td>
</tr>
<tr>
<td>Plot of compliance with GSDF (ΔL/L)/(JNDn-JNDn-1) versus ((JNDn+JNDn-1)/2)</td>
<td>≤15% of the response described by DICOM softcopy display grey-scale function (GSDF).</td>
<td>≤10% of the response described by DICOM GSDF.</td>
</tr>
<tr>
<td>The average number of JNDs per luminance interval</td>
<td>≤3</td>
<td></td>
</tr>
<tr>
<td>The maximum deviation from the average number of JNDs per luminance interval</td>
<td>≤2</td>
<td></td>
</tr>
<tr>
<td>The root mean square deviation from the average number of JNDs per luminance interval</td>
<td>≤1</td>
<td></td>
</tr>
<tr>
<td>The ambient light level (L_A) or Luminance due to ambient light reflected from the monitor to radiologist’s eyes</td>
<td>20 ≤ L_A ≤ 40 lux</td>
<td>&lt;&lt; 1/250 luminance of maximum image brightness</td>
</tr>
</tbody>
</table>

TIMEFRAME FOR CORRECTIVE ACTION

Immediately, before any further patient images are read.

**NOTE:** Failure of a review workstation monitor test does not mean that patient image acquisition must cease, only that interpretation of patient images using that monitor must cease until the problem is corrected.

ADDITIONAL INFORMATION

*Photometric Measurements*

Luminance is the amount of light either scattered or emitted by a surface, measured in cd/m² (nit).

Illuminance is the amount of light falling on a surface, measured in lux (1 lux = 1 lumen/m²).

One lux falling on a perfectly diffusing (Lambertian) surface with 100% reflectance produces a luminance of 1/π cd/m².

Other units often used for luminance and illuminance are footlamberts and footcandles,
respectively. To convert footlamberts to cd/m\(^2\), multiply the numerical value by \(10.76/\pi\) (3.425). To convert footcandles to lux, multiply the numerical value by 10.8.

Viewbox and monitor luminance measurements are made with a photometric system. The detector-filter-optics combination is placed near the viewbox surface, taking care to exclude any extraneous room light. Typical viewbox luminance values range from 1,500 to 3,500 cd/m\(^2\) and monitors can range from 0.1 to 500 cd/m\(^2\).

**Table 16: Equipment for Basic Photometric Measurements**

<table>
<thead>
<tr>
<th>Purpose</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luminance and Illuminance</td>
<td>Autoranging handheld power meter</td>
</tr>
<tr>
<td>Luminance</td>
<td>CRT luminance sensor** with photometric filter, lens, and ambient light shade</td>
</tr>
<tr>
<td>Illuminance</td>
<td>Illuminance sensor** with photometric filter and cosine diffuser</td>
</tr>
</tbody>
</table>

**Suggested Acceptable Viewing Conditions**

1. The room lights will be off.

2. All curtains and hall-way doors will be closed.

3. All viewboxes in that could cause light to fall on the face of the monitor will be off, or fully masked, if used for previous cases.

4. The illuminance due to ambient light in the room used for image interpretation should be in the range of 20 to 40 lux.

5. The resulting ambient luminance of the monitors will not degrade the monitors’ luminance response functions to the point where they do not comply with the DICOM GSDF.
15. PROCEDURE: VIEWBOX LUMINANCE AND ROOM ILLUMINANCE

Some facilities using digital mammography print and interpret mammograms from hardcopy films. Almost all facilities have the need to view analogue mammograms for comparison with the current study. It is important that these images be viewed under appropriate conditions. Because many of the tests described here are analogous to those performed on the soft copy displays and use the same equipment, it is convenient to perform the two sets of tests together.

View-boxes should be positioned to avoid light from windows, monitors, other view-boxes, and other sources of bright light, either direct or reflected. View-boxes should have functioning masks in the area around the mammograms to exclude extraneous light, which reduces image contrast and low contrast perceptibility and also limits the maximum densities that can be seen without “bright-lighting” each image.

OBJECTIVE

To assure that the luminance of the viewboxes for interpretation or quality control of mammography images meet or exceed minimum levels, that the room illuminance levels are below prescribed levels, and that viewing conditions have been optimized.

APPLICABILITY

This procedure should be performed on all viewboxes interpretation of screen-film mammograms or hard-copy digital mammograms are viewed.

TEST FREQUENCY

Equipment evaluation & semi-annually

REQUIRED EQUIPMENT

Photometer designed to measure both luminance and illuminance that meets or exceeds the NAPM recommendations.

TEST PROCEDURE STEPS

Viewing conditions

1. Reproduce the typical ambient lighting conditions for the reading room including overhead and task lighting which is used when mammograms are typically interpreted. Doors and window coverings shall be in their normal (open or closed) position. If light from other viewboxes can fall on the surface of the viewbox being evaluated, these viewboxes shall be on, but the viewing surface shall be covered with radiographs.
2. With the light-level set for film reading and the viewbox turned off, measure the ambient luminance of the viewbox with film on it, by pointing the photometer at the viewbox. If the photometer used is a near-range contact type (not telescopic), the distance that the meter is held away from the viewbox surface should be chosen based on the meter’s acceptance angle. A large amount of the viewbox should be included in the measurement without any surrounding objects.

3. Place the luminance meter with its detector parallel to and facing away from the viewbox surface, with the rear side of the detector in contact with the viewbox surface. The meter should be held so that the medical physicist’s body is not within the angle of acceptance.

4. Make the measurement and record the result of the illuminance falling the viewbox surface on Chart 14.

5. Place the illuminance meter 50cm from the viewbox with its detector parallel to and facing toward the viewbox surface, centred on the viewbox. (see Figure 33).
6. Make the measurement and record the result of the illuminance seen by the observer on Chart 14.

7. Confirm that the view-box has appropriate, functioning masks available to exclude extraneous light from the light box.

8. Confirm that the view-box is free of obvious dirt and marks.

9. Repeat the tests for all view-boxes used for interpreting printed mammograms and for the view-boxes used by the radiographer to check the printed mammograms during the examination.
**Luminance and homogeneity of the view-boxes**

1. For each view-box that is used for mammographic interpretation, turn on the lights in the view-box at least 20 minutes before making the following measurements.

2. Assess the need for replacing defective fluorescent tubes, noting lack of cleanliness, colour of the tubes and the view-box panels, vibrations, etc.

3. Record the information on the data collection sheet.

4. Select five measurement points (one point should be centrally located and the other 4 should located towards the corners of the view-box) and at least 50 mm away from the edges.

5. Place the luminance meter in contact with the surface of the view-box at each selected point.

6. Measure the luminance at each point. Record the values on the data collection sheet.

7. Repeat the tests for all view-boxes used for interpreting printed mammograms and for the view-boxes used by the radiographer to check the printed mammograms during the examination.

**DATA INTERPRETATION AND ANALYSIS**

1. In a single view-box or single panel of a view-box bank: Select the central luminance value ($L_c$) and the most discrepant reading recorded ($L_{disc}$). Apply the following expression:

$$\text{Maximum Deviation(%) } = 100 \left| \frac{L_{disc} - L_c}{L_c} \right|.$$  

For view-boxes consisting of several panels or for view-boxes adjacent to one another: the maximum deviation between the central luminance value of any panel, $L_{cx}$, and the calculated mean of the central luminance of all panels, $L_{mean}$, is found:

$$\text{Maximum Deviation(%) } = 100 \left| \frac{L_{cx} - L_{mean}}{L_{mean}} \right|.$$  

---

3 It is recommended that an inventory of the view-boxes in the institution be maintained, noting their location, age and a history of the replacement of the fluorescent lamps.
RECOMMENDED PERFORMANCE CRITERIA AND CORRECTIVE ACTION

1. Luminance: acceptable; maximum luminance for each panel: > 3000 cd/m² (nit).

2. Luminance uniformity: acceptable; <30% maximum deviation for different areas of a single view-box or single panel in a view-box bank and <15% maximum deviation between central luminance of panels in a view-box bank or between adjacent view-boxes.

3. Room illuminance: acceptable; 20 - 40 lux.

4. A convenient and effective method for masking view-boxes to exclude bright light around the edges of mammograms should be available.

Note: Tri phosphor or quad phosphor tubes are recommended because of their increased luminance output. If possible all tubes should be replaced in a view-box or view-box bank at the same time to ensure uniformity. It is advisable to purchase fluorescent tubes in one batch to ensure that the colour matches between the tubes.

---

4 If the view-box is to be used only for viewing laser-printed hardcopy film, a luminance less than 3000 cd/m² is probably acceptable.
16. PROCEDURE: EVALUATION OF IMAGE QUALITY

It is recognized that no phantom is currently available that truly mimics the complex problem of imaging the breast. Nevertheless, it is possible to assess some key features of mammography quality by imaging a subjective breast phantom. This, for example is the basis of image quality assessment in the OBSP QA program for screen-film mammography [71].

In digital mammography it is useful to perform routine imaging of such a phantom to confirm that there have been no substantial changes in imaging performance from baseline. No particular phantom can be recommended at this time. Instead the facility should use whatever nationally or internationally recommended phantom currently used for its screen-film or digital mammography QC programmes.

OBJECTIVE

To establish a baseline level of subjective image quality. To ensure that the overall image quality has not degraded from baseline performance levels.

APPLICABILITY

This procedure should be performed on digital mammography systems.

TEST FREQUENCY

Equipment evaluations, semi-annually, after service or modifications to the system.

REQUIRED EQUIPMENT

Phantom containing structures mimicking those found in the breast (CAR phantom)
Magnifying lens (4-5x)

PROCEDURE

This evaluation can be performed on the ghost-generation image from Procedure 7 if the CAR phantom was used and a processed version of the image is available.

1. Place the phantom on the breast support positioned flush with the chest wall and centered laterally.

2. Lower the compression paddle to apply a compression force typically used clinically (e.g. 80 N)\textsuperscript{5}.

\textsuperscript{5} The actual force should be similar to the typical value used clinically, but the same value should be used for all testing. Note that in some systems and in some modes of operation the compressed breast...
3. If there is a separate AEC sensor, confirm that it is correctly located under the phantom.

4. Select the technique factors that are used in the clinical practice for a breast of equivalent characteristics to the phantom. Normally this is achieved by using the automatic exposure mode. Otherwise, select target, filter, kV, grid, density control position, operation mode (semiautomatic or automatic) as appropriate.

5. Make an exposure.

6. Record the exposure factors and the technique used.

7. Process the image using the algorithms that would be used clinically.

8. Compare this image with the baseline image obtained on this system. Determine if there are artefacts that can be confused with any of the phantom details. With the magnifying lens, examine carefully the image for non-uniform areas, dirt or dust, lines (if the grid is used), processing artefacts or any other type of artefact.

9. If desired, evaluate the image according to the evaluation method provided by the manufacturer\(^6\). Note the results on the data collection sheet.

10. Investigate the causes of any artefacts.

RECOMMENDED PERFORMANCE CRITERIA AND CORRECTIVE ACTION

1. There should be no significant degradation of image quality or changes in exposure factors from the baseline image.

2. The image quality assessment of the phantom should yield results that are as good as or better than those expected with high quality screen-film mammography as tested with the same phantom. The CAR phantom should score at least 4 Fibres, 3 Speck Groups and 3 Masses

3. If the image quality deteriorates over time, it will be necessary to carry out other investigations (for example kV, AEC, display, processing algorithms, etc) to determine the source of the change\(^7\).

---

\(^6\) A description of how this is done for the ACR Accreditation Phantom is provided in the IAEA Report on QA for Screen-Film Mammography.

\(^7\) Due to the subjective component associated with the observer, it is recommended that the test always be performed by the same person, using the same criteria and viewing conditions.
V. EVALUATION OF THE MAMMOGRAPHY SITE’S TECHNOLOGIST QC PROGRAM

The medical physicist can provide a valuable service to mammography sites by assessing the sites’ quality control programs and identifying areas where quality and quality control testing can be improved. At most sites, the visit by the medical physicist can serve as an external assessment of quality and a comparison of quality and quality control practices with those of other mammography sites. This review provides an opportunity for valuable feedback to the site on methods of quality improvement.

For this opportunity to be realized, the medical physicist must be familiar with the quality control practices that are performed by the QC technologist. In addition, the physicist should check that QC tests are properly performed and documented and that appropriate actions are being taken to correct problems when they occur.

Each mammography site should have a QC or QA Procedures Manual that documents the individuals responsible for QC testing, the testing performed, and the results of that testing. The manual should also document the on-site training of technologists on equipment operation, positioning, compression, mammography technique selection, and patient and operator safety, including radiation safety. (See a more complete listing of the items that should be contained in a procedures manual in the “Radiologist’s Section”.) The medical physicist should review the Procedures Manual on each visit to a site, reviewing contents to ensure that the manual is up-to-date and contains at least summary results of the last year’s QC tests. A checklist to aid the medical physicist in reviewing the site’s QC procedures is provided in Section IV.

The medical physicist can also provide a useful independent check of film viewing conditions.

Problems with the mammography site’s quality and QC program and recommendations to the site for improvement should be clearly communicated in a cover letter or summary sheet of Problems and Recommendations. Too often, communications back to mammography sites are ignored by the site because they lack clarity or are too obscure to interpret. The Medical Physicist’s Mammography QC Test Summary forms in Section VI have been included to aid in communicating the results of physics tests to the mammography site. A Preliminary Results form is also provided in Section VI for the medical physicist to leave brief, handwritten results for the facility prior to departure. This immediate communication is particularly essential to allow adequate time for the facility to take corrective action should any tests fail.
VI. SUMMARY REPORTING FORMS

All Technologist Baseline Worksheet results should be left on site for use in the daily Quality Control Program.
OBSP Mammography Physics Group

Site Review Summary and Action Report

This report is completed on-site and is not a full summary of items tested. The following outlines any problems the physicist encountered, any actions taken by the physicist, and any follow-up actions that are expected by the site.

A detailed analysis will be performed upon the data gathered and will be presented in a formal report.

If there are any outstanding issues following a site review, the physicist will contact the site directly.

<table>
<thead>
<tr>
<th>Problems encountered:</th>
<th>Actions taken:</th>
<th>Actions expected:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Status:

Continue screening as usual  Suspend screening pending further review

Physicist Contact:
Digital Mammography QC Phantom Baseline Calculation Worksheet

<table>
<thead>
<tr>
<th>FFDM Unit</th>
<th>Room</th>
</tr>
</thead>
<tbody>
<tr>
<td>AEC Setting</td>
<td>AEC Sensor Position</td>
</tr>
<tr>
<td>Target</td>
<td>Filter</td>
</tr>
<tr>
<td>kV</td>
<td>mAs</td>
</tr>
<tr>
<td>Window Width</td>
<td>Window Level</td>
</tr>
</tbody>
</table>

Softcopy

Op Levels

mAs

Disc MPV (A)

Background MPV (B)

Background St. Dev. (C)

SDNR = (B - A)/C

<table>
<thead>
<tr>
<th>Target</th>
<th>Lower Limit</th>
<th>Eqn</th>
<th>Upper Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>mAs</td>
<td>mAs X 0.9</td>
<td>mAs X 1.1</td>
<td></td>
</tr>
<tr>
<td>SDNR</td>
<td>SDNR X 0.9</td>
<td>SDNR X 1.1</td>
<td></td>
</tr>
<tr>
<td>MPV (B)</td>
<td>MPV X 0.9</td>
<td>MPV X 1.1</td>
<td></td>
</tr>
</tbody>
</table>

Reason for setting new target values: new installation, service to detector, service to generator, software upgrade, other)

Target Values currently in use (from Technologist’s weekly QC)

mAs

MPV

SDNR

Window Level

Window Width
## Digital Mammography QC Artefact Evaluation Viewing Baselines

**FFDM Unit** _______  **Room** __________

**P** = “For Presentation” or “Processed”  
**R** = “For Processing” or “Raw”

<table>
<thead>
<tr>
<th>Test</th>
<th>Image Type</th>
<th>AEC Setting</th>
<th>AEC Sensor Position</th>
<th>Target</th>
<th>Filter</th>
<th>Window Width</th>
<th>Window Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily Flat-Field</td>
<td>P</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monthly Artefacts, Tabletop</td>
<td>R</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monthly Artefacts, Mag</td>
<td>R</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Viewing Conditions**

---

---

---

---

---

---

---

---
VII. IMPORTING AND EXPORTING IMAGES AND MISCELLANEOUS TIPS

IMPORTING DICOM IMAGES

- Many PACS workstations will import from a DICOM compliant CD.
- If that doesn’t work, try asking the PACS people to read the CD for you and put the images on the central PACS that way.
- Sometimes the best way to get a TG18-QC image onto the Acquisition Workstation is to push it from the Review Workstation

Agfa IMPAX

1. Put the DICOM CD in the CD drive
2. Click on the search bar (possibly right click?) and check the “advanced” checkbox.
3. In the drop-down box switch from the database to the CD/DVD drive (D: drive)
4. Hit search, and watch the list of patients on the CD come up
5. Double-click on the desired series to load it.

GE

1. Put the DICOM CD in the CD drive
2. Click on the CD icon and wait for the list of patients on the CD to come up.
3. Highlight the patient(s) you wish to load
4. Click on the “import” button (icon shows an arrow pointing to the computer).

Siemens Syngo

1. Insert CD
2. Select Patient
3. Import

EXPORTING DICOM IMAGES

- Some systems let you export to USB key, which is generally fastest.
• Others let you burn to a CD you put in the CD drive.

• Others are configures so only the PACS/Film Library people can burn cases to CD for you.

**GE**

1. Put the blank CD in the CD drive.

2. Select the patients you wish to save to CD

3. Click on the button (below the patient list) with an arrow pointing to the CD icon.

**Philips Microdose / Sectra Mamea**

You can copy the images directly off the hard-drive onto a USB key. Note that the format isn’t quite DICOM. QuickQC will open the files, but be unable to do DICOMDIR on-the-fly. You can fix this by pushing the images to WinScippy or similar before analysis.

To figure out where the images are, do a “DICOM dump” on one of your images. The path to the file will be listed at the top. Copy and paste into Windows browser/Explorer, and delete the “image000x.dcm” part and hit return. Odd numbered images are raw, even are processed.

The file folder structure is like this:

D:\SectraMDM\AWStorage\YYYY\MM\DD\study_UID

**Linearity testing:**

Sectra adjusts the gain of the detector to maintain a fairly constant pixel value, so one cannot expect pixel value to scale with mAs. Instead pixel value multiplied with exposure time should scale with mAs.

**Siemens Novation**

1. Enter the browser,

2. Highlight your images

3. Choose “Archive to CD” from the button bar at the top of the screen.
WORKSTATION TIPS

Agfa

To cycle through images in a series, you can just mouse-over the image and hit the up/down arrows.

GE Advantage Workstation 4.2 Monitor Calibration

To calibrate the monitors yourself:

1) Ensure the luminance puck is plugged into the serial port in the back of one of the high-res monitors.

2) Hit the "More...." button below the list of applications on the small monitor.

3) Select "SMFit"

4) Select "service level 2" for the login type

5) enter the password "monilisa"

6) select multi-monitor calibration

7) follow the directions on the screen.

Note - if the lowest point on the GSDF conformance plot is out of bounds (to low), it might be because the minimum luminance is set to low. Try upping it to 1.0 nits.

GE Centricity RA1000

If the monitors do not seem to be calibrated to the DICOM GSDF and instead the luminance response plots show a convex curve, there is a line in a configuration file that may need to be changed, or you could have a presentation state being applied that is changing the LUT used to display the test images

First make sure that the “Presentation State” is set to “None”.

If that doesn’t fix things tell the service person to edit the “platinum_custom.properties” on the RA1000 PACS workstation such that the “UseRadworksLutForMammo” property is set to “false”.

eFilm Workstation

To easily change the WW and WL to a desired setting, go to Tools -> Window/Level Option -> Custom Level
If the button for moving between series is missing (so you can only see the first image in the TG18-LN series for instance), you need to customize the toolbar. Go to Toolbars->Customize. On the “MG” tab add the Series-forward and Series-back buttons.

*Siemens Syngo*

To bring images up on the RWS monitors instead of the "regular" monitor: There's a button with a little mammogram on the left and what looks like a folder tree on the right (when you mouseover it, you see "OPEN SCR MAMMO BROWSER") -- click it to open the browser on the RWS monitors.

There's a button at the bottom of the viewer with a little mammogram icon on the left and right and an arrow between them (when you mouseover it, you see "Enhancement") -- MAKE SURE THIS IS OFF! Or it takes your "flat" pixel regions and adds variation to the pixels.

To see the image at 1:1 (it's called "Actual Pixels" on this system), find a button with a tall, skinny black triangle pointing downward -- when you click it, you'll see a few options on how to view the image (e.g. "Fit to Screen", "Actual Pixels"). The little mammogram with four arrows emerging from it is "Actual Pixels".

To view the two series side-by-side, press the button on the control pad (it will be sitting on the tabletop) which looks like ( | ) (i.e. LCC | RCC).

R-Click and hold to pan around an image.

To access the service configuration menus, the password is the six characters after the site name displayed on the login window (highlighted in Figure 34).
Figure 34: Service password for Siemens Syngo workstations.
VIII. GLOSSARY

A

Active display area. The part of the softcopy viewer used for showing images, applications and the desktop.

Acquisition workstation (AWS). The computer, display, and associated equipment used to collect and verify image data. There is a graphical interface, which permits patient identification, includes a viewer for displaying either the single image or multiple images, and provides a connection to the radiology information system (RIS) and picture archiving and communication system (PACS). The viewer provides functions for adjusting window width and level, zooming, scrolling, adding text and graphical annotations, and permits validation of positioning and image quality. It is not used for diagnostic interpretation.

Acquisition time. The date, hour, minute, and second at which collection of data to form an image began. It could also be the duration of image acquisition.

ADU. Analog to digital unit. The signal or pixel value in the raw image.

Air kerma. The energy deposited per unit mass in air. The unit used to measure air kerma is the Gray (Gy). For x-rays with energies less than 300 kilo-electron volts (keV), 1 Gy = 100 rad. In air, 1 Gy of absorbed dose is delivered by 114 roentgens (R) of exposure.

Algorithm. A set of well-defined instructions for accomplishing a task. It is often a step-by-step procedure, performed by a computer. From a given set of initial information, the same result will always occur.

Aliasing. An effect that causes different continuous signals to become indistinguishable from one another when sampled. In images, it gives rise to image artefacts such as superimposed image data, moiré patterns (when the original image is finely textured) or jagged outlines. (See Figure xx in Effective Resolution of the Technologist’s Section)

Array. A rectangular arrangement of data in rows and columns, as in a matrix, or an arrangement of detector or memory elements in one or more planes.

Artefact. Any structure or pattern visible in the image that is not part of the object being imaged.

Assistant. A trainee or un-certified person who performs tests under the supervision of a certified medical physicist.

Automatic optimization of parameters (AOP) mode. An automatic exposure control mode whereby the kVp, target material, and filtration material are determined to give an appropriate signal-to-noise ratio with an adequately short exposure time. A short pre-
exposure is used to determine the attenuation in the breast.

**Automatic exposure control (AEC) systems.** A device designed to determine the spectrum (target material, filtration material, and kVp) and/or the exposure (mAs) needed to produce an adequately penetrated x-ray image. This is typically done by sampling the x-ray intensity after it passes through the patient and image receptor.

**Average glandular dose (AGD).** The energy deposited per unit mass of glandular tissue (the most radiosensitive tissue in the breast) averaged over all the glandular tissue in the breast. The average glandular dose delivered during a single craniocaudal view of an FDA-accepted phantom simulating a standard breast shall not exceed 3.0 milligray (mGy) (0.3 rad or 300 millirad) per exposure. The dose shall be determined with technique factors and conditions used clinically for a standard breast. The AGD is calculated from values of entrance exposure in air, the x-ray beam quality (half-value layer), and compressed breast thickness. See also: dose. As opposed to the entrance exposure, AGD or mean glandular dose can be used to estimate the risk of cancer induction from the exposure.

**B**

**Bad pixel map.** A specification which describes which array elements in the detector are defective.

**Banding.** A pattern of subtle stripes on an image.

**Bar pattern.** A tool for determining the limiting spatial resolution of an imaging system. It is composed of groups of highly x-ray attenuating strips spaced by an equal length of non-attenuating material. Each group of strips is smaller than the previous. The last group in which each bar is visible as a distinct line indicates the limiting spatial resolution of the system.

**Bit-depth.** Number of values that can be assigned to a pixel in a certain digital system, expressed in powers of two.

**Black.** The lowest light level displayed on a monitor. In normal mammographic viewing, this represents the maximum x-ray transmission. Photometric Interpretation Monochrome 1 represents images with highest x-ray intensity being black, while Monochrome 2 represents images with the maximum x-ray intensity being white.

**Brick.** An outboard power transformer of the kind associated with laptops, modems, routers and other small computing appliances, especially one of the modern type with cords on both ends. In the SELENIA system, the x-ray generator, detector, and acquisition computer communicate with each other through a device called a "brick".

**Broker.** A device or application that provides a software interface between systems that do not comply with a particular specification. Messages to or from a system are instead sent to the broker, which translates between the system and the required specification.
C

Clipping. The truncation of a signal because one of the stages in the system has saturated or gone beyond the maximum (or minimum) numerical value. Further increases (or decreases) in signal cannot be recorded. The system is not linear at levels when clipping occurs, and often is not linear near the clipping level.

Compression device. A plastic paddle used to flatten and immobilize the breast. Compression helps reduce motion blurring in the breast, separate structures within the breast, and to decrease the thickness of breast tissue, minimizing the amount of radiation used and the amount of scattered radiation reaching the image receptor. Ideally, the compression device is made of rigid, thin plastic and has a flat bottom surface that is parallel to the plane of the image receptor and with edges perpendicular to the plane of the image receptor to assist in moving breast tissue away from the chest wall and into the field of view.

Computer aided detection or diagnosis (CAD). Software for the computer-aided analysis of mammograms, marking suspicious areas to increase the sensitivity of the radiologist.

Conformance Statement. A formal statement that describes a specific product implementation that uses the DICOM Standard. It specifies the Service Classes, Information Objects, and Communication Protocols supported by the implementation.

Contrast to noise ratio (CNR). A measure of image quality defined as the signal difference between two known structures divided by the system noise within one or both of those structures. The CNR represents the ability to distinguish subtle lesions on a uniform background in which only image noise is present.

Control chart. A graphical means of displaying data in which the variable of interest is plotted on the vertical axis as a function of time on the horizontal axis. The control chart allows for easy and rapid review of the data to determine whether the process is within the desired control limits ("in control").

Control limit. The upper and lower values indicating that the process is "out of control" and requiring that corrective action be taken. It is prudent to immediately repeat the measurement to verify that the system is "out of control" before taking corrective action. If the repeated measurement is "out of control," then corrective action is required immediately (or in some cases within 30 days). Synonym for Action Limit

Consistent Presentation of Images (CPI). [IHE] The CPI profile ensures that image views are consistent throughout the enterprise, regardless of the monitor or printer used. It prevents confusion about patient orientation and enables display calibration or exchange of specific print settings.

Craniocaudal (CC) view. One of two routine views for mammography. The image receptor is placed caudad to (below) the breast and the vertical x-ray beam is directed
from cranial to caudal (downward) through the breast.

**D**

\[D_{\text{max}}, D_{\text{min}}\]. The maximum and minimum optical density on a film. \(D_{\text{max}}\) is the darkest area of the film, where the highest exposure of x-rays occurs. \(D_{\text{min}}\) is the base plus fog optical density of the film.

**Del.** Discrete element in a digital detector. The del spacing specifies the smallest possible sampling pitch of an imaging system. This would also be the nominal sampling pitch in a storage phosphor system.

**Dekanewton or Decanewton (daN).** A unit of force equal to 10 Newtons. The spelling deka (rather than deca) is recommended by NIST to reduce confusion with deci (1/10).

**Densitometer.** An instrument for measuring the optical density or degree of blackening of film.

**Detective quantum efficiency (DQE).** The fraction of incident photons that would have to be detected without additional noise to yield the same SNR as is actually observed by the detector. The DQE gives the efficiency with which the device uses the available quanta.

**Detector.** A device that converts incident x-rays into an electrical representation of that image.

**Detector defect cluster.** A grouping of detector elements that do not respond correctly (approximately linearly with exposure), as do other detector elements.

**Detents.** Mechanical settings that limit or prevent the motion, rotation, or exposure of an x-ray tube, cassette assembly, or image receptor system.

**DICOM.** Digital Imaging and Communications in Medicine. The established standard for the exchange of digital information between medical imaging equipment and other systems.

**Diagnostic mammography.** Mammography performed on patients who, by virtue of symptoms, physical findings, or a prior screening examination, are considered to have some likelihood of having breast cancer.

**DICOM grayscale standard.** Part 14 of the DICOM standard that describes the characteristics of a display monitor to enable consistent display of images (see GSDF).

**DICOM header.** The initial block of data associated with an image that describes the patient, facility, and image format information. The DICOM header uses tagged fields to convey information about the modality, image format, acquisition time, patient demographics, and technical factors. In a mammographic image, a number of fields are
compulsory. Digital Mammography images are either MG, DR, CR or DX modality types.

**DMUP.** Digital Mammography Uniform Phantom – A 4 cm thick block of PMMA large enough to cover the detector, supplied to each OBSP site by the OBSP physics group for the performance of QC.

**Digitization.** The process of turning an analog signal into a digital representation of that signal. The term is also used for the scanning of radiographic films into a data format that can be stored by computer or a PACS system.

**Digitized / Digital image.** A data file or structure normally representing a rectangular grid of pixels, also referred to as a raster graphics image, or bitmap. Often people make the distinction between a “digitized image” and a “digital image”: Digitized images are generally acquired in analog form and then “recaptured” by digitization, while a digital image is originally acquired by a digital detector.

**Direct radiography (DR).** Digital radiology technology using sealed units mounted on a radiography system, which captures x-rays and produces a digital image.

**Dose.** The amount of energy per unit mass deposited in tissue due to x-ray exposure. The S.I. unit of absorbed dose is the gray (Gy) representing 1 J/kg. One gray is equal to 100 rads; 1 milligray (mGy) is equal to 0.1 rad or 100 millirad.

**Dose indicator.** A manufacturer-provided value indicated on each image which is derived from the digital image receptor system and indicates the amount of x-ray exposure used to form the image.

**Dose optimization.** An attempt to balance the contrast, noise and dose while obtaining the highest amount of information from the exposure.

**Dry processing.** Laser film printers that use thermal processes to produce and fix the blackness on the transparency film. They use a heat-sensitive development process rather than chemicals, and normally have frequent self re-calibration to ensure stability of images.

**Dynamic Range.** The difference between, or ratio of, the highest and lowest signals in an electronic circuit or image.

**E**

**Effective resolution.** The limiting spatial resolution measured with a line pair test pattern located at the level of the top surface of the average breast. It is affected by both focal spot size and detector resolution. The effective resolution is typically measured in the orthogonal directions parallel to and perpendicular to the anode-cathode axis.

**Equipment Evaluation.** Inspection to verify compliance with CFR21 – 900 and MQSA
regulations.

**Exposure.** The amount of x-irradiation, quantitated by measuring the amount of ionization in air caused by the radiation.

**Exposure indicator (index).** Number ascribed to an image related to the exposure.

**Exposure time.** The duration of primary x-rays striking the breast and image receptor.

**F**

**Full field digital mammography (FFDM).** An x-ray imaging system dedicated to providing an image of the entire breast that is stored by computer, as opposed to screen-film mammography or a digital biopsy unit that acquires small field-of-view images of a segment of the breast.

**Fill factor.** The fraction of the area of a detector element that is actively sensitive to the incident x-rays.

**Flat fielding.** Correction of a digital image for non-uniform detector response and x-ray beam non-uniformities. Flat-fielding helps reduce artefacts and structured noise in DR images.

**Focal spot.** The area of the target or anode that is bombarded by electrons from the cathode of the x-ray tube to produce x-rays. The smaller the focal spot, the better the limiting spatial resolution of the x-ray system, especially in magnification mammography.

**Fog.** The unwanted signal added to an image by the exposure of the image receptor to light, radiation, or heat between patient exposures.

**Format.** A particular way to encode information for storage in a computer file. Each digital image has its own headers, codes, and rules for laying out image content. There are many different file structures for each kind of file, including executable programs, word processing documents, image, graphics files and databases.

**For Presentation.** Images that are appropriate for diagnostic interpretation. They may or may not have had image processing performed to alter their characteristics.

**For Processing.** Images that have been corrected to account for characteristics of the detector but which are intended to be further processed before being used for interpretation. These are also called “raw” images.

**Full-field digital mammography system.** A digital mammography system designed to produce digital mammograms of the entire breast.

**G**
Ghost image. An image whose intensity is related to previous exposures. As used here, ghosting includes two phenomena: 1) “lag”, which is a residual image from previous exposures to the image receptor. This is caused by incomplete readout of the previous image, or incomplete erasure of prior images, 2) true ghosting, which is a change of detector sensitivity related to previous detector exposure and may be caused by incomplete erasure of prior images. In both cases, an artefactual image pattern is superimposed on subsequent images.

Gigabyte. A unit of computer memory or data storage capacity equal to 1,024 megabytes ($2^{30}$ bytes).

Gray scale display function (GSDF). A DICOM standard established to ensure that images are displayed with similar grey scale perception and basic appearance on display systems of different luminance. It is linearly related to human perceptual response, allowing applications to know apriori how image values are transformed to viewed luminance values by a display system.

Gray-scale ramp. A region on the TG-18 or other test pattern in which the pixel intensity is increased by one unit at a time to cover the entire display range. The gray-scale ramp is used to test display system software and hardware.

Grid. A set of thin, closely spaced strips of highly attenuating material, such as lead, interspaced by a radiolucent support material, such as carbon fiber. In mammography the grid is placed between the breast and image receptor to reduce scattered radiation reaching the image receptor. Scattered radiation reduces image contrast in mammography and limits the detection of low-contrast structures such as fibers and masses. Grids improve the contrast of radiographic images at the price of increased dose to the patient.

H

Half-value layer (HVL). The thickness of a specified substance which, when introduced into the path of a beam of radiation, reduces the exposure rate by one-half. HVL is a measure of beam quality and is usually specified in millimeters of aluminum for diagnostic x-ray equipment. The higher the HVL, the more penetrating the x-ray beam.

Hanging protocol. A description of the way a series of mammograms is presented to a radiologist on the workstation, since the entire case cannot be viewed in its entirety at full resolution in a single view presentation.

Hard Copy. The display of digital mammograms on film.

Health Level 7 (HL7). The established standard for the exchange, management and integration of data that support clinical patient care and the management, delivery and evaluation of healthcare services.

Heel effect. Non-uniformity of the radiation field striking the image receptor caused by
the geometry of the x-ray target (both the angulation of the x-ray target and it’s position relative to the detector). X-ray intensity is generally higher toward the chest wall than nipple, due to the increased path length through the target and filter of x-rays striking the nipple side of the image receptor, as well as the increased distance to the detector.

I

**Illuminance.** A photometric quantity describing the light intensity per unit area falling on a surface. The SI unit for illuminance is lux (candela-steradians per square meter). In mammography it is important that the illuminance in the reading room be low.

**Image blur.** The spatial spread or unsharpness of distinct edges in a image, caused by the finite size of the focal spot, light spread in a phosphor, or motion of the object, resulting in reduced perception of detail and indistinct edges in the image.

**Image compression, Lossless and Lossy.** The process by which data is reduced to minimize storage space. Lossless data compression allows the exact original data to be reconstructed from the reduced data. Lossy compression provides high degrees of compression, but result in a certain amount of information loss when the image is restored.

**Image contrast.** The pixel value difference between adjacent areas in an x-ray image resulting from an attenuation difference in the imaged object.

**Image manipulation.** The action of changing the appearance of the image by modifying the underlying data. It might involve changing the spatial frequency information by smoothing or edge-enhancement, or adjusting the contrast by histogram manipulation.

**Image noise.** See radiographic noise.

**Image quality.** The overall clarity of a radiographic image. Image sharpness, image contrast and image noise are three common measures of image quality.

**Image receptor.** A device that detects and records the distribution of x-rays to form an image.

**Image sharpness.** The overall impression of detail in a radiographic image.

**Integrating the Healthcare Enterprise (IHE).** An initiative by healthcare professionals and industry to improve the way computer systems in healthcare share information.

J

**Just noticeable differences (JND).** A measurement of the difference in signal level which may just be reliably discerned on the monitor at different intensity levels. See DICOM grayscale standard.
K

**Kilovoltage, peak (kVp).** The maximum value of the potential difference (kVp) between anode and cathode in an x-ray tube. The kVp determines the maximum energy of x-rays emitted by the x-ray tube, usually measured in kilo-electron volts (keV).

L

**Lag.** A phenomenon related to the temporal characteristics of the signal from a detector. If the detector is “read-out” before the entire signal has been collected, the left over signal may show up the next time that detector element is read. This may cause the blurring of moving objects, or a shadow image.

**L-number.** For some CR systems, the latitude index which indicates the dynamic range of the system. See S-number.

**Linearity.** System response where the output increases in direct proportion to the input signal.

**Luminance.** A photometric quantity describing the light power per unit area per unit solid angle emitted by a light source. The SI unit for luminance is candelas per square meter (nits). In mammography it is important that the display devices used for viewing mammograms have high luminance.

**Lux.** The SI unit of illuminance. One lux equals one lumen per square meter. The lumen is derived from the candela and is the luminous flux emitted into unit solid angle (1 steradian) by an isotropic point source having a luminous intensity of 1 candela.

M

**Mammography Quality Standards Act (MQSA).** A United States law that went into effect in 1994, with the final rules promulgated in 1997. MQSA requires all mammography facilities in the United States to be accredited by an approved body and undergo annual inspections by state or federal inspectors. The Food and Drug Administration (FDA) is responsible for implementing MQSA and developing national mammography regulations. The latest guidelines can be found at: www.fda.gov/cdrh/mammography/

**Matrix.** An arrangement of objects in rows and columns. Pixel signal values in this arrangement are used to represent an image in the computer.

**Matrix, active.** A set of transistors used to sample a set of discrete detector elements.

**Mean glandular dose.** See Average glandular dose.
**Mediolateral view.** One of the more common diagnostic views for mammography, which has been replaced by the mediolateral oblique view as a standard screening view. The image receptor is placed lateral to the breast, and the horizontal x-ray beam is directed from medial to lateral aspect through the breast.

**Mediolateral oblique view.** Now one of the standard two views of the breast. The image receptor is angled 30°-60° from horizontal so that the cassette assembly is parallel to the pectoral muscle and the corner of the cassette holder fits comfortably into the axilla. The x-ray beam is directed from the superomedial to the inferolateral aspect of the breast.

**Megabyte.** A unit of computer memory or data storage capacity equal to 1,048,576 \(2^{20}\) bytes.

**MG.** The DICOM modality type for digital mammography which ensures that the acquired images contain all relevant information that is necessary for further processing and usage. This profile is absolutely necessary for generating correct mammography image content and for proper display on the review workstation.

**Milliampere (mA) setting.** The electron current passing from the cathode to the anode in an x-ray tube. For a fixed kVp, the output of x-rays per unit time from the tube is linearly proportional to the mA setting.

**Milliampere-seconds (mAs).** The product of electron current (mA) and the exposure time (in seconds). For a fixed kVp, total x-ray output is linearly proportional to mAs.

**Modulation transfer function (MTF).** A parameter that describes the contrast captured by the imaging system at each spatial frequency.

**Modality.** The DICOM classification of a diagnostic device, such as computed tomography (CT), magnetic resonance imaging (MRI), nuclear medicine (NM), ultrasound (US), computed or direct radiography (CR), secondary capture (SC) or digital mammography (MG).

**Mean pixel value (MPV).** The mean (or average) value of the pixels in a region of interest in a digital mammogram.

**N**

**Noise.** Fluctuations of the signal that are not associated with the imaged object. Elevated levels of noise can be caused by the use of too few x-ray photons, random electronic pulses, and non-uniformities in the detector. In mammography systems, quantum noise (or quantum mottle) should be the dominant noise source. The standard deviation in a region-of-interest (ROI) in the output image is taken as a measure of noise.

**Noise power spectrum (NPS).** Function which describes image noise as a function of spatial frequency, also known as the Wiener spectrum.
**nit.** The SI unit of luminance. One nit equals one candela per square meter, or one lumen per steradian per square meter.

**O**

**Operating level.** The central value about which we expect day-to-day measurements to fluctuate, for example, the empirically determined mid-density on a sensitometric film.

**P**

**Picture archiving and communication system (PACS).** The local image storage and transfer system within the facility. It is comprised of a communications backbone with acquisition devices (digital mammography units as well as other modalities), workstations (both mammographic quality as well as those not of high enough quality for primary diagnosis), output devices (printers or CD writers), and an archive. All of these communicate using DICOM, and patient studies and images can be stored, queried and displayed at a number of locations.

**P-value.** See presentation value.

**Phantom.** A test object that simulates some aspect of human anatomy. A breast phantom simulates a typical breast in terms of size, composition, and x-ray attenuation and may contain test objects that simulate anatomy in the breast.

**Pixel.** One picture element of an acquired or displayed image. On a presentation device, in some cases, not every pixel is displayed unless there is a 1:1 or “full” display mode. Without which information may be lost.

**Pixel pitch.** The physical distance between the centers of adjacent pixels on the digital detector or display. In the DICOM tags, pixel pitch is called imager pixel spacing and is generally equal to detector element spacing.

**Pixel value.** Numeric value assigned to a pixel. In current FFDM systems pixel values can range from 1 to 1024 (for 10-bit storage), 1 to 4096 (12-bit storage), or 1 to 16384 (14-bit storage), depending on the detector. Most systems provide linear scales for pixel values, but some present the data in logarithmic form. (see ADU)

**Pixel value offset.** A constant value is added to the measured signal values of all pixels. Only some manufacturer’s systems use a pixel value offset.

**Polymethyl methacrylate (PMMA).** Also known by the generic name acrylic, and trade names Plexiglas (Rohm and Haas) and Acrylate (General Electric).

**Portable Data for Imaging.** [IHE] Enables creating DICOM-compliant image CDs on the modality.

**Presentation value.** Pixel value after a value of interest (VOI) look-up table (LUT) or
window width and window level settings have been applied.

**Primary class display device.** A display device used for the interpretation of medical images (also referred to in the text as ‘diagnostic display device’).

**Processed image.** The image after image processing, ready for presentation on the monitor or print-out. In the DICOM file, the value of tag Pixel Intensity Relationship (0028,1040) is ‘for presentation’. In digital mammography, processed images have typically been thickness-equalized to make the image visible with approximately uniform background densities out to the skin line without re-windowing.

**Processor artefact.** Any unwanted or artificial image feature appearing on an image due to malfunction or misuse of the film processor or laser imager.

Q

**Qualified Workstation.** A workstation which has passed all tests of resolution and GSDF compliance with images from a particular manufacturer’s acquisition device. A workstation which has not passed all of the tests must not be used as a primary diagnostic display device.

**Quality assurance (QA).** A management tool that includes policies and procedures (including quality control tests and tasks) designed to optimize the performance of facility personnel, equipment, and procedures.

**Quality control (QC).** The routine performance of tests and tasks and the interpretation of data from those tests to characterize equipment and personnel function. QC includes the corrective actions taken when systems are found to be “out of control”.

**Quality control technologist.** The technologist assigned the task of QC testing and maintaining QC records for radiographic imaging systems.

R

**Radiographic noise.** Fluctuations in signal values from pixel to pixel due to the discrete nature of x-ray photons and the resulting random fluctuations in the number of photons contributing to the image at each location. Also called quantum noise or quantum mottle, radiographic noise increases with increasing x-ray fluence, but less rapidly than the radiographic signal.

**Radiographic sharpness.** The distinctness or perceptibility of the boundary or edge of a structure in the x-ray image.

**Raw image.** See “unprocessed image” and “for processing”.

**Raw noise.** The noise in an unprocessed, but flat-fielded image. See noise.
Repeat analysis. A systematic approach to determine the number of and causes for images being repeated or re-taken. Analysis of data on repeats helps identify technical problems and/or operational difficulties and suggests ways to improve mammography quality.

Review workstation (RWS). A computer with high-resolution monitors designed for the interpretation of digital mammograms. There is often a graphical interface, which incorporates a DICOM browser, a viewer with hanging protocols for displaying multiple images at a time, and a connection to the radiology information system (RIS). The viewer provides functions for adjusting window width and level, zooming, scrolling, adding text and graphical annotations, and performing measurements.

Resolution. The fineness of detail that can be distinguished by an imaging system, often described by the MTF and measured by a bar pattern.

RIS. Radiology information system. A system used by radiology departments to maintain a record of patients, their demographics, and their imaging results.

Sampling aperture. The linear dimension of an area over which a single sample of a spatially varying quantity is measured. Spatial variations finer than the sampling aperture are integrated to produce a single measurement.

Sampling pitch. The distance between the centers of adjacent sampling apertures.

SC. The DICOM modality representing “Secondary Capture” images, normally digitized screen-film mammograms. Depending on the vendor, the acquired images may or may not contain all relevant information that is necessary for further processing and usage.

Scanning systems. Units that either have a moving detector, or use a scanning laser beam to read the signal off the detector.

Scatter fraction. The ratio of the x-ray exposure due to scattered radiation to the x-ray exposure due to both scattered and primary radiation detected by an image receptor.

Screen-film mammography. Radiographic images of the breast performed with high-detail intensifying screen(s) that are in close contact with the film in the cassette.

Screening mammography. X-ray breast examination of asymptomatic women in an attempt to detect breast cancer when it is small, nonpalpable, and confined to the breast.

Screen processing. Image processing applied in a CR system during readout of the imaging plate.
**Secondary class display device.** A display device used for viewing the images, but not acceptable for diagnostic purposes. This can include the acquisition workstation or operator’s console.

**Server.** A computer system or program that performs specific tasks, such as access to files or shared peripheral devices, and constantly listens to machines on the network for requests to perform those tasks. Permissions may need to be granted to certain machines or users to enable it to perform the task.

**Service class.** [DICOM] A function, such as storage or printing, specified by DICOM and implemented by a device, which may provide or use the service.

**Service class provider (SCP).** [DICOM] A system or application that provides a DICOM Service (often viewed as the “server” of a service).

**Service class user (SCU).** [DICOM] A system or application that uses a DICOM Service (often viewed as the “client” of a service).

**S - Nominal sensitivity setting.** Indication of the sensitivity setting of the system, comparable to the speed class in screen-film systems. A speed class 100 corresponds to a mean absorbed dose to the detector of 10 microGray.

**Sharpness (or unsharpness).** The subjective impression of the distinctness of the edge of a structure in an image. It is related to the magnitude and width of the object, that is, the abruptness of the signal level change across the boundary.

**Signal.** In digital mammography, the signal is considered to be the pixel value. Normally, the image values are highest with the most x-ray transmission, and in the raw image, are either linear or logarithmic with increasing exposure.

**Signal to noise ratio (SNR).** The ratio of the signal content to the noise content of an image. The SNR is calculated as the mean signal value in an area divided by the standard deviation of signal in that area, assuming the object was uniform.

**Signal Difference to Noise Ratio (SDNR).** SDNR is a measure of the ability of a system to differentiate an object of low contrast from its background. For digital mammography, the reference contrast is 1.0 mm PMMA on a 4.0 cm PMMA background.

**Soft copy.** An image displayed on a high-resolution computer monitor rather than printed on a film.

**Standard breast.** A 4.2 centimeter (cm) thick compressed breast consisting of 50 percent glandular and 50 percent adipose tissue used as the “average” breast for dosimetry calculations. This may be represented by 4.0 cm of PMMA, a thickness which attenuates approximately the same amount as the standard breast.

**Standard Deviation.** A mathematical representation of the degree of fluctuation in a set
of values. In mammography, the standard deviation is used to quantify noise. It is defined as
\[
\sigma = \frac{1}{N-1} \sqrt{\sum_{i=1}^{N} (P_i - P)^2}
\]
where N is the number of pixels whose standard deviation is to be calculated, \(P_i\) is the value of the ith pixel, and \(\bar{P}\) is the average pixel value. The summation is taken from \(i = 1\) to \(N\) of the difference between each pixel’s signal value and the mean pixel value squared.

**Standard test block.** A PMMA test object representing the attenuation of the average breast (although not an exact tissue-substitute) so that the x-ray machine operates correctly under automatic exposure control and the dosimeter readings may be converted from exposure to average glandular tissue. The thickness is 40 ± 0.5 mm. The standard test block covers the whole detector.

**Standard region-of-interest.** The region of interest (typically 4 cm², but always > 1 cm²) in which mean pixel (ROI) values and standard deviation are measured. The center of the region-of-interest is positioned 60 mm perpendicular to the chest wall edge of the image, and centered laterally.

**Stitching.** The method to join and re-align images from smaller sized detectors to form a full-sized image. It is sometimes used to mask the presence of dead columns in detectors.

**Structured noise.** A background pattern in a radiograph that often adds visual clutter and degrades or masks the detection of a lesion. In a clinical image, normal anatomy can provide structured noise. In phantom images, structure noise is typically the result of systematic artefacts such as roller marks in screen-film images, grid lines, or poor flat-fielding of digital images.

**T**

**Test Pattern.** Artificially produced image for the evaluation of gray tone rendition, contrast, resolution, or the geometric characteristics of image display equipment.


**Thermoluminescent dosimeter (TLD).** A radiation exposure measurement device using a chip or powder that absorbs radiation and when subsequently heated produces light whose intensity is proportional to the amount of radiation absorbed.

**Threshold contrast.** The smallest detectable contrast for a given detail size and x-ray exposure that can be shown by the imaging system over its whole dynamic range. The threshold contrast is a measure for imaging of low-contrast structures, and is determined largely by the DQE of the detector.
Trainee. An individual who is in the process of becoming certified, and performs testing under the direct supervision of a certified mammographic medical physicist.

U

Uncorrected image. The image from a digital imaging system before any image processing, including detector corrections and flat-fielding, is performed.

Unprocessed image. The image from a digital imaging system after flat-fielding and detector corrections (corrections for individual pixel sensitivity variations and electronic gain of the readout) but before other image processing (such as thickness equalization) has been applied. The pixel value is in general linearly related to exposure in the unprocessed image. The international standard IEC MT 31 refers to the unprocessed image as ‘raw data’.

V

Viewbox. A device providing a relatively uniform surface luminance for viewing mammographic films. Mammographic viewboxes should have a luminance level of at least 3,500 nit.

Variation. The change in intensity or pixel value across an image of a uniform object.

Value of interest lookup table (VOI LUT). The VOI LUT defines the (non-linear) transformation of pixel signal values into values meaningful for presentation (presentation values).

W

Window center or level. The signal setting at which a median gray scale is displayed.

Window width. The range of signal values over which gray scales ranging from black to white are displayed. The window center or level is at the center of that range.
IX. REFERENCES


57. Houn, F. “Medical Physicist’s Annual Survey Requirements ” (letter to medical physicists), Department of Health and Human Services, Food and Drug Administration. March 29, 1996.


62. International Electrotechnical Commission, Medical electrical equipment-characteristics of digital imaging devices. 1 : Determination of the detective


