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Navy Diagnostic Imaging Equipment Performance Survey Manual

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NEHC Technical Manual TM-6470.03-1; CH-2, *Navy Radiological Systems and Performance Evaluation Manual*, dated 14 Nov 2006, is hereby cancelled.

This manual may be accessed through the NMCPHC website:
<http://www.med.navy.mil/sites/nmcphc/occupational-and-environmental-medicine/rhd/Pages/rsoep.aspx>.

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TABLE OF ISSUANCE AND REVISIONS/CHANGES

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LIST OF FORMS AND REPORTS

1. Forms. The following Navy and Marine Corps Public Health Center (NMCPHC) forms are available electronically at: <https://navalforms.documentservices.dla.mil/web/public/forms>.

Form No.	Form Title
NMCPHC 6470/21	General Radiographic Unit Survey
NMCPHC 6470/22	Dental Radiographic Unit Survey
NMCPHC 6470/23	General Fluoroscopy Unit Survey
NMCPHC 6470/24	Computed Tomographic Unit Survey
NMCPHC 6470/25	Ultrasound Scanner System Survey
NMCPHC 6470/26	Magnetic Resonance Imaging Unit Survey
NMCPHC 6470/27	Nuclear Medicine Camera Survey
NMCPHC 6470/28	Direct Digital Radiographic System Survey
NMCPHC 6470/29	Computed Radiographic System Survey

2. Reports. The reporting requirements for this manual are exempt from reports control per SECNAV M-5214.1 of December 2005, paragraph 7j.

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ACRONYM LIST

AAPM	American Association of Physicists in Medicine
ABC	Automatic Brightness Control
ABHP	American Board of Health Physicists
ABR	American Board of Radiology
ACR	American College of Radiology
AEC	Automatic Exposure Control
AKR	Air Kerma Rate
ALARA	As Low As Reasonably Possible
AP	Anterior/Posterior
BB	Ball Bearing
BUMED	Bureau of Medicine and Surgery
BW	Bandwidth
CBCT	Cone Beam Computed Tomography
CFOV	Central Field Of Vision
CNR	Contrast to Noise Ratio
COR	Center Of Rotation
cov	coefficient of variation
CR	Computed Radiography
CRCPD	Conference of Radiation Control Program Directors
CRT	Cathode Ray Tube
CT	Computed Tomography
CTDI	Computed Tomography Dose Index
DC	Direct Current
DDR	Direct Digital Radiography
DICOM	Digital Imaging and Communications in Medicine
DPSC	Defense Personnel Support Center
DQA	Delivery Quality Assurance
DR	Digital Radiography
DRMO	Defense Reutilization and Marketing Office
DSOV	Diameter of Spherical Volume
EPI	Electronic Portal Imaging
ESE	Entrance Skin Exposure
ESK	Entrance Skin KERMA
ESKR	Entrance Skin KERMA Rate

ACRONYM LIST (continued)

FDA	Food and Drug Administration
FDD	Focus to Detector Distance
FOV	Field Of Vision
frs	frame rate per second
ftcd	foot candles
FWHM	Full Width at Half Maximum
GAF	General Aniline & Film
GFI	General Fluoroscopic Units
GRE	Gradient Echo
HAZMAT	Hazardous Materials
HDR	High Dose Radiation
HLC	High Level Control
HU	Hounsfield units
HVL	Half Value Layer
ICRP	International Council on Radiation Protection
II	Image Intensifier
IMRT	Intensity Modulated Radiation Therapy
IRI	Interventional Radiology Imaging
JCAHO	Joint Commission for Accreditation of Healthcare Organizations
KERMA	Kinetic Energy Released in Material
keV	Kilo-electron volts
KVCT	Kilovoltage Computed Tomography
kVp	kilovolt peak
LINACs	Linear Accelerators
lp/cm	line pairs per centimeter
LR	Lower Right
LSF	Line Spread Function
LUT	Look Up Table
mA	milliamp
Mammo	Mammography
mAs	milliamp seconds
mGy	milliGrey
MHz	megahertz
MPAB	Medical Physics Advisory Board

ACRONYM LIST (continued)

MQSA	Mammography Quality Standards Act
mR	milli-Roentgen
mrem	milirem
MRI	Magnetic Resonance Imaging
MSAD	Multiple Scan Average Dose
msec	millisecond
MTF	Modulation Transfer Function
MVCT	MegaVoltage Computed Tomography
NAVMED	Navy Medicine
NCRP	National Council of Radiation Protection and Measurements
NMCPHC	Navy and Marine Corps Public Health Center
NME	Navy Medicine East
Nuc Med	Nuclear Medicine
NxT	Clinical Protocol
OBI	onboard imaging
OD	Optical Density
OID	Object to Image Distance
PACS	Picture Archiving and Communication System
PET	Photon Emission Tomography
PIU	Percent Image Uniformity
PMMA	Acrylic
PMT	Photomultiplier Tube
PQS	Personal Qualification Standard
PSG	Percent Signal Ghosting
QA	Quality Assurance
QC	Quality Control
RAD	Radiation Absorbed Dose
RF	Radiofrequency
ROI	Region Of Interest
SD	Shielding Design
SID	Source to Image Distance
SMPTE	Society of Motion Picture and Television Engineers
SNR	Signal to noise ration
SPECT	Single Photon Emission Computed Tomography

ACRONYM LIST (continued)

SSD	Source to Skin Distance
STP	System Transfer Properties
TE	Echo Time
TFT	Thin Film Transistor
TG	Task Group
TGC	Time Gain Compensation
TM	Tissue Mimicking
UFOV	Useful Field Of Vision
UL	Upper Left
US	Ultrasound
USUHS	Uniformed Services University of the Health Science

Chapter 1

Navy Diagnostic Imaging Equipment Performance Survey Manual Introduction

A. Background

In accordance with BUMEDINST 6470.22, this manual has been prepared to provide the surveyor with standard procedures for acceptance and periodic testing of diagnostic imaging equipment throughout the Navy and Marine Corps. It provides a uniform methodology for testing equipment and reporting results. Standardized procedures ensure that required parameters are evaluated and are consistent throughout all naval medical facilities. Standardized formats and procedures also provide a means for comparing results between facilities, among surveyors, between manufacturers and among individual systems from a single manufacturer. This manual will provide objective quality evidence that the radiographic unit has been evaluated and the result of the assessment. This will facilitate trending equipment performance, identifying equipment and training deficiencies, and other applications.

This manual establishes diagnostic imaging equipment survey periodicity, parameters to be measured, surveyor training and qualifications, and reporting requirements. The manual does not address therapeutic radiological systems. Navy radiation oncology services should establish local equipment performance programs aligned with nationally accepted protocols (e.g. American Association of Physicists in Medicine (AAPM)).

The manual provides guidance for performing survey measurements which will be instructional for surveyors-in-training. It may also be of use to diagnostic radiologists and biomedical equipment repair technicians in the performance of their duties.

B. Extent of Surveys

In addition to the survey periodicity listed in the following chapters, diagnostic imaging equipments should be surveyed prior to first clinical use (acceptance) and after major repairs. Invasive acceptance testing is complex and time-consuming since almost all combinations of variable settings are evaluated. Detailed acceptance testing procedures

are not covered in this manual, manufacturer's technical

specification and Federal Regulations should be consulted to ensure adequate acceptance testing. Non-invasive periodic testing is less rigorous and should cover the range of clinical use. Testing after repairs should be limited to those parameters potentially affected by the work performed unless deemed necessary by qualified medical physics authority.

An effective radiation protection survey should include communication between clinicians, radiological technologists, repair technicians and surveyors. Equipment parameters, operational procedures, patient exposures and related factors should be evaluated. Coordination with facility personnel prior to the survey is necessary to ensure equipment is operational and available for testing. Significant findings should be discussed with facility personnel responsible for ensuring equipment repairs are completed prior to leaving the facility.

C. Radiation Protection

X-ray producing machines are tested for technical performance and radiation safety. The objective of an effective x-ray survey program is to provide a safe diagnostic tool that benefits both the patient and the medical practitioner by providing acceptable image quality while simultaneously keeping patient radiation dose as low as reasonably achievable (ALARA).

Radiation dose received by patients may be decreased by eliminating unnecessary procedures and procedures of minimal value and using technical advances, such as using high speed image receptors and ensuring that x-ray equipment is operating in compliance with the Radiation Control for Health and Safety Act of 1968, in clinical practice.

Radiation dose received by medical, dental and allied health personnel should also be minimized. Fundamental methods to reduce staff dose include the provision of protective barriers, protective clothing

and the implementation of appropriate operational procedures. A well-managed dosimetry program for medical x-ray personnel is also very important. When performing radiological equipment surveys at other commands, the individual should make themselves available to perform the command's annual external Radiation Health Program audit as required by NAVMED P-5055, Navy Radiation Health Protection Manual.

D. Training and Qualification

Training guidelines for qualification as a surveyor for each modality are established by the Medical Physics Advisory Board (MPAB) and are included in this manual. Individuals applying to be designated as a qualified surveyor will complete and submit the appropriate Personal Qualification Standard (PQS) to the Navy and Marine Corps Public Health Center (NMCPHC). The MPAB will review completed PQS packages and forward the applications to the Bureau of Medicine and Surgery (BUMED) for final approval. Approved PQS packages will be maintained by NMCPHC to document the training of individual surveyors.

Senior qualified physicists at each Naval Medical Center and at Uniformed Services University of the Health Science (USUHS) will mentor surveyors. Other personnel qualified as surveyors at the appropriate level can provide mentored training with prior approval from MPAB. Surveys by trainees should be reviewed and countersigned by the mentoring senior physicist.

Physicists certified by the American Board of Radiology (ABR) or American Board of Medical Physics (ABMP) are considered qualified to survey any diagnostic or therapeutic unit in the field in which they are certified. However, the ABR or ABMP certification letter must be forwarded to NMCPHC for documentation of qualifications. Special qualifications are needed by the physicist of record for mammography surveys in accordance with the Mammography Quality Standards Act (MQSA) of 1992. All documentation must be forwarded to NMCPHC and MPAB for review.

All qualified surveyors will maintain continuing education hours and continuing experience as practicable in their current assignments. Annual peer review of all active surveyors will be performed by the MPAB.

E. Qualification Levels

Diagnostic Imaging Equipment modality surveying qualification is separated into two categories: Basic and Advanced Diagnostic Imaging Equipment. Surveyors should be fully qualified at Basic Diagnostic Imaging Equipment prior to testing Advanced Diagnostic Imaging Equipment modalities. Surveyors may, and will likely be, qualified for individual Advanced Diagnostic Imaging Equipment modalities.

Basic x-ray surveyors should be qualified to perform surveys of A) general radiographic units, B) dental radiographic units, C) computed radiographic units and D) digital radiographic units. Basic surveyors should also be qualified to evaluate local quality control programs for these systems.

Advanced Diagnostic Imaging Equipment surveyors should be qualified (on a type basis) to perform surveys of fixed and mobile General Fluoroscopic Units (GFI), Interventional Radiology Imaging (IRI) of fluoroscopic units including angiography and cardiac catheterization systems, Ultrasound (US) units, Magnetic Resonance Imaging (MRI) systems, Nuclear Medicine (Nuc Med) imaging systems, mammography (Mammo) and Computed Tomography (CT) and Cone Beam CT (CBCT) systems. Advanced surveyors may also be qualified to perform radiographic Shielding Design (SD) evaluations.

Diagnostic Imaging Equipment modality levels are listed in Table 1-1. Basic and Advanced Diagnostic Imaging Equipment PQSs are provided elsewhere in this manual

Qualifications are valid for a maximum of 5 years. After 5 years, the MPAB will review each surveyor's activity to determine if proficiency has been maintained. If the board determines the surveyor has not maintained proficiency, he/she should repeat initial qualifications to regain certification.

Individuals certified by the ABR and ABMP in Diagnostic Radiological Physics are by virtue of certification qualified to perform testing all modalities listed in this manual.

Individuals qualified as surveyors of mammography systems must also meet the requirements listed in MQSA. Once the individual has satisfied MQSA requirements, he/she should forward his/her state certification to NMCPHC for verification of qualification.

F. Reports

Reports document the parameters of each piece of equipment evaluated during a survey. A unit survey

summary sheet describing equipment discrepancies, recommended corrective actions, and specific unit information should be sent to the facility possessing the surveyed unit. If required, the facility should forward a corrective action report to the surveyor within 30 days. The surveyor should track corrective actions and should report all corrective action reports delinquent greater than 60 days to NMCPHC and the facility's regional command (i.e. Navy Medicine East) for further action.

Each discrepancy should be identified as minor or significant in the professional judgment of the surveyor. Significant discrepancies are conditions that impact patient/operator safety or image quality. The entire survey package need not be forwarded. Each regional command, as listed in BUMEDINST 6470.22, will forward a summary listing of radiological system evaluations performed to NMCPHC quarterly using the current NMCPHC approved computerized reporting system.

G. How to Use This Manual

Each chapter in this manual lists the required tests for each type of imaging system or procedure, and the frequency and tolerances to which they should be performed. The level of training appropriate for the particular unit being surveyed and supplementary recommended references is also included. Surveyors should maintain proficiency and stay abreast of current issues regarding the modalities they are qualified to survey.

Table 1-1.—Diagnostic Imaging Equipment Surveyor Qualification Levels.

	Qualified Modalities
Basic Diagnostic Imaging Equipment	1. General Radiographic Units 2. Dental Radiographic Units 3. Computer Radiographic Units 4. Digital Radiographic Units
Advanced Diagnostic Imaging Equipment	1. General Fluoroscopic Imaging (GFI) 2. Interventional Radiology Imaging (IRI) 3. Ultrasound (US) 4. Magnetic Resonance Imaging (MRI) 5. Nuclear Medicine (Nuc Med) Imaging 6. Shielding Design (SD) 7. Computer Tomography (CT) 8. Cone beam Computed Tomography (CBCT)

1. Surveyors should be fully qualified as Basic Diagnostic Imaging Equipment Surveyor before progressing to Advanced Diagnostic Imaging Equipment Surveyor.
2. Surveyors may be qualified for sublevels (individual systems) within Advanced Diagnostic Imaging Equipment.
3. Surveyors may perform tests on equipment without being certified; however, the senior regional physicist must review and approve their survey report.
4. Mammography qualifications are performed in accordance with MQSA.

Basic Diagnostic Imaging Equipment
 Surveyor Personal Qualification Standard

NMCPhC TM 6470.1
 JUNE 2013

Name	Rank	Command

Knowledge Factors:

All applicable knowledge factors in accordance with AAPM Report 90 have been adequately demonstrated.

Senior Physicist	Date

Practical Factors:

Perform a minimum of three (3) Under Instruction evaluations of each modality:

Each evaluation must include all parameters performed during acceptance testing.

General Radiographic Unit:

Qualified Surveyor Date	Qualified Surveyor Date	Qualified Surveyor Date

Dental Radiographic Unit:

Qualified Surveyor Date	Qualified Surveyor Date	Qualified Surveyor Date

Computed Radiographic Systems:

Qualified Surveyor Date	Qualified Surveyor Date	Qualified Surveyor Date

Digital Radiographic Systems:

Qualified Surveyor Date	Qualified Surveyor Date	Qualified Surveyor Date

Applicant is recommended for qualification of Basic Diagnostic Imaging equipment

Senior Physicist	Date

Applicant is qualified to perform all modalities listed as Basic Diagnostic Imaging equipment

BUMED	Date

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Advanced Diagnostic Imaging Equipment
 Surveyor Personal Qualification Standard

NMCPHC TM 6470.1
 JUNE 2013

Name	Rank	Command

Knowledge Factors:

All applicable knowledge factors in accordance with AAPM Report 90 have been adequately demonstrated.

Senior Physicist	Date

Practical Factors:

Perform a minimum of three (3) Under Instruction evaluations of each modality:

Each evaluation must include all parameters performed during acceptance testing.

General Fluoroscopic Imaging (GFI):

Qualified Surveyor	Date	Qualified Surveyor	Date	Qualified Surveyor	Date

Interventional Radiology Imaging (IRI):

Qualified Surveyor	Date	Qualified Surveyor	Date	Qualified Surveyor	Date

Ultra Sound (US):

Qualified Surveyor	Date	Qualified Surveyor	Date	Qualified Surveyor	Date

Magnetic Resonance Imaging (MRI):

Qualified Surveyor	Date	Qualified Surveyor	Date	Qualified Surveyor	Date

Nuclear Medicine Imaging (NMI):

Qualified Surveyor	Date	Qualified Surveyor	Date	Qualified Surveyor	Date

Advanced Diagnostic Imaging Equipment
 Surveyor Personal Qualification Standard

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Shielding Design (SD):

Qualified Surveyor	Date	Qualified Surveyor	Date	Qualified Surveyor	Date

Computed Tomography (CT):

Qualified Surveyor	Date	Qualified Surveyor	Date	Qualified Surveyor	Date

Cone Beam Computed Tomography (CBCT):

Qualified Surveyor	Date	Qualified Surveyor	Date	Qualified Surveyor	Date

Applicant is fully qualified as Basic Diagnostic Imaging Equipment surveyor and is recommended for qualification the following modality: (circle all that apply)

General Fluoroscopic Imaging (GFI)

Nuclear Medicine Imaging (NMI)

Interventional Radiology Imaging (IRI)

Shielding Design (SD)

Ultra Sound (US)

Computed Tomography (CT)

Magnetic Resonance Imaging (MRI)

Cone Beam Computed Tomography (CBCT)

Senior Physicist Date

Applicant is qualified to perform diagnostic performance surveys of the above modalities.

BUMED Date

Chapter 2

General Radiographic Unit (Fixed and Portable)

A. Minimum Required Personnel Qualifications

Basic Diagnostic Imaging Equipment Surveyor

B. Testing Periodicity

Facility	Frequency
Ashore Facilities	Annually
Afloat Units	Every 24 Months
Deployed Medical Units	Prior to Fielding
Hospital Ships	Annually
Veterinary Clinics	Every 24 Months
All Units	Upon Acceptance

C. Equipment

1. Ionization chamber/solid state detector
2. kVp meter
3. Light meter
4. Type 1100 10 x 10 cm Al plates (9 mm total, three 2 mm, two 1.0 mm, two 0.5 mm thicknesses)
5. 1.0 mm Copper plate (>10 x 10 cm)
6. X-ray beam alignment test tool (if available)
7. Lead plate (at least 3.2 mm x 20 x 20 cm)
8. TO20 threshold contrast test object
9. Resolution test object (e.g. Huttner 18)
10. CR DIN Phantom
11. M1 geometry test object
12. Contact mesh
13. Tape measure
14. Tape
15. Level
16. General Radiographic Unit Survey

D. References

1. AAPM Report 31, *Standardized Methods for Measuring Diagnostic X-ray Exposures*. 1990.
2. AAPM Report 60, *Instrumentation Requirements of Diagnostic Radiological Physicists*. 1998.
3. AAPM Report 74, *Quality Control in Diagnostic Radiology*. 2002.
4. Bushberg, J.T., Seibert, J.A., Leidholdt, E.M. Jr., Boone, J.M. *The Essential Physics of Medical Imaging*. Williams & Wilkins, 2011.
5. Code of Federal Regulations, Title 21, Chapter 1, Section 1020.30/31. April 2011.
6. Curry, T.S. III, Dowdey J.E., Murry, R.C. Jr. *Christensen's Physics of Diagnostic Radiology*. Lea & Febiger, Philadelphia. 1990.
7. Fluke Biomedical, Nuclear Associates, 07-605-7777-1 Rev. 3, EZ CR-DIN Phantoms, Users Manual, May 2006.
8. KCARE *DDR Commissioning and Annual QA Protocol Draft 8.0*. 2005/
9. NCRP Report 99, *Quality Assurance for Diagnostic Imaging Equipment*, National Council on Radiation Protection and Measurements, Bethesda, 1988.

E. General Radiographic Unit

1. Radiation Exposure Reproducibility

- a. Purpose. To ensure that exposure received for the same mA, time, and kVp is the same from exposure to exposure.
- b. Regulations. Determination of reproducibility should be based on 10 consecutive measurements within a time period of one hour, using the same technique factors. For any specific combination of selected technique factors, the estimated coefficient of variation of radiation exposure should be no greater than 0.05. (21CFR1020.31)
- c. The Coefficient of Variation (COV) is the ratio of the standard deviation to the mean value of a population of observations. (21CFR1020.30)

$$C = \frac{s}{\bar{x}} = \frac{1}{\bar{x}} \left[\frac{(X_i - \bar{X})^2}{n - 1} \right]^{\frac{1}{2}}$$

- s = Estimated standard deviation of the population
 \bar{X} = Mean value of observation in sample
 X_i = i th observation sampled
 n = Number of observations sampled

- d. Equipment. Ionization chamber or solid state detector
- e. Procedure. Set the x-ray tube at 40 inches source-to-table distance, if possible. If using an ionization chamber, place the center of the chamber 4 inches above the x-ray table top and center the chamber in the light field (solid state detectors are usually have lead backing). Determine the distance from the focal spot to the center of the ion chamber/solid state detector. Collimate the light field to a narrow beam geometry (e.g. 4x4 cm field) to include the ion chamber/solid state detector. Make radiation exposures at the selected technique. For efficiency, the evaluator is reminded that some meters will read out both exposure and time, therefore, record both for future measurements.
- f. Interpretation of Results. If the coefficients of variation deviate from the criteria listed in 1b,

consult a qualified service engineer. Exposure reproducibility is critical as it directly influences image quality and patient dose.

2. Timer Reproducibility

- a. Purpose. To ensure that the x-ray generator is producing exposure times that are the same from exposure to exposure.
- b. Regulations. Determination of reproducibility should be based on 10 consecutive measurements within a time period of one hour, using the same technique factors. For any specific combination of selected technique factors, the estimated coefficient of variation of radiation exposure should be no greater than 0.05.
- c. Equipment. Exposure meter with timer combination
- d. Procedure. Utilize the procedure described for reproducibility measurements. Measure and record the actual exposure time for 10 exposures at the same timer setting (e.g. 100 msec).
- e. Interpretation of Results. If the cov deviates from the criteria listed in 2b consult a qualified service engineer. Timer reproducibility is critical as it directly influences image quality and patient dose.

3. Timer Accuracy

- a. Purpose. To ensure that the x-ray generator is producing the exposure time as set on the control panel.
- b. Regulations. The accuracy of the timer should be within $\pm 5\%$ of the selected timer setting or ± 1 ms for exposure times less than 10 ms or 1 pulse for exposure times less than 10 pulses.
- c. Equipment. Exposure meter with timer combination
- d. Procedure. Utilize the procedure described for reproducibility measurements. Measure and record the full range of clinically useful exposure times.
- e. Interpretation of Results. Refer units deviating from the criteria in Table 2.1 for

adjustment by a qualified service engineer. Timer accuracy is critical as it directly influences image quality and patient dose.

4. *Linearity of mA/mAs*

- a. Purpose. To ensure that similar exposures are obtained for the same mAs and kVp regardless of the exposure time and mA used.
- b. Regulations. The average ratios of exposure to the indicated mAs product (mR/mAs) obtained at any two consecutive tube current settings should not differ by more than 0.10 times their sum.

$$(X1 - X2) < 0.10(X1 + X2)$$

Where X1 and X2 are the average mR/mAs values obtained at each of two consecutive tube current settings. (21CFR1020.31)

- c. Equipment. Exposure meter with timer combination
- d. Procedure. Utilize the setup described for reproducibility measurements. Measure and record the exposures at 5 different mA settings while keeping kVp and time constant. With some x-ray units, the mA cannot be varied without varying time. In this instance mA must be constant and time varied. Divide the mR output by mAs setting, record mR/mAs as calculated.
- e. Interpretation of Results. If each of the average ratios between mA stations deviate from the criteria listed in 4.b, consult a qualified service engineer. Linearity of mA/mAs is critical as it directly influences image quality and patient dose.

5. *Kilovoltage Accuracy*

- a. Purpose. To ensure that the x-ray generator is producing the kVp as indicated on the control panel.
- b. Regulations. The accuracy must be $\pm 5\%$ of the nominal control panel setting or within manufacture specifications.
- c. Equipment. kVp meter

- d. Procedure. Place the kVp meter on the x-ray table top. Set the distance from the focal spot to the table top as indicated in the kVp meter owner's manual. Collimate the beam to the active area of the kVp meter. Set the desired starting kVp, mA, and time stations on the generator using the manufacturer's suggested techniques. Evaluate kVp settings from 50 kV up to the maximum kV incrementing by 5 kV. During periodic evaluation it may be necessary to evaluate only kVp settings from 60 kV to the maximum kV incrementing by 20 kV unless further measurements are necessary. Make an exposure and record the display value of the kVp meter.

- e. Possible Pitfalls.

- (1) The Half Value Layer (HVL) should always be measured after assuring the kVp is correct.
- (2) The major cause of kVp variation is calibration. Some generators maintain their calibration well and others drift constantly. It is important to note that a change in kVp may not always show as a change in image density because changes in the mA will often compensate for the change in kVp.
- (3) Since the kVp affects the radiographic contrast, it must be checked to assure that it is acceptable.
- (4) Other major causes of variations in kVp are line voltage drops and electrical component failure.

- f. Interpretation of Results. Refer units deviating from the criteria listed in 5b for adjustment by a qualified service engineer. Proper kVp calibration is critical as it directly influences image quality and patient dose.

6. *Beam Quality*

- a. Purpose. To assure that the permanently installed filtration at the x-ray tube is maintained at an appropriate level to help minimize patient exposure.
- b. Regulations. Federal and many state regulations specify minimum required HVLs at various kVp values. Refer to 21CFR1020.30 for acceptable values.

- c. **Equipment.** Ionization chamber or solid state detector, five 1 mm Type 1100 Aluminum (Al) sheets, two 0.5 mm Type 1100 Al sheets (if available)
- d. **Procedure.** Place the ion chamber 5 cm above the table top (solid state detectors are usually have lead backing and do not need to be above the table). Collimate the light field to a narrow beam geometry to include the ion chamber/solid state detector. The Al sheets should be placed between the ion chamber/solid state detector and the x-ray tube at a distance $X/2$, where X = focal spot to detector distance. Make sure the Al sheets intercept the entire beam (light field). Make two exposures without any Al sheets in the beam, one before and one after, ensuring that the geometry has not changed. (An exposure made using 80 kVp, 0.10 sec and 320 mA to achieve an output of approximately 300 mR will ensure that you have a high enough exposure to make the measurements accurately). Add Al sheets and make additional exposures until the exposure is less than half of the original exposure. Recommend using 2, 3, and 4 mm Al. Remove all Al sheets and make one exposure. If exposure is not within 2% of the initial exposure, made with 0 mm of Al, repeat the measurement series ensuring that the technique and geometry selected remain the same throughout the procedure.
- e. **Possible Pitfalls.**
- (1) The entire ion chamber must be in the x-ray beam. When placing the sheets of Al in the beam, be sure that the entire beam is intercepted by the Al sheet. Once selected, the technique factors must not be altered for subsequent exposures.
 - (2) The kVp should be checked before measuring the HVL to ensure that it is within acceptable limits.
 - (3) The Al used for HVL measurements should be type 1100.
- f. **Interpretation of Results.** If the HVL is not greater than the minimum requirements listed in 21CFR1020.30, consult a qualified service engineer. If the HVL is greater than 3.5 mm of Al, further evaluation should be conducted to

determine if the unit contains too much filtration.

7. *Light Field Intensity*

- a. **Purpose.** To ensure that the light field intensity is adequate to illuminate the field.
- b. **Regulations.** The light should provide an average illumination of not less than 160 lux (15 foot candles) at 100 cm or at the maximum Source Image Distance (SID), whichever is less. (21CFR1020.31)
- c. **Equipment.** Light meter capable of providing either lux or foot candles.
- d. **Procedure.** Place the light meter on the x-ray table top. Set the SID to 100 cm or the maximum available whichever is less. Collimate the x-ray beam to a 25 x 30 cm field. Illuminate the field. Measure and record the illumination in the 4 quadrants. Calculate an average.
- e. **Interpretation of Results.** Consult a qualified service engineer if the alignment deviates from the criteria listed in 7b.

8. *Light Field/X-Ray Beam Alignment*

- a. **Purpose.** To ensure that the x-ray field and the light field are congruent.
- b. **Regulations.** The light field/x-ray field alignment should be within $\pm 2\%$ of the SID (21CFR1020.31).
- c. **Equipment.** Digital rulers, fluorescent film
- d. **Procedure.** Place rulers at edge of light field according to manufacturer's directions. If using film, mark the edge of the light field on the film and expose and measure distance from edge of exposed area to mark on film.
- e. **Interpretation of Results.** Consult a qualified service engineer if the alignment deviates from more than 2% of the SID.

9. *X-ray Field Size- Indicated vs. Actual*

- a. **Purpose.** To ensure that the actual and indicated X-ray field are congruent.

- a. Regulations. The indicated vs. actual x-ray field should be within $\pm 2\%$ of the SID. (21CFR1020.31)
- b. Equipment. X-ray beam alignment tool and measurement plate
- c. Procedure. Measure the deviation between the displayed and the actual x-ray field.
- d. Interpretation of Results. Consult a qualified service engineer if the alignment deviates from more than 2% of the SID.

10. Central Beam Alignment

- a. Purpose. To ensure that the central x-ray beam is perpendicular to the table.
- b. Regulations. The perpendicularity of the central beam should be within 5mm.
- c. Equipment. X-ray beam alignment tool and measurement plate
- d. Procedure. If the x-ray beam alignment tool was used, measure the deviation between the upper (magnified) bead and the lower bead.
- e. Interpretation of Results. Consult a qualified service engineer if the perpendicularity measured deviates by more than 5 mm.

11. Indicated Source to Image Distance (SID)

- a. Purpose. To ensure the actual SID distance and the indicated SID are congruent.
- a. Regulations. The actual SID should be within $\pm 2\%$ of the indicated SID.
- b. Equipment. Tape measure
- c. Procedure. Position the tube assembly at 40 inches from the image receptor. Measure the SID. If automatic detent is available, position the assembly utilizing the detent. Measure the SID.
- d. Interpretation of Results. Consult a qualified service engineer if the measurement deviates from the criteria in Table 2.1.

12. Automatic Exposure Control (AEC) System (if applicable)

- a. Purpose. To ensure that the Automatic Exposure Control (AEC) system is responding adequately. The system compensates for variations in technique factors and patient thickness such that resulting films appear with constant, optimal densities. The following AEC parameters should be evaluated during testing: reproducibility, balance, maximum exposure time, kVp compensation, thickness compensation and density control tracking (if available).
- b. Regulations. For each AEC cell (phototimer) measurement the reproducibility should be within $\pm 5\%$. Back up timer should terminate the exposure at 600 mAs or 2000 mAs for tube potentials less than 50 kVp.
- c. Equipment. 4 cm Al, 1.6 mm Lead (Pb) plate, ionization chamber/solid state detector
- d. Procedure. For a radiographic system, set the x-ray tube at 40 in (72 in for chest systems) SID distance and center to the bucky. Set selector such that only one phototimer is activated. To determine the location of the phototimer(s) look at the chest unit pattern of rectangles on the chest board surface. Use the same layout for the table, noting that the center chamber is usually located at the lateral center of the table when the tube and bucky are aligned. If using a Computed Radiography (CR) machine, place a cassette in the bucky tray (not necessary for digital). Place 4 cm of Al in the beam. Ensure that the Al covers all the AEC detector cells. Set the control in the AEC mode, 80 kVp and select the detector to be checked (e.g. table, center, left or right chamber). If using a CR system, a single cassette should be used for all testing, to reduce variability. This will require processing the cassette after each exposure.
- (1) Output Reproducibility. Use the setup previously described in 12.d. Place the ion chamber/solid state detector along the beam central axis at the phantom beam entrance surface. Set the technique at 80 kVp, 200 mA, AEC setting to neutral (0). If using a CR machine, ensure you have a clean cassette for this test. Perform three exposures, record the readings and

calculate their mean. All three readings should line within $\pm 5\%$ of their mean. Repeat for each detector (note: if using CR and your process your cassette after each exposure you can obtain data (mAs) needed for phototimer balance test).

- (2) Back-up Timer. Use the setup previously described. Place the lead sheet (lead apron can also be used) in the area of the beam as to cover all of the AEC detector fields so that no radiation reached them. Set the technique at 80 kVp, 200 mA, AEC setting to neutral (0). Record the elapsed mAs. The beam should terminate prior to the accumulation of 600 mAs or 2000 mAs for tube potentials less than 50 kVp.
- (3) Phototimer Balance. Use the setup previously described. Set the technique at 80 kVp, 200 mA, AEC setting to neutral (0). Record the elapsed mAs and use the mR from the output reproducibility test to chart mR/mAs.
- (4) Patient Thickness Compensation. Use the setup described previously. Set the technique at 80 kVp, 200 mA, AEC setting to neutral (0). Vary the Al thickness over the range: 2, 4 cm Al. Record the elapsed mAs for each image and measure Optical Density (OD) at the center of each image. The densities should lie within the range of ± 0.3 of the baseline density.
- (5) kVp Compensation. Use the setup previously described. Set the technique at 80 kVp, 200 mA, AEC setting to neutral (0). Vary the kVp over the clinically used range 70, 90, 110 and record the elapsed mAs and mR.
- (6) Density Control Tracking (if available). Use the setup previously described. Place the ion chamber/solid state detector just off the beam central axis at the phantom beam entrance surface. Set the technique at 80 kVp and 200 mA. Vary AEC density over the range of available positive and negative settings. Record the elapsed mAs and mR.

13. Entrance Skin Exposure Measurements (ESE)

See Chapter 12

F. Survey Procedures for Portable and Mobile Radiographic Equipment

The following modifications of quality control procedures and acceptance parameters from fixed x-ray units apply for portable and mobile units:

1. Visual Inspection

- a. The minimum source to skin distance must be no less than 12 inches (30 cm). This can be measured directly with a tape measure provided the location of the focal spot is known.
- b. The operator must be able to stand at least six feet away from the x-ray tube during the actual exposure. This is normally accomplished by attaching the exposure switch to the unit with at least a six foot long cord.
- c. Each portable unit should be supplied with at least two lead aprons and gonadal shields.

Table 2.1—General Radiography System Survey Requirements (Fixed, Portable, Digital).

Test	Frequency	Measurements	Tolerance
Exposure Reproducibility	A	10 repeat measurements	cov< 0.05
	P	4 repeat measurements	if cov>0.05, do 4 more
Timer Reproducibility	A	10 repeat measurements	cov< 0.05
	P	4 repeat measurements (all at 100mSec)	if cov>0.05, do 4 more
Timer Accuracy	A	From 1 second to the minimum timer setting in increments of decreasing time of 50%.	± 5% of nominal setting
	P	Minimum and 1 second plus 3 others evenly spaced between.	± 5% of nominal setting
Linearity of mA/mAs	A	All focal spots, all mA stations. If continuous, in 100 mA increments from min to max	change <0.1 of the sum of measurements at adjacent mA stations
	P	5 adjacent mA stations over range of clinical use	
kVp Accuracy	A	for each generator: from 50 up to the maximum kVp setting by 5's	±5% of nominal setting
	P	for each generator: from 60 up to the maximum kVp setting by 20's	±5% of nominal setting
Beam Quality	A/P	@ 80 kVp, 1st HVL	minimum HVL of 2.3 mm Al
Light Field Intensity	A/P	Average of 4 quadrants of 25x30 cm light field	average illuminance ≥ 160 lux (15 fcd) at 100 cm or at the max SID whichever is less
Light Field/x-ray beam alignment	A/P	Set any clinically used field size (e.g. 18 x 24 cm)	total misalignment of edges of light field vs x-ray field not to exceed 2% of SID along either length or width
X-ray field size (Indicated vs. Actual)	A/P	Set any clinically used field size (e.g. 18 x 24 cm)	± 2% SID
Central Beam Alignment	A/P	Measurement of perpendicularity of central beam	5 mm
Indicated SID	A/P	Measuring tape vs indicated distance	± 2% SID

**Table 2.1—General Radiography System Survey Requirements (Fixed, Portable, Digital)
 (continued).**

Test	Frequency	Measurements	Tolerance
AEC	A/P	Table and Wall	
a. Thickness Compensation			
b. kVp compensation		70, 90, 110 kVp	
c. DCF tracking			
d. Reproducibility		3 exposures each detector	All \pm 5% of mean
e. Back-up timer		Max exposure time, Pb over all detectors	Elapsed < 600 mAs or 2000 mAs for tube potentials < 50 kV

Abbreviations: A: acceptance, P: periodic, HVL: Half Value Layer, kVp: kilovolt peak, mA: milliamp, mAs: milliamp seconds, fcd: foot candles SID: Source to Image Dis tance, Pb: Lead.

General Radiographic Unit Survey

NMCPHC-TM 6470.1
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Facility:	Date:
Room Number/Location:	ECN:
Manufacturer:	
Model Number:	Tube Serial Number:

Test Performed	Pass	Fail	N/A	Comments (failure comments must annotate minor or significant finding)
Exposure Reproducibility				
Timer Reproducibility				
Timer Accuracy				
Linearity of mA/mAs				
kVp Accuracy				
Beam Quality				
Light Field Intensity				
Light Field/X-ray beam alignment				
Central Beam Alignment				
Indicated SID				
PBL				
Focal Spot Size/Constancy				
AEC				
Safety Equipment/ Mechanical Checks				
Additional Comments:				

Purpose:	Results:
Surveyor Name:	
Surveyor Signature:	

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Chapter 3

Dental Radiographic Units

Intraoral, Panoramic, and Cone Beam Computed Tomography (CBCT)

A. *Minimum Required Personnel Qualifications*

1. Intraoral and Panoramic – Basic Diagnostic Imaging Equipment Surveyor
2. CBCT - Advanced Diagnostic Imaging Equipment Surveyor

B. *Introduction (Intraoral)*

1. These units are the simplest x-ray machines to evaluate.
2. The relatively low output is the biggest obstacle to performing a survey. However, this can be overcome by increasing exposure time or decreasing the target to chamber distance.
3. Record the settings of all variable controls on the control console and return to these settings at the end of the survey.
4. Table 3-1 list required survey requirements

C. *Introduction (Panoramic)*

1. Panoramic dental x-ray units pose a challenge for even the most experienced surveyors. The arcing motion of the tube head during exposure, thinly collimated beam and cowling hiding tube and image receptor make measurement of tube output and other parameters difficult at best.
2. Some digital panoramic machines have the ability to perform flat field exposures. As damage to the unit could occur due to excessive heat loading when placed in this condition, contact a manufacturer field engineer prior to using this mode.
3. The following parameters may, however, be evaluated, without significant difficulty:
 - a. Timer accuracy;
 - b. Beam quality; and,
 - c. Beam/film slit alignment.
4. Table 3-2 list required survey requirements

D. *Introduction- Cone Beam Computed Tomography (CBCT)*

1. The CBCT systems represent an exotic imaging modality that does not lend itself well to performance testing under either the panoramic or true CT paradigm.
2. The CBCT characteristic features of a widely collimated longitudinal beam and single rotation data acquisition (vice gapless multiple sequential or helical scans) pose difficulties in defining and assessing dose using conventional ionization chambers and established techniques. Monte Carlo and empirical testing demonstrate that the standard 10 cm chamber pencil and Computed Tomography Dose Index (CTDI) phantom are not appropriate for CBCT. Additionally, use of a single flat panel detector vice a multiple detector element matrix predicts different image quality performance levels compared to conventional CT used for similar purposes and tested with established phantoms.
3. These significant differences will require the development of innovative testing methods not directly comparable with conventional CT.
4. Table 3-3 list required survey requirements

E. *Testing Periodicity*

Facility	Frequency
Intraoral and Panoramic units	Every 36 months, upon acceptance and after major repairs
Cone Beam Computed Tomography (CBCT)	Every 12 months, upon acceptance and after major repairs

F. Equipment

1. Electrometer with small ion chamber
2. kVp meter
3. Pulse counter
4. Type 1100 10 x 10 cm Al plates (varying thicknesses; at least 5mm total)
5. Stopwatch
6. Tape measure
7. Cardboard cassette or ready pack film
8. Surgical adhesive tape
9. Fluorescent screen or bitewing film
10. Optional: BRH test stand
11. Optional: Acrylic Ball and Pin Phantom
12. Dental Radiographic Unit Survey

G. References

1. AAPM Report 31 (Rev. 2), *Standardized Methods for Measuring Diagnostic X-ray Exposures*. JUNE 2005.
2. Code of Federal Regulations, Title 21, Chapter 1, Section 1020.30, 1020.31, 01 April 2005 edition.
3. Curry, T.S. III, Dowdey J.E., Murry, R.C. Jr. *Christensen's Physics of Diagnostic Radiology*. Lea & Febiger, Philadelphia. 1990.
4. Gray, J.E., Winkler, N.T., Stears, J., Frank, E.D. *Quality Control in Diagnostic Imaging*; University Park Press, Baltimore, 1983.
5. HPA Report HPA-CRCE-010, *Guidance on the Safe Use of Dental Cone Beam CT Equipment*. November 2010.
6. Yu, L., et al., *Dose and Image Quality Evaluation of a Dedicated Cone-Beam CT System for High-Contrast Neurologic Applications*; AJR:194, Feb 2010.
7. Pauwels, R., et al., *Development and Applicability of a Quality Control Phantom for Dental Cone-beam CT*; JACMP:12, No. 4, Fall 2011.

H. Performance Test Requirements for Intraoral Dental Units

1. Exposure and Timer Reproducibility

- a. Purpose. To ensure that exposure received for the same mA, time, and kVp is the same from exposure to exposure.
- b. Regulations. Determination of reproducibility is based on five consecutive measurements within a time period of thirty minutes, using the same technique factors. The exposures

must have a COV less than 5%. Reference: 21 CFR 1020.31(b)(1).

c. Equipment. Ion chamber

d. Procedure.

- (1) Place the probe 10 in from the focal spot as marked on the tube head.
- (2) Visually center the probe in the beam, checking from the front and the sides to ensure that the beam will strike the probe. Once established, this set up should not be varied during this test.
- (3) Select the most commonly used patient technique and make five exposures, rotating all dial settings between exposures. Always wait at least 30 seconds between exposures so as not to overheat the tube.
- (4) Record the pulse exposure in mR and the pulse duration in msec.

e. Interpretation of Results. The exposures must have a COV less than 5%. See section 1 of Appendix B for calculation of COV. If all values are within a few mR of each other, this calculation is not necessary.

2. Timer Accuracy

a. Purpose. To ensure that the x-ray generator is producing the exposure time as set on the control panel.

b. Regulations. The accuracy of the timer should be within 10% of the selected setting.

c. Equipment. Same as above

d. Procedure. Keep the same set-up as for reproducibility, holding kVp and mA constant. Select three commonly used patient timer settings by consulting either the technician or the technique chart. Make an exposure at each setting, recording mR and msec.

e. Interpretation of Results. Pulse duration measured should be within 10% of the nominal setting or as specified by the manufacturer. Also, pulse exposure should increase linearly with time, i.e., exposure

should increase by approximately the same percentage as the time is increased.

3. *Linearity of mR/mAs*

NOTE: This test cannot be performed on fixed kVp or mA units.

- a. Purpose. To ensure that similar exposures are obtained for the mAs and kVp regardless of the exposure time and mA.
- b. Regulations. The average ratios of exposure to indicated mAs (mR / mAs) obtained at two tube current settings should not differ by more than 0.10 times their sum.
- c. Equipment. Same as above
- d. Procedure.
 - (1) With the equipment in the same set-up as above, record one of the reproducibility results as the first reading.
 - (2) Switch to another mA station if one exists while holding kVp and timer settings constant.
 - (3) Make an exposure and record pulse exposure, then divide mR output by mAs setting.
 - (4) Record this mR / mAs as calculated.
- e. Interpretation of Results. These two mR/mAs results should be similar, specifically the difference between the two divided by sum of the two should not exceed 10%. Repeat this test at several kVp settings.

4. *kVp Accuracy and Precision*

- a. Purpose. To ensure that the x-ray generator is producing the kVp as indicated on the control panel.
- b. Regulations. The accuracy must be within 5 kVp of the control panel setting (Some units have fixed kVp and must be within 5 kVp of that value).
- c. Equipment. kVp meter

d. Procedure.

- (1) Select the proper phase switch on the kVp meter (most dental units are single phase).
- (2) Center the end of the cone on the kVp meter so that the x-ray field will COVER the required area of the kVp meter.
- (3) Check 90 kVp at one-half second, 80 kVp at one second and 70 kVp at two seconds. Four measurements should be obtained at the most clinically used setting.
- (4) For fixed kVp units, determine the actual kVp.
- (5) Allow for tube cooling between longer shots, e.g., 1 minute for 1 second, 2 minutes for 2 seconds, etc.

- e. Interpretation of Results. The meter reading should be within 5 kVp of each setting. The coefficient of variation should be less than 0.02.

5. *Beam Quality (Half-Value Layer [HVL] Determination)*

- a. Purpose. To assure that the permanently installed filtration at the x-ray tube is maintained at an appropriate level to help minimize patient exposure.
- b. Regulations. The minimum value of the HVL should be as stated in Table 3-4 for the actual kVp determined above.
- c. Equipment. Electrometer with small ion chamber, sheets of type 1100 alloy Al

d. Procedure.

- (1) Set the tube voltage potential to 80 kVp, if the unit has variable kVp.
- (2) Take an exposure using the reproducibility test set-up.
- (3) Measure the radiation and record the value as the exposure with 0 mm Al added.
- (4) Tape 1 mm Al (use tape which does not leave marks, such as paper surgical tape, or whatever is conveniently available) on

the end of the cone and take a reading at the same settings, recording this for 1 mm Al added. Maintain good beam geometry.

- (5) Repeat for 2, 3 and 4 mm Al.
 - (6) Finally, remove all Al and take one last reading with zero mm Al. The four mm trial is not needed if 3 mm added Al reduces the initial reading by half. If the final exposure is not within 2% of the initial exposure made with 0 mm Al, repeat the measurement series ensuring that the technique and geometry selected remain the same throughout the procedure.
- e. Interpretation of Results.
- (1) Use the average of the two 0 readings as the unattenuated value.
 - (2) The HVL may be determined mathematically using logarithmic interpolation or graphically using semi-log paper. Refer to the general radiographic beam quality section for further instructions.
 - (3) The HVL must meet Food and Drug Administration (FDA) standards for the actual kVp used which was determined above. FDA standards for HVLs, for dental units, are included in Table 3-4.

6. Source to Skin Distance and X-Ray Field Size/Cone Alignment

- a. Purpose. To determine the minimum source to patient distance and field size.
- b. Regulation. The source to skin distance and field size should be as stated in 21 CFR 1020.31(f) & (h).
- c. Equipment. Measuring tape and fluorescent screen
- d. Procedure.
 - (1) Measure and record the length of the removable cone, the distance between the focal spot and end of the cone and the inner diameter of the cone.
 - (2) Use the fluorescent screen to ensure the x-ray beam at the end of the cone is the same size as the cone.

7. Entrance Skin Exposure (ESE)

See Chapter 12.

I. Performance Test Requirements for Dental Panoramic Units

1. Exposure and Timer Reproducibility

- a. Procedure. (Same as for the dental intraoral unit.) The ion chamber must be secured to the chin rest with adhesive tape for measurement to be taken.

2. Duration of Exposure Cycle

- a. Purpose. To ensure that the x-ray generator is producing the exposure time set by the manufacturer.
- b. Regulations. The accuracy of the timer should be as stated by the manufacturer.
- c. Equipment. Stopwatch or electrometer with small ion chamber. Comment: The MDH Model 1515 cannot be used for this test, as it will over-range.

d. Procedure.

- (1) Select the most commonly used clinical technique. Make one exposure at this setting.
- (2) Start and stop the stopwatch based on the tone which indicates radiation production.
- (3) Record the exposure duration from the stopwatch in seconds.
- (4) If the electrometer is used, secure the small ion chamber to the patient chin rest, using strong adhesive tape with the probe pointing up. (Since the machine will be moving during the exposure, the ion chamber and converter box must be secure. Dropping the ion chamber can cause extensive damage).
- (5) Select the most commonly used clinical technique. Make an exposure at this setting. Record the exposure duration using electrometer pulse mode.

3. Linearity of mR/mAs

(Same as for dental intraoral unit)

4. Beam Quality- Half Value Layer (HVL) Determination

- a. Purpose. To ensure that the permanently installed filtration at the x-ray tube is maintained at an appropriate level to help minimize patient exposure.
- b. Regulations. The minimum value of the HVL should be as stated in Table 3-4, for the operating kVp of the unit.
- c. Equipment. Electrometer with small ion chamber and sheets of varying thicknesses of type 1100 alloy Al
- d. Procedure.
 - (1) Secure the ionization chamber to the patient chin rest securely, e.g., using strong adhesive tape with the probe pointing up. [Since the machine will be moving during the exposure, the ion chamber and converter box must be secure]

- (2) Set the tube voltage potential to 80 kVp, if the unit has variable kVp.
- (3) Take a reading with the meter in the exposure rate (mR / hr) mode. Record this as the exposure rate for zero mm of added Al.
- (4) Tape 1 mm Al to the face of the cone, take a second reading and record these results for 1 mm Al added. Repeat using 2, 3 and 4 mm of Al. (the 4 mm iteration is unnecessary if 3 mm added Al reduces the initial reading by half).
- (5) Remove all Al and take another reading. If the final exposure is not within 2% of the initial reading, repeat the measurement series ensuring that the technique and geometry remain the same throughout the procedure.

NOTE: There are procedures to keep the unit from rotating during exposure. However, these are usually invasive, and require the assistance of a field engineer. They are not recommended for performance surveys performed by an inexperienced physicist.

e. Interpretation of Results.

- (1) Use the average of the two readings using zero mm Al as the unattenuated value.
- (2) The HVL may be determined mathematically using logarithmic interpolation or graphically using semi-log paper. Refer to the general radiographic beam quality section for further instructions.
- (3) The HVL must meet FDA standards for the actual kVp used which was determined above. FDA standards for half-value layers, for dental units, are included in Table 3-4.

5. X-Ray Beam/Image Detector Slit Alignment

- a. Purpose. To ensure that the x-ray beam and image receptor (e.g. film) slit are in alignment.

- b. Regulations. The beam dimensions should not exceed the slit opening.
- c. Equipment. Fluorescent screen or intraoral film and tape
- d. Procedure.
 - (1) This test may be performed in real time by using a piece of fluorescent screen taped to the image receptor holder COVERing the slit. Mark the outline of the slit on the screen. Dim the room lighting and position yourself so as to be able to see the screen. Make an exposure and watch for the slit area to glow.
 - (2) The slit alignment may also be recorded on film for documentation as follows:
 - (a) Tape two pieces of intraoral film diagonally across the slit, one at the top and one at the bottom of the slit, or place a piece of ready pack film across the film holder.
 - (b) Mark the slit location using a pin to prick the film at the edge of the slit opening and make an exposure only a few seconds in duration.
 - (c) Develop the film.
- e. Interpretation of Results.
 - (1) Fluorescent screen: The entire slit should be seen.
 - (2) For film, a diagonal line should be seen across each film from corner to corner or between pin marks.

6. Entrance Skin Exposure (ESE)

(See Chapter 12)

7. Calibration file (if applicable)

- a. Purpose. To ensure the digital image is properly calibrated to only view the area in which radiation is being detected on the image receptors.
- b. Regulations. Average Pixel Value should be within manufacture's specifications. When

comparing the calibrated and non-calibrated images, notice that the calibrated image fills the frame window completely, without any white areas on any sides of the image. Also, the calibrated image has an even, consistent quality while the non-calibrated image appears "noisier", with sharper differences between the rows.

- c. Equipment. Computer image processing and calibration software as provided by manufacturer upon installation.
- d. Procedure. This procedure should be performed by the manufacture technical representative upon installation and demonstrated during acceptance. The specific procedure should be obtained from the manufacturer's technical manual.

Note: For bi-directional systems, if the panoramic machine scans in both left-to-right and right-to-left directions, you will need to create two calibration files, one for each direction

8. Laser Alignment/Phantom Ball and Pin Test (if applicable)

- a. Purpose. To ensure the positioning lasers are properly aligned to provide sharp and symmetric images.
- b. Regulation. The balls in the center of the picture should be sharp and symmetric. If they are too wide and blurred, the lateral laser is positioned to far forward. The opposite is true if the balls appear elongated and narrow.
- c. Equipment. Ball and pin phantom as supplied by the manufacturer
- d. Procedure.
 - (1) Turn on the positioning lasers, and adjust the lateral laser position so its projected line falls on the center ball of the ball and pin phantom. If necessary, manually adjust the laser to ensure proper alignment. If manual adjustment of the laser is not available, contact the system field engineer to have the laser alignment corrected.

- (2) With a recalibrated system, take an image by pressing and holding down the exposure switch until rotation of the unit stops.
- (3) The balls in the center of the post calibration image should be sharp and symmetric.

J. *Performance Test Requirements for Dental Cone Beam Computed Tomography (CBCT)*

Reserved.

Table 3-1.—Dental Intraoral Unit Survey Requirements.

	Test	Frequency	Measurements	Tolerance
1.	Exposure Reproducibility	A	10 repeat measurements	cov< 0.05
		P	4 repeat measurements	if cov>0.05, do 4 more
2.	Timer Reproducibility	A	10 repeat measurements	cov< 0.05
		P	4 repeat measurements (all at 100mSec)	if cov>0.05, do 4 more
3.	Timer Accuracy	A	From 1 second to the minimum timer setting in increments of decreasing time of 50%.	± 5% of nominal setting
		P	Minimum and 1 second plus 3 others evenly spaced between.	± 5% of nominal setting
4.	Linearity of mA/mAs	A	All focal spots, all mA stations. If continuous, in 100 mA increments from min to max	change <0.1 of the sum of measurements at adjacent mA stations
		P	5 adjacent mA stations over range of clinical use	
5.	kVp Accuracy	A	for each generator: from 50 up to the maximum kVp setting by 5's	±5% of nominal setting
		P	for each generator: from 60 up to the maximum kVp setting by 20's	±5% of nominal setting
6.	X-ray Beam Quality	A/P	@ 80 kVp, 1st HVL	HVL of 2.3 mm Al or greater
7.	X-ray field size/cone alignment	A/P	Measure x-ray beam alignment with end of cone	x-ray field size of 2.5 cm Beam aligns with cone
8.	Minimum SSD	A	SSD ≥ 18 cm	Diameter of x-ray field ≤ 7 cm
		P	SSD < 18 cm	Diameter of x-ray field ≤ 6 cm

Abbreviations: A: acceptance, P: periodic, HVL: Half Value Layer, kVp: kilovolt peak, mA: milliamp, mAs: milliamp seconds, SSD: Source To Skin Distance

Table 3-2.—Dental Panoramic Unit Survey Requirements.

	Test	Frequency	Measurements	Tolerance
1.	Exposure Reproducibility	A	10 repeat measurements	cov< 0.05
		P	4 repeat measurements	if cov>0.05, do 4 more
2.	Duration of Exposure Cycle	A/P	Measure during exposure reproducibility	± 1 Second
3.	mAs Linearity	A/P	Measure at 2 mA stations if available	< 0.1 of the sum of the measurements of adjacent mA stations
4.	X-ray Beam Quality	A/P	@ 80 kVp, 1st HVL	HVL of 2.3 mm Al or greater
5.	X-ray Beam/Image Receptor Slit Alignment	A	-View beam slit fluorescence using fluorescent screen or	-View of entire image receptor slit
		P	-Expose 2 pieces of intraoral film taped diagonally across beam slit or use ready pack	-Diagonal line across each film from corner to corner -Mark slit on film
6.	Calibration file	A	To be performed by manufacturer representative upon installation.	IAW manufacturer's specifications
7.	Laser Alignment / Phantom Ball and Pin Test	A/P	Ensures lasers are properly aligned to produce sharp and symmetric images	IAW manufacturer's specifications

Abbreviations: A: acceptance, P: periodic, cov: coefficient of variation, HVL: Half Value Layer, kVp: kilovolt peak, mA: milliamp, mAs: milliamp seconds

Table 3-3.—Dental Cone Beam CT Unit Survey Requirements.

	Test	Frequency	Measurements	Tolerance
1	Reserved	Reserved	Reserved	Reserved
2				
3				
4				

Abbreviations: A: acceptance, P: periodic

Table 3-4.—Minimum Half Value Layer Requirements (HVL).
 (From Code of Federal Regulations, 21 CFR Part 1020.30)

X-ray Tube Voltage (kVp)		Minimum HVL (millimeters of Al)		
Designed Operating Range	Measured Operating Potential	Specified Dental Systems ¹	I – Other X-Ray Systems ²	II – Other X-Ray Systems ³
Below 51...	30	1.5	0.3	0.3
	40	1.5	0.4	0.4
	50	1.5	0.5	0.5
51 to 70	51	1.5	1.2	1.3
	60	1.5	1.3	1.5
	70	1.5	1.5	1.8
Above 70	71	2.1	2.1	2.5
	80	2.3	2.3	2.9
	90	2.5	2.5	3.2
	100	2.7	2.7	3.6
	110	3.0	3.0	3.9
	120	3.2	3.2	4.3
	130	3.5	3.5	4.7
140	3.8	3.8	5.0	
	150	4.1	4.1	5.4

¹Dental x-ray systems designed for use with intraoral image receptors and manufactured after December 1, 1980.

²Dental x-ray systems designed for use with intraoral image receptors and manufactured before or on December 1, 1980, and all other x-ray systems subject to this section and manufactured before June 10, 2006.

³All x-ray systems, except dental x-ray systems designed for use with intraoral image receptors, subject to this section and manufactured on or after June 10, 2006.

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Dental Radiographic Unit Survey

NMCPHC-TM 6470.1
JUNE 2013

Facility:		Date:
Room Number/Location:		ECN:
Manufacturer:		Type:
Model Number:	Tube Serial Number:	

Test Performed	Pass	Fail	N/A	Comments (failure comments must annotate minor or significant finding)
Exposure Reproducibility				
Timer Reproducibility				
Timer Accuracy				
Linearity of mA/mAs				
kVp Accuracy				
Beam Quality				
kVp Precision				
X-ray field size/cone alignment				
Minimum SID				
Duration of Exposure Cycle				
X-ray Beam/Slit Alignment				
Safety Equipment/Mechanical Checks				
Additional Comments:				

Purpose:	Results:
Surveyor Name:	
Surveyor Signature:	

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Chapter 4

Fluoroscopy

A. *Minimum Required Personnel Qualifications*

Advanced Diagnostic Imaging Equipment General Fluoroscopic Imaging (GFI)

B. *Testing Periodicity*

All units: Acceptance, annually, and after major repairs.

C. *Equipment*

1. Ionization chamber/solid state detector
2. kVp meter
3. High resolution test patterns
 - a. RMI® 141, 141-H (low/high level)
4. 2 Al plates (17.8 cm x 17.8 cm x 1.9 cm)
5. Lead plate (20 cm x 20 cm x 1.6 mm)
6. 1.5, 3.1, 4.7, & 6.3 mm perf. Al sheet (17.8 cm x 17.8 cm x 0.8 mm)
7. 1100 Al alloy sheets (10 cm x 10 cm) (varying thicknesses; at least 8 mm total)
8. Collimator/beam alignment test tool
 - a. Etched plate (25 cm x 20 cm x 1.5 mm)
 - b. Plastic cylinder with imbedded steel balls
9. Tape measure
10. CR cassette (14" x 17", 35 cm x 43 cm)
11. Optional
 - a. Contact mesh
 - b. Copper plate (20 cm x 20 cm x 1.5 mm)
 - c. Acrylic phantom (30 cm x 30 cm x 15-20 cm)
12. General Fluoroscopy Unit Survey

D. *References*

1. AAPM Report 12. *Evaluation of Radiation Exposure Levels in Cine Cardiac Catheterization Laboratories*, 1984.
2. AAPM Report 25. *Protocols for the Radiation Safety Surveys of Diagnostic Radiological Equipment*, 1988.
3. AAPM Report 70. *Cardiac Catheterization Equipment Performance. 2001*
4. Bushberg, J.T., Seibert, J.A., Leidholdt, E.M. Jr., Boone, J.M. *The Essential Physics of Medical Imaging*. Williams & Wilkins, 2011
5. Chakraborty, D.P. *Routine Fluoroscopic Quality Control*, 1991 AAPM Summer School Proceedings, 1994.
6. Code of Federal Regulations, Title 21, Chapter 1, Section 1020.30, 1020.31, 1020.32
7. Curry, T.S. III, Dowdey J.E., Murry, R.C. Jr. *Christensen's Physics of Diagnostic Radiology, Fourth Edition*, Lea & Febiger, Philadelphia. 1990.

E. *Performance Tests for Fluoroscopy*

1. *kVp Accuracy*

- a. Purpose. To verify that tube voltage potential accurately tracks the nominal generator setting.
- b. Equipment. kVp meter
- c. Procedure.
 - (1) Follow the meter manufacturer's instructions.
 - (2) Test the unit in manual kVp mode whenever possible. Test units without manual kVp control at the voltage provided by the Automatic Brightness Control (ABC) system for the kVp meter assembly in the beam.

- (3) Record average or effective kVp, as available, when using a meter offering multiple reading formats.

d. Interpretation of Results. Refer units deviating from the criteria in Table 4-1 for adjustment by a qualified service engineer. Proper kVp calibration is critical as it directly influences image quality and patient dose.

2. Air Kinetic Energy Released in Material (KERMA) Rate (AKR) Measurements

a. Purpose.

- (1) To establish AKR for varying thicknesses.
- (2) To verify that measured and displayed AKR are within ± 35 percent.
- (3) To verify long term AKR consistency.
- (4) To verify proper automatic brightness control of exposure rate with varying Image Intensifier (II) field size.

b. Equipment. 4 cm Al or 15 cm acrylic phantom, solid state detector or ion chamber with exposure meter.

c. Procedure.

- (1) Typical and maximum AKR measurements can be made with the same equipment arrangement.
- (2) Place the solid state detector or ion chamber at the location specified by 21 CFR 1020.32.
- (3) Invert C-arms for testing. This allows for easier phantom placement.
- (4) Treat lithotripsy systems as standard/ C-arm hybrids (i.e. meet both conditions).
- (5) Place the phantom close to the solid state/ion chamber. If using an ion chamber, make sure that there is enough distance as to minimize backscatter. The II is very sensitive; ensure that it is always shielded by the phantom. 1100 Al alloy or acrylic are acceptable.

- (6) Try to use a phantom to chamber distance of approximately 8 cm. This distance allows for adequate shielding of medium and larger image intensifiers. Very large IIs may require that the phantom be placed closer to the ion chamber.

(7) Place the scatter grid in the beam path.

(8) Collimate the field to the phantom ensuring chamber is in the Field Of Vision (FOV).

(9) Maintain consistent phantom/ solid state detector/ion chamber/image intensifier positions to assure reproducibility (record distances).

d. Measurement Considerations.

(1) Make AKR measurements using all available output modes and II size combinations. Include manual and pulse modes, if available. ABC systems will demonstrate different output rates at each II size to compensate for the loss of magnification gain.

(2) For manual mode readings, adjust kVp and mA to provide a monitor image brightness equal to that of ABC normal mode.

(3) Make AKR measurements with and without the grid in place, as warranted. The grid generally remains in the beam but may be removed if no-grid studies are performed.

(4) Use minimal "beam-on" time to prevent unnecessary x-ray tube wear.

(5) If the unit is equipped with High Level Control (HLC), a distinct tone must be heard when HLC is active.

e. Cine Output Measurements.

(1) Most cine systems work at 7.5, 15 and 30 frs⁻¹.

(2) Measure AKR using the most commonly used II size and ABC or manual techniques suitable for an average patient (i.e. 4 cm aluminum/15 cm acrylic). Evaluate all available II sizes during acceptance.

- f. Interpretation of Results. Typical AKR values should be significantly lower than their maximum output rate counterparts. Use acceptance inspection values to set baselines for future reference. Subsequent annual evaluation results should agree reasonably well with original levels (e.g. $\pm 10\%$).

3. *Maximum Air Kinetic Energy Released in Material (KERMA) Rate (AKR)*

- a. Purpose. To prevent excessive exposure to patients subjected to fluoroscopic examinations by verifying that the maximum AKR conforms to the limits of 21 CFR 1020.32.
- b. Regulations. 21 CFR 1020.32 specify maximum exposure rates allowed for fluoroscopic equipment.
- c. Equipment. 4 cm Al or 15 cm acrylic phantom, 1.6 mm Pb plate, solid state detector or ion chamber with exposure meter.
- d. Procedure.
- (1) Set up the fluoroscopy unit, phantom, and solid state detector/ion chamber as for typical AKR measurements.
 - (2) Place the lead sheet on top of the phantom between the solid state/ion chamber and image intensifier.
 - (3) Make AKR measurements for all available output modes. For manual modes, set kVp to its maximum level.
 - (4) Maximum AKR measurements need only be made at the largest II size.
 - (5) Radiation streaming around the lead plate should not be visible during testing.

WARNING: Image intensifiers may be irreparably damaged if exposed to unattenuated high energy x-ray beams for extended periods.

- e. Interpretation of Results. Ensure that proper solid state/ion chamber/lead/II distances are maintained. When using an ion chamber, maximum AKR measurements may be unduly

influenced (10 to 15 % above equivalent free in air measurements) by backscatter from the lead sheet if it is too close to the phantom/lead assembly. If maximum exposure rates exceed limits set in 21 CFR 1020.32, recommend that the unit be temporarily removed from patient use and recalibrated by a qualified service engineer as soon as possible. If practicable, verify that the new maximum exposure rates are acceptable before the service engineer leaves the facility.

4. *Transmission Through Primary Barrier*

- a. Purpose. To verify that the radiation attenuation provided by the II housing is adequate.
- b. Equipment. 4 cm Al or 15 cm acrylic phantom, 1.6 mm Pb plate, solid state detector or ion chamber with exposure meter.
- c. Procedure.
- (1) Arrange the fluoroscopy unit, phantom, and Pb sheet in the same manner as for evaluating maximum AKR.
 - (2) Place the large ion chamber 10 cm beyond the rear surface of the primary barrier (i.e. II housing) with the large flat surface perpendicular to the beam axis.
 - (3) Irradiate the phantom using the maximum AKR technique. Record the radiation level and compare it with the maximum AKR recorded previously.
- d. Interpretation of Results. Radiation levels at 10 cm beyond the II housing should not exceed 3.34×10^{-3} percent of the entrance AKR. Refer units showing excessive radiation transmission for repair by a qualified service engineer.

5. *Beam Quality (Half Value Layer)*

- a. Purpose. To verify that the permanently installed filtration in the tube housing is thick enough to minimize patient exposure.
- b. Regulations. 21 CFR Part 1020.30 specifies the minimum beam quality (HVL) requirements for a range of tube potentials.

- c. Equipment. 1100 aluminum alloy HVL sheets, solid state detector or ion chamber with exposure meter, 4 cm aluminum or 15 cm acrylic phantom.
- d. Procedure.
- (1) Set up the fluoroscopy unit, phantom, and solid state detector/ion chamber as for typical AKR measurements.
 - (2) If the unit allows manual kVp and mA control, use the following procedure:
 - (a) Manually set kVp = 90.
 - (b) Place the 4 cm Al or 15 cm acrylic phantom between the solid state detector/ion chamber and II. Allow some separation between the two to minimize the effect of backscatter (ion chamber).
 - (c) Under fluoroscopy, collimate the beam to an area just larger than the ion chamber. Ensure that the phantom always intercepts the beam. Failure to do so may damage the II.
 - (d) Set mA to produce an output rate between 300 and 500 mR/min.
 - (e) Measure the exposure rate without any Al sheets between the tube and ion chamber. Repeat the measurement with 1, 2, 3, 4, and 5 mm Al between the tube and ion chamber.
 - (3) If the unit does not permit manual technique control (i.e. ABC only), use the following procedure:
 - (a) Place the Al or acrylic phantom and collimate the beam as per steps 5.d.(2) (b) and (c).
 - (b) Place all 8 mm Al sheets between the ion chamber and II (e.g. above the Al or acrylic phantom).
 - (c) Measure the exposure rate without any Al sheets between the tube and ion chamber, allowing ABC to set kVp for all the aluminum in the beam (i.e. phantom + sheets).
 - (d) Repeat the measurement with 1 through 8 mm Al between the tube and ion chamber; moving each Al sheet from behind the ion chamber to in front of it near the tube output. A constant Al thickness must remain in the beam throughout the procedure to prevent ABC from changing technique factors. Varying factors will lead to erroneous readings.
 - (4) Determine HVL for the appropriate voltage potential (set manually or obtained through ABC) mathematically.
- e. Interpretation of Results. 21 CFR 1020.30 lists minimum HVLs for various voltage potentials. If the beam does not meet the minimum standard, refer the unit for adjustment by a qualified service engineer. Insufficient filtration may lead to unnecessary patient dose. A unit with a hard beam need not be removed from service. However, a high HVL often indicates the presence of an older tube that may fail shortly thereafter.

6. Minimum Source to Skin Distance (SSD)

- a. Purpose. To prevent unnecessary patient exposure resulting from an unduly short SSD.
- b. Regulations. 21 CFR 1020.32 specifies the minimum source to skin distance requirements based on fluoroscopy unit mobility and application.
- c. Equipment. Tape measure, etched brass plate, 14" x 17" (35 cm x 43 cm) CR cassette.
- d. Procedure.
 - (1) For C-arm systems, determine minimum SSD using a tape measure. Measure from the external target position mark to the end of the collimator assembly or spacing cone if permanently installed.
 - (2) For fixed SID, overhead tube systems, measure minimum SSD in the same manner as step (1).
 - (3) For fixed under-table tube systems that allow tube access, measure minimum SSD using a tape measure as the distance from

the target mark to the tabletop. For systems with variable SSD, set the target to table distance to minimum before measuring.

- (4) For fixed SSD, under-table systems without tube access, measure minimum SSD using triangulation. Calculate SSD as:

$$SSD = \frac{OID}{(w_2/w_1) - 1}$$

Where:

- OID = Brass plate to film image distance
 w_2 = Division length at SID
 w_1 = Division length on the plate

- e. Interpretation of Results. If the source to skin distance is less than required, refer the unit for adjustment by a qualified service engineer.

7. *Minimum and Maximum Fluoroscopic Image Size (Beam Limitation Devices)*

- a. Purpose. To verify that the fluoroscopic imaging system displays the geometrically appropriate anatomical area of interest.
- b. Regulations. 21 CFR 1020.32 specifies that the minimum radiation field size at maximum SID should be contained within a square of 5 cm by 5 cm.
- c. Equipment. Etched brass plate, 14" x 17" (35 cm x 43 cm) CR cassette (do not need for DR).
- d. Procedure.
- (1) Arrange the unit for maximum SID, largest available II size, grid in the beam, and all collimators fully open.
 - (2) Position the brass plate between the tube and image intensifier to fully intercept the beam.
 - (3) Using appropriate protection, place the CR cassette as close to the II face as possible with the screen facing the tube. Center the CR cassette over the II housing assembly.

- (4) Expose the cassette for 1 - 2 sec using a low technique (50-60 kVp @ 1 mA).
- (5) Close all collimators to minimum setting.
- (6) Move the CR cassette over to align the center of the image intensifier with a corner of the cassette.
- (7) Re-expose the cassette per step (4).
- (8) Measure the dimensions of the darkened areas on the processed film. Correct the measurements if a significant cassette to II distance existed during exposure.

- e. Interpretation of Results. If the maximum or minimum field size dimensions exceed tolerance limits, recommend that a qualified service engineer recalibrate the collimators. One method to eliminate the film based beam limitation test procedure is to calibrate the collimator shutters so that they are just visible along the edges of the live image at maximum field size. Once the collimators are properly calibrated, maximum field size conformance can be verified visually on the monitor image.

8. *Fluoroscopy Display Field Alignment*

- a. Purpose. To verify that the fluoroscopy beam is properly collimated so that only the tissue volume corresponding to the active entrance area of the II is irradiated, & that the same volume is presented on the monitor.
- b. Equipment. Etched brass plate, plastic cylinder with stacked steel balls, 14" x 17" (35 cm x 43 cm) CR cassette or GAF film.
- c. Procedure.
- (1) Arrange the system for minimum SID, largest available II size, grid in the beam, and collimators fully open.
 - (2) Position the brass plate to obtain an Object to Image Distance (OID) of approx. 30 cm. and collimate the image as necessary so that the plate fully intercepts the beam.
 - (3) Place the cassette as close to the II face as possible with the screen facing the tube. Center the CR cassette over the II housing assembly.

- (4) Expose the CR cassette using normal fluoroscopy to acquire a background film density of approximately 1.2 (≈ 1 sec at 80 kVp and 200 mA).
 - (5) On both the monitor and CR images, determine the indicated distance between opposing edges of the viewing field (LCD) or radiation field (cassette) along the two axes on the plate.
 - (6) Compare the axis lengths in the monitor and film images and calculate the difference between the two as a fraction of SID.
 - (7) If the unit allows, increase SID to maximum and repeat steps (5) and (6) during acceptance testing. In a properly functioning unit, collimation should track automatically with changing SID.
- d. Interpretation of Results. If the difference between the lengths of either monitor/film axis pair exceeds 3 % of SID or if the sum of the differences for both axis pairs exceeds 4 % of SID, refer the system for recalibration by a qualified service engineer.

9. Beam Central Alignment

- a. Purpose. To verify that the fluoroscopy beam central axis is properly aligned with the center of the image intensifier.
- b. Equipment. Etched brass plate, plastic cylinder with stacked steel balls, 2-Dimension level.
- c. Procedure.
 - (1) Complete steps (1) through (3) of the fluoroscopy display field alignment procedure.
 - (2) If the fluoroscopy beam and II are properly aligned, the two balls will be superimposed and all four axis arms will have equal length. Absence of these two conditions indicates imperfect alignment.
 - (3) Reposition the plate to provide four equal axis arm lengths. On the monitor image, locate the position of the upper steel ball relative to the pair of etched concentric

circles indicating central axis deviations of 1.5 and 3 degrees from the perpendicular.

- d. Interpretation of Results. If the beam axis/II misalignment exceeds 1.5 degrees, refer the system for imaging chain repositioning by a qualified service engineer.

10. Pin-cushion and "S-ing" Distortion

- a. Purpose. To verify that the fluoroscopic image contains minimal spatial distortion and artifacts.
 - (1) It is difficult to quantify an amount of acceptable distortion. However, any distortion should be horizontally and vertically symmetrical. It should also be visibly similar for fluoroscopic, cine, and digital spot images produced using the same II.
 - (2) Two major forms of spatial distortion are pincushion distortion and S-ing. Pincushion is characterized by bowing of peripheral chords into the center of the image. S-ing is characterized by warping of straight lines passing through the center of the image into "S" shapes in the central quarter to third of the image.
- b. Equipment. Contact Mesh
- c. Procedure.
 - (1) Verify that the unit meets the standards for fluoroscopy display field and beam central alignment.
 - (2) Place contact mesh on II and take image with fluoroscopy.
 - (3) Observe the image, paying special attention to the effects of excessive spatial distortion.
 - (4) For adjustable units, move the imaging chain through its full SID range noting changes in the level of distortion with changing SID.
- d. Interpretation of Results. If the amounts of pincushion distortion or S-ing exceed the levels prescribed in Table 4-1, refer the system for adjustment by a qualified service engineer. Due to the subjectivity of this test,

last hold hard copy reference images showing the level of distortion during acceptance may be invaluable during subsequent periodic testing.

11. High Contrast Resolution

- a. Purpose. To verify the system's ability to resolve high contrast objects under variable operating conditions and using multiple recording modes.
- b. Equipment. High resolution test patterns.
- c. Procedure.
 - (1) Arrange the unit for maximum SID, largest available II size, grid & compression cone out of the beam, and all collimators open.
 - (2) Attach the test pattern as close to the II face as possible.
 - (3) If the unit allows manual kVp and mA control, set kVp = 60 and adjust mA for image brightness that provides the best viewing. If the unit uses ABC, use the kVp and mA provided by the unit for 1 mm Al and test pattern in the beam.
 - (4) Determine the highest density mesh visible at the image center and periphery. A resolvable mesh should clearly show bright wires separated by dark spaces and be free of Moiré patterns. Due to variable electronic focusing across the II, resolution is typically better in the field center than at the periphery.
 - (5) Repeat the measurements using all available output rate and II size combinations. Include manual and pulse fluoroscopy, cine, and spot filming (mechanical & digital) during acceptance testing to set image quality baselines for future reference. During periodic testing, evaluate a representative subset of the acceptance group. Refer to Table 4-1.
- d. Interpretation of Results. Refer to manufacturer's recommendation.

12. Low Contrast Sensitivity

- a. Purpose. To verify the system's ability to display low contrast information.
- b. Equipment. 4 cm Al phantom, multi-perforated Al sheet.
- c. Procedure.
 - (1) Arrange the fluoroscopy unit in the same manner as for making AKR measurements, with largest available II size and grid in the beam.
 - (2) Place the perforated sheet between the two larger pieces. For units with attached tables, place the combination phantom on the tabletop. For C-arms, place the combination phantom at the same location as for AKR measurements.
 - (3) Collimate the field to the periphery of the phantom, ensuring that all sets of holes are within the image.
 - (4) If the unit allows for manual kVp and mA control, set kVp to between 85 - 90 and adjust mA for image brightness that provides best viewing. During contrast sensitivity viewing, ensure that enough tube current is applied to prevent the brightness difference from being lost in the image noise. If the unit uses ABC, use the kVp and mA provided by the system for the combination phantom in the beam.
 - (5) Determine the smallest pair of targets visible with the unaided eye. To count a given target, both circles should be clearly visible against the phantom background.
 - (6) Repeat the measurement using all available output rate and II size combinations. Include manual and pulse fluoroscopy, cine, and spot filming during acceptance testing to set image quality baselines for future reference. During periodic testing, evaluate a representative subset of the acceptance group. Refer to Table 4-1.
- d. Interpretation of Results. Image intensified fluoroscopy systems should resolve at least a 3.1 mm diameter object at 2% nominal subject contrast. Pulse fluoroscopy images may be

formed with sub-second photon bursts, making them difficult to assess visually. Low pulse rate images should not be held to the same standards as their continuous beam counterparts. If the observed sensitivity does not meet the baseline set at acceptance, refer the unit for adjustment by a qualified service engineer.

13. Automatic Exposure Control (AEC) Systems

a. Purpose.

- (1) AEC systems attached to fluoroscopy spot film devices provide the same function as their radiographic system counterparts; i.e. compensation for variations in technique factors and patient thickness such that resulting spot films appear with constant, optimal densities.
- (2) This evaluation assumes proper operation of the processor used to develop spot films. It also assumes that the AEC system is calibrated for the CR combination used with the unit. Therefore, the processor, CR cassette, and film used for testing should be those actually used during patient imaging.
- (3) The following AEC parameters should be evaluated during testing: reproducibility, maximum exposure time, kVp compensation, patient thickness compensation, density control function, and multi - image format (field size) compensation.

b. Equipment. 4 cm Al or 15 cm acrylic phantom, 1.6 mm Pb plate, 14 in x 17 in (35 cm x 43 cm) CR cassette, solid state detector or ion chamber with exposure meter.

c. Procedure.

- (1) Arrange the unit in the same configuration used for measuring fluoroscopic AKR. Ensure that if a grid is used clinically, it is in the beam path during testing.
- (2) Record the SID, film/screen combination, and film size used for future testing reproducibility.

- (3) Place the CR cassette in the bucky.
- (4) Place a 4 cm aluminum or 15 cm acrylic phantom in the beam in the same manner as for measuring AKR. Ensure that the phantom covers all the AEC detector cells.
- (5) Set the II field to its largest setting, collimating to the phantom periphery if necessary. Fluoroscopy the phantom briefly, allowing the ABC to select an appropriate kVp. Several systems apply the ABC selected kVp directly to the mechanical spot film technique. For those that do not, the fluoroscopy kVp serves as a useful guideline for manual spot film technique programming. For units without ABC, use 80 kVp.
- (6) If more than one detector cell is available and cells can be programmed to work independently, select the center cell, otherwise use all cells simultaneously.
- (7) Use a single CR cassette for testing. This will require processing the image after each exposure.
- (8) Measure and record the Optical Density (OD) at the center of the field. The OD should be at least 1.2. The radiologist may set a higher baseline density. The range of densities should be within ± 0.15 of the baseline density.

d. Output Reproducibility.

- (1) Use the basic imaging chain arrangement and phantom thickness. Place the solid state detector or ion chamber along the beam central axis at the phantom beam entrance surface. Set technique factors as follows: kVp from the fluoroscopy image or, in the absence of ABC, 80 kVp; 200 mA, AEC setting to neutral (0).
- (2) Irradiate the phantom, ion chamber and cassette holding exposed film three times. Record the exposure readings and calculate their mean.
- (3) All three readings should lie within $\pm 5\%$ of their mean.

e. Maximum Exposure Time.

- (1) Use the basic imaging chain arrangement and phantom thickness. Place the lead sheet over the AEC detector fields so that no radiation reaches them. Set technique factors as follows: kVp from the fluoroscopy image or, in the absence of ABC, 80 kVp; 200 mA, AEC setting to neutral (0). Retain the previously exposed film from the reproducibility test.
- (2) Irradiate the phantom until AEC shuts off the beam. Record the elapsed mAs.
- (3) The beam should terminate prior to the accumulation of 600 mAs.

14. kVp Compensation

Use the basic imaging chain arrangement and phantom thickness. Set technique factors as follows: 200 mA, AEC setting to neutral (0).

Vary kVp over the clinically used range 70, 80, 90, 100, and 110 kVp, irradiating a separate film for each voltage potential. Record the elapsed mAs for each image and measure the optical density at the center of each processed film using a densitometer.

The densities should lie within the range of ± 0.3 of the baseline density.

a. Patient Thickness Compensation.

- (1) Use the basic imaging chain arrangement. Set technique factors as follows: kVp from the fluoroscopy image or, in the absence of ABC, 80 kVp; 200 mA, AEC setting to neutral.
- (2) Vary phantom thickness over the range: 2, 4 cm Al or 5, 10, and 15 cm acrylic, irradiating a separate CR cassette (ignore if DR) for each phantom thickness. Record the elapsed mAs for each image and measure optical density at the center of each processed film using a densitometer.
- (3) The densities should lie within the range of ± 0.3 of the baseline density.

b. Density Control Tracking.

- (1) Use the basic imaging chain arrangement and phantom thickness. Place the solid state detector or ion chamber just off the beam central axis at the phantom beam entrance surface. Set technique factors as follows: kVp from the fluoroscopy image or, in the absence of ABC, 80 kVp; 200 mA.
- (2) Vary AEC density over the range of available positive and negative settings, exposing a new CR cassette (not needed for DR) for each setting. Record the elapsed mAs, density at the center of each film, and exposure for each image.
- (3) The density function should operate as expected; (+) gives exposure and density increase, (-) gives exposure and density decrease. The exposure difference per step should meet the manufacturer's specifications or in the absence of such data, be balanced about the neutral setting output at 25 % per step.

- c. Interpretation of Results. Units deviating from the criteria in Table 4-1 should be referred for adjustment by a qualified service engineer. Spot films can constitute a significant fraction of the total radiation output during fluoroscopy procedures. Unfortunately, spot film AEC performance is frequently omitted in periodic testing following acceptance. Proper operation of the spot film device is essential as it frequently provides the only permanent record of the fluoroscopic procedure.

Table 4-1.—Fluoroscopy Survey Requirements.

	Test	Freq	Measurements	Tolerance
1.	kVp Accuracy	A	50 kVp to max in 5 kVp increments*	± 5 % of nominal setting or readout or suggested mfr. recommendations.
		P	50 kVp to max in 10 kVp increments* <i>*If manual kV control isn't available, use ABC provided voltage</i>	Same as acceptance
2.	Air Kinetic Energy Released in Material (KERMA) Rate (AKR)	A/P	All available output modes [manual, ABC (NL & HLC), pulse, cine] at each available II size, 4 cm Al*	A. Less than max AKR (88 mGy/min, 176 mGy/min HLC) P. No sig change from acceptance (± 10 %)
3.	Maximum AKR (Max AKR)	A/P	All available output modes [manual (at max kVp), ABC (NL & HLC)], at largest II size. 4 cm Al or 15 cm acrylic phantom and Pb	Cannot exceed 88 mGy/min if no HLC and 176 mGy/min for HLC
4.	Transmission Through Primary Barrier	A/P	Al or acrylic phantom + Pb sheet set as for Test 3., max AKR technique Large volume ion chamber	Not to exceed 3.34×10^{-3} percent of entrance AKR @ 10 cm from primary barrier rear surface
5.	Beam Quality (HVL)	A/P	Manual mode - 90 kVp	$2.5 \text{ mm} \leq x \leq 3.5 \text{ mm}$ 1100 Al
			ABC only - kVp provided by unit for 5 mm Al in beam	$x \geq$ min allowed for kVp; see 21CFR1020.30
6.	Minimum SSD	A/P	Directly using tape measure or indirectly through triangulation	≥ 38 cm (stationary) ≥ 30 cm (conv C-arm) ≥ 20 cm (surg C-arm) Never < 19 cm, if source to image distance is less than 45 cm

Table 4-1.—Fluoroscopy Survey Requirements (continued).

	Test	Freq	Measurements	Tolerance
7a.	Beam Limitation (Minimum Field Size)	A/P	Max SID, minimum collimation, film at II face	Dark area $\leq 5 \times 5$ cm ²
7b.	Maximum Field Size	A/P	Max SID, widest collimation, max II size, film at II face	Dark area \leq maximum nominal II size Collimator tracks with changing SID
8.	Fluoro Display Field Alignment	A	Largest II size, CR cassette at II face, etched plate at table top For variable SID units: determine at minimum and maximum SID	Diff between CR image and screen X or Y axis lengths ≤ 3 % of SID Sum of X & Y axis diff ≤ 4 % of SID
		P	Test at largest II size, min SID only	Same as acceptance
9.	Beam Central Alignment	A/P	Minimum SID, max II size, widest collimation	≤ 1.5 degrees from vertical
* Alternatively use 15 cm thick acrylic phantom, if available.				
10a	Pin-Cushion Distortion	A/P	Manual or ABC (NL) mode at largest II size	Spatial linearity visually uniform over center 75 % of FOV
10b	“S-ing” Distortion	A/P	Manual or ABC (NL) mode at largest II size	Etched plate lines visually linear along X & Y axes in center 75 % of FOV
11.	High Contrast Resolution	A	All available output modes [manual, ABC (NL & HLC), pulse, cine, spot (digital & mech.)] at each II size Manual - 60 kVp ABC only - minimum kVp provided for 1 mm Al in beam	Use Manufacturer's suggested values.
		P	Manual or ABC (NL) mode at each commonly used II size and large II spot film using digital or mechanical AEC medium setting, as available	Same as acceptance

Table 4-1.—Fluoroscopy Survey Requirements (continued).

	Test	Freq	Measurements	Tolerance
12.	Low Contrast Sensitivity	A	All available output modes [manual, ABC (NL & HLC), pulse, cine, spot (digital & mech.)] at each II size Manual - 85 to 90 kVp, as available ABC only - kVp provided by unit	See at least 3.1 mm test tool holes at 2 % contrast (4 cm Al) (Pulse modes exempt)
		P	Manual or ABC (NL) mode at each commonly used II size and large II spot film using digital or mechanical AEC medium setting, as available	Same as acceptance
13.	AEC	A/P	Std: ABC sel or 80 kVp, 1:1 format, 4 cm Al phantom*, AEC = 0 Reproducibility: 3 exposures Max exp time, Pb over all detectors Vary kVp: 70 - 110 by tens Vary thickness: 2 and 4 cm Al** Vary field size: 1:1, 4:1 Vary density: -- to ++, as available	OD = OD _{BL} ± 0.15 (OD _{BL} must be > 1.2) All ≤ ± 5 % of mean Elapsed mAs < 600 OD = OD _{BL} ± 0.3 OD = OD _{BL} ± 0.3 OD = OD _{BL} ± 0.1 Exp dens/exp behavior

* Alternatively use 15 cm thick acrylic phantom, if available.

** Alternatively use 5, 10, and 15 cm thick acrylic phantom, if available.

Abbreviations: A: acceptance, P: periodic, kV: kilovolt, kVp: kilovolt peak, HVL: Half Value Layer, cm: centimeters, SID: Source to Image Distance, OD: Optical Density, OD_{BL}: Optical Density Baseline, ESE: Entrance Skin Exposure, ABC: Automatic Brightness Control, HLC: High level Control, NL: Normal, Al: Aluminum, Pb: Lead, FOV: Field Of View, SSD: Source to Skin Distance, AEC: Automatic Exposure Control, II: Image Intensifier, medium setting: mean available technique setting for the given output mode.

General Fluoroscopy Unit Survey

NMCPHC TM 6470.1
JUNE 2013

Facility:	Date:
Room Number/Location:	ECN:
Manufacturer:	Type:
Model Number:	Tube Serial Number:

Test Performed	Pass	Fail	N/A	Comments (failure comments must annotate minor or significant finding)
kVp Accuracy				
Air KERMA Rate (AKR)				
Maximum AKR				
Transmission Through Primary Barrier				
Beam Quality (HVL)				
Minimum SSD				
Minimum / Maximum Field Size				
Fluoro Display Field Alignment				
Beam Central / Mechanical Spot Film Alignment				
Pin-Cushion / "S-ing" Distortion				
High Contrast Resolution / Low Contrast Sensitivity				
Mechanical Spot Film AEC				
Mechanical / Digital Spot Film ESE				
Safety Equipment/ Mechanical Checks				
Additional Comments:				

Purpose:	Results:
Surveyor Name:	
Surveyor Signature:	

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Chapter 5

Computed Tomography (CT) Units

A. Introduction

X-ray CT scanners represent a departure from conventional film/screen x-ray performance. CT scanners generate a thin, well collimated beam of x-rays to a cross section of the patient's body from multiple rotational angles. The transmitted beam is collected by radiation detectors, and the information is fed into a computer which analyzes the data and constructs an image which reflects variations of the physical attenuation characteristics of the material.

The CT is unique in its ability to detect exceptionally fine variations in linear attenuation of adjacent structures and incorporate these differences into a diagnostic quality image suitable for further use in radiation therapy treatment planning and stereotactic surgical navigation.

Due to the potential complexity of CT scanner operation, a radiological technologist, trained and experienced on the CT scanner being evaluated should be present during testing. The technologist should operate the scanner while the physicist performs the tests.

B. Minimum Required Personnel Qualifications

Advanced Diagnostic Imaging Equipment (CT)

C. Testing Periodicity

All units: Annually, upon acceptance and after major repairs, i.e. x-ray tube replacement.

D. Equipment

1. Electrometer with 10 cm CT and large (180 cc) volume ion chambers
2. Manufacturer's QC Phantoms
3. ACR, AAPM or Catphan performance phantom
4. Computed Tomography Dose Index (CTDI) phantoms (16 cm diameter-head and 32 cm diameter-body)

5. Tape measure, 10 - 20 cm ruler (marked in mm)
6. Bubble level
7. CT compatible kVp meter
8. Computerized Tomography Unit Survey

E. References

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F. Performance Tests for Computed Tomography (CT) Units

1. Table Loading

- a. Purpose. To verify manufacturer's weight loading specifications for the patient support device.
- b. Criteria. Refer to manufacturer's specifications.
- c. Equipment. Weights and/or persons totaling the manufacturer's loading specifications.
- d. Procedure. Distribute specified weight over table top in proportion to normal weight distribution. Check full range of vertical and horizontal motion. Record maximum weight and range of motion. Do not load table beyond manufacturer's specification.
- e. Interpretation of Results. If table loading requirements do not meet manufacturer's specifications consult a qualified service engineer.

2. Table Positioning

- a. Purpose. To ensure that table movement and localization is accurate.
- b. Criteria. Manufacturer's specifications or ± 1 mm.
- c. Equipment. Ruler.
- d. Procedure. Tape a ruler to the fixed portion of the patient support assembly. Make a mark on the table adjacent to the tape measure. Move the table both in and out of the gantry to predetermined distances. Record the actual and selected distances traveled (typically 1, 10 and 40 cm.).
- e. Interpretation of Results. The table should move smoothly and accurately to within 1 mm of target in either movement direction. Consult a qualified engineer if the requirement is not met.

3. Table/Gantry Alignment

- a. Purpose. To ensure proper alignment of the table and gantry isocenter.

- b. Criteria. Manufacturer's specifications or ± 5 mm.
- c. Equipment. Ruler
- d. Procedure.
 - (1) Using the laser light, raise the scanning table until the lateral lasers intersect the horizontal plane.
 - (2) Insert the table into the gantry opening.
 - (3) Scan the table using the standard head technique. Using the electronic ruler and grid, project the distance from grid center to right and left table edges onto the grid.
 - (4) Compare the two distances and determine the difference between them.
 - (5) Calculate misalignment as half the difference between the two measurements.
- e. Interpretation of Results. Misalignment of the two table edges and isocenter should be ≤ 5 mm. If it is not consult a qualified service engineer.

4. Kilovoltage (kV) Accuracy

- a. Purpose. To ensure that the x-ray generator is producing the kVp as indicated on the control panel.
- b. Criteria. The accuracy must be $\pm 5\%$ of the nominal control panel setting or within manufacturer's specifications.
- c. Equipment. Noninvasive tube potential measuring device calibrated for CT use.
- d. Procedure. Noninvasive devices may not work well in CT if detector sensitive region is too large for narrow CT beams. Be certain that the device is calibrated for the kV range and beam quality to be tested (consult device manufacturer) and is set for direct current (dc) or three-phase wave forms. Hardening corrections may be necessary with some instruments to compensate for heavily filtered CT beams.
 - (1) From operator's console, rotate tube to overhead Anterior/Posterior (AP) position.

- (2) Put table at lowest scan position, move tabletop into gantry opening and place kV sensor on table. Align detector(s) to scan alignment light. If instrument detector is large, place it at bottom of gantry opening where the field size is greatest, with tabletop out of field.
 - (3) Operate CT system in service mode with tube and tabletop stationary (consult service engineer).
 - (4) Set widest collimator setting and expose detector. Proceed only if instrument obtains a reading without error indication.
 - (5) Measure tube potential at each generator power level for each potential setting. Record which focus is selected with dual focus xray tubes.
- e. Possible Pitfalls.
- (1) The HVL should always be measured after assuring the kVp is correct.
 - (2) The major cause of kVp variation is calibration. Some generators maintain their calibration well and others drift constantly. It is important to note that a change in kVp may not always show as a change in image density because changes in the mA will often compensate for the change in kVp.
 - (3) Since the kVp affects the radiographic contrast, it must be checked to assure that it is acceptable.
 - (4) Other major causes of variations in kVp are line voltage drops and electrical component failure.
- f. Interpretation of Results. Refer units deviating from the criteria for adjustment by a qualified service engineer. Proper kVp calibration is critical as it directly influences image quality and patient dose.

5. Tube Current Linearity

- a. Purpose. To ensure radiation exposures vary linearly with tube current (mA).
- b. Criteria. (10 CFR 1020) The average ratios of exposure to the indicated mAs product (mR/mAs) obtained at any two consecutive tube current settings should not differ by more than 0.10 times their sum: $(X1-X2) < 0.10(X1+X2)$.

Where X1 and X2 are the average mR/mAs values obtained at each of two consecutive tube current settings.

- c. Equipment. Calibrated Ionization chamber or solid state detector and electrometer.
- d. Procedure.

- (1) From operator's console, rotate tube to overhead (AP) position.
- (2) Put table at lowest scan position, move tabletop into gantry opening and place detector on table. Align detector to scan alignment light. If instrument detector is large, place it at bottom of gantry opening where the field size is greatest, with tabletop out of field.
- (3) Operate CT system in service mode with tube and tabletop stationary (consult service engineer).
- (4) Set widest collimator setting and expose detector. Proceed only if instrument obtains a reading without error indication.
- (5) Measure and record the exposures at 5 different mA settings while keeping kVp and time constant. With some x-ray units, the mA cannot be varied without varying time. In this instance mA must be constant and time varied. Divide the mR output by mAs setting, record mR/mAs as calculated.

e. Interpretation of Results.

- (1) If each of the average ratios between mA stations deviate from the listed criteria, consult a qualified service engineer. Linearity of mA/mAs is critical as it

directly influences image quality and patient dose.

- (2) Significant deviation from linearity may indicate miscalibration of potential, current, or exposure time. If the coefficient of linearity of mGy/mAs between the mean of all values and any single value (absolute difference divided by sum) is greater than 0.05 then significant miscalibration may be present. If time values are obtained, determine if measured times correspond to scan time settings. Errors with constant potential generators can indicate shutter problems.

6. *Beam Quality*

- a. Purpose. To assure that the permanently installed (added) filtration at the x-ray tube is maintained at an appropriate level for optimal image quality and patient dose.
- b. Criteria. Federal and many state regulations specify minimum required HVLs at various kVp values (21 CFR 1020.30). Refer to manufacturer's specifications for HVL.
- c. Equipment. Ionization chamber or solid state detector, a total of 10 mm Al Type 1100 plates; combination of 1 mm and 0.5 mm Al plates.
- d. Procedure.
 - (1) Position the radiation detector as described in section 2 above.
 - (2) Set the CT system to operate in service mode with tube and tabletop stationary as described in section 2 above.
 - (3) The Al sheets should be placed between the ion chamber/solid state detector and the x-ray tube at a distance $X/2$, where X = focal spot to detector distance. Make sure the Al sheets intercept the entire beam. Make two exposures without any Al sheets in the beam, one before and one after, to ensure that the geometry has not changed.
 - (4) Acquire an exposure using 90 kVp, and mAs to provide an exposure of approximately 300 mR.

- (5) Add Al sheets and make additional exposures until the exposure is less than half of the original exposure. Note that CT beams are heavily filtered, and the HVL is normally greater than 5 mm Al at 90 keV.

- (6) Remove all Al sheets and make one exposure. If exposure is not within 2% of the initial exposure, made with 0 mm of Al, repeat the measurement series ensuring that the technique and geometry selected remain the same throughout the procedure.

e. Possible Pitfalls.

- (1) The radiation detector must be in the x-ray beam. When placing the sheets of Al in the beam, be sure that the entire beam is intercepted by the Al sheet. Once selected, the technique factors must not be altered for subsequent exposures.
- (2) The kVp should be checked before measuring the HVL to ensure that it is within acceptable limits.
- (3) The Al used for HVL measurements should be type 1100.

- f. Interpretation of Results. The HVL should easily meet minimum HVL thickness per 21 CFR 20120. However, if the HVL significantly exceeds manufacturer's specifications a qualified service engineer should be contacted immediately. Excessive HVLs will reduce CT tube life.

7. *Image Quality: American College of Radiology (ACR) Phantom Tests The Phantom*

The American College of Radiology (ACR) CT accreditation phantom has been designed to examine a broad range of scanner parameters. These include:

- a. Positioning accuracy
- b. CT number accuracy
- c. Image thickness
- d. Low contrast resolution
- e. High contrast resolution
- f. CT number uniformity
- g. Image noise

The ACR CT accreditation phantom (Gammex 464) is a solid phantom containing four modules, and is constructed primarily from a water-equivalent material. Each module is 4 cm in depth and 20 cm in diameter. There are external alignment markings scribed and painted white (to reflect alignment lights) on EACH module to allow centering of the phantom in the axial (z-axis, cranial/caudal), coronal (y-axis, anterior/posterior), and sagittal (x-axis, left/right) directions. There are also “HEAD”, “FOOT” and “TOP” markings on the phantom to assist with positioning as shown in Figure 5-1.

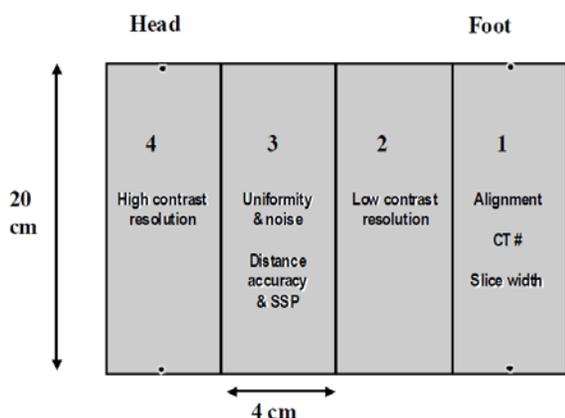


Figure 5-1.

Prior to scanning the ACR CT phantom, perform tube warm-up and any necessary daily calibration scan (air/water scans) as recommended by the manufacturer.

ACR phantom test procedures can be found at the ACR Accreditation website: <http://www.acr.org/~media/ACR/Documents/Accreditation/CT/PhantomTestingInstruction.pdf>

8. Position Accuracy

- Purpose.** To ensure the CT phantom is aligned properly with the scanner and alignment lights (lasers).
- Regulations.** ACR or Manufacturer’s specifications.
- Equipment.** ACR CT Accreditation Phantom.
- Procedure.**

- Pull back the table padding and position the ACR CT phantom so that it is “HEAD” first into the gantry. (Be sure to

choose a patient orientation of “supine head first” on the scanner.)

- Carefully position the phantom so that the CT scanners alignment lights are accurately positioned over the scribe line corresponding to the center of Module 1 (FOOT END of the phantom). Use the set of alignment lights, internal or external, that are used clinically. Align the phantom in the sagittal, coronal, and axial planes. Zero (or landmark) the table at this point (or be sure to note the table location, as all scans will be acquired in reference to this location). While maintaining careful alignment, secure the phantom so it will not move.
- Use a single axial scan at the landmark location (0 or S0). Use an image thickness ≤ 2 mm to verify adequate alignment Use a display field of view (reconstructed image diameter) as close to, but not smaller than, 21 cm.

- Interpretation of Results.** Examine the image to determine whether all four Ball Bearings (BBs) are visible in the image (Figure 2). Use WW = 1000 and WL = 0. All four BBs should be visible as shown in Figure 5-2. The longer central wires should be symmetrically located in the center of the image. This indicates good positioning of the phantom. If this fails, consult a qualified service engineer.

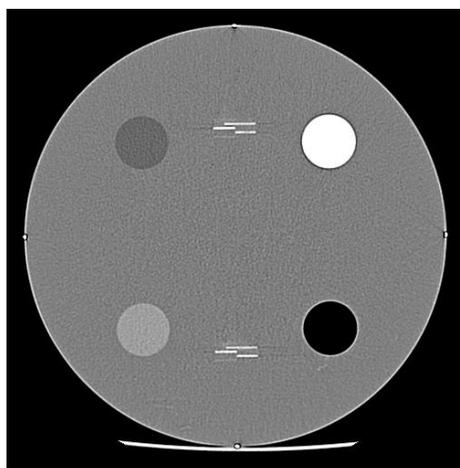


Figure 5-2.

9. CT Number Accuracy

a. **Purpose.** To ensure that the CT numbers associated with air, water, acrylic, polyethylene and bone are accurate and that the system is properly calibrated.

b. **Criteria.** ACR Accreditation Standards:

Polyethylene HU:	between -107 and -84
Water HU:	between -7 and +7
Acrylic HU:	between +110 and +135
Bone HU:	between 850 and 970
Air HU:	between -1005 and -970

NOTE: Manufacturer's criteria for water and air CT numbers may differ from the ACR standards. In this case if the facility is not applying for or under ACR Accreditation status, the results should meet the manufacturer's specification.

c. **Equipment.** ACR Accreditation Phantom.

d. **Procedure.**

- (1) Using the best Module 1 image scanned with the facility's adult abdomen protocol, place a circular Region Of Interest (ROI, approximately 200 mm²) within each cylinder and record the mean CT number for each material.
- (2) It is important to center the ROIs within each cylinder. The water cylinder is subtly seen as a large gray ring. Be sure to place the water ROI between the polyethylene and acrylic cylinders.
- (3) Figure 5-3 shows Modular 1 regions of interest (ROIs) for each material and for the water-equivalent background material.

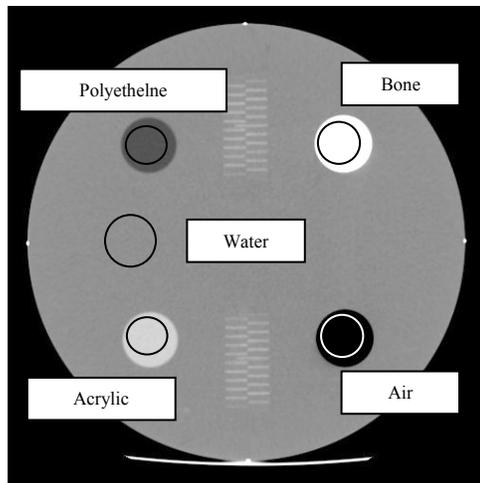


Figure 5-3.

(4) Measure only the water number for all other CT protocols.

e. **Interpretation of Results.** If the CT numbers do not meet the criteria, consult a qualified service engineer.

10. Low Contrast

a. **Purpose.** To evaluate low contrast capability of the system.

b. **Criteria.** ACR Accreditation Standards. The Contrast to Noise Ratio (CNR) must be greater than 1.0 for the adult head & abdomen and, pediatric head protocol. The CNR must be greater than 0.5 for the pediatric abdomen protocol.

c. **Equipment.** ACR Accreditation Phantom.

d. **Procedure.**

- (1) View the best image located in Module 2 scanned with the facility's adult head, adult abdomen, and pediatric abdomen protocols using a WW = 100 and a WL = 100. Note the four cylinders for each of following diameters: 2, 3, 4, 5, and 6 mm are not evaluated.
- (2) Place a ROI ($\approx 100 \text{ mm}^2$) over the large (25-mm diameter) cylinder and between the large cylinder and the 6 mm cylinders.

- (3) Figure 5-4 shows low contrast resolution image at WW = 100 and WL = 100 with ROI placements.

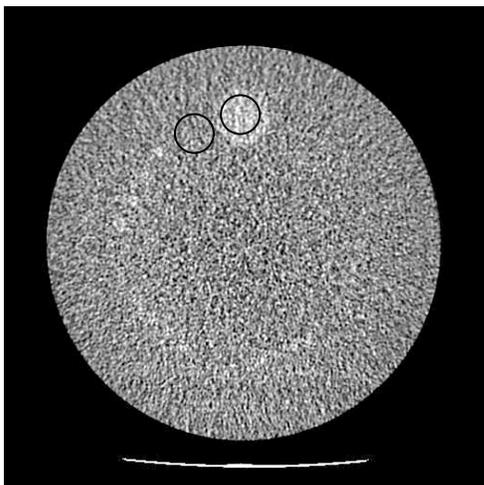


Figure 5-4.

- (4) Record the mean signal in the ROI inside the 25mm rod (A), the mean signal in the ROI outside the 25 mm rod (B), and the Standard Deviation (SD) from the ROI outside the 25 mm rod for your records.

e. Interpretation of Results.

- (1) Use the following formula to calculate the CNR:

$$\text{CNR} = |A-B|/SD$$

- (2) Use the absolute value of the difference – that is, **do not** take into consideration whether the CNR is a positive or negative number.
- (3) If the CNR numbers do not meet the criteria, consult a qualified service engineer.

11. Uniformity, Artifact, & Scaling Accuracy

- a. Purpose. To evaluate image uniformity across a homogenous field of view, presence of artifacts, and in-plane scaling accuracy.

b. Criteria.

- (1) Uniformity. ACR Accreditation Standards: The CT numbers for all five ROIs must be

within ± 5 HU of the center ROI mean value.

NOTE: Manufacturer's criteria for uniformity may differ from the ACR test protocol and standards. In this case if the facility is not applying for or under ACR Accreditation status, the results should meet the manufacturer's specification.

- (2) Artifact. Rings or streaks that are considered clinically significant.
- (3) Scaling Accuracy. The measured distance should be within 10% of the nominal distance (100 mm).

c. Equipment. ACR Accreditation Phantom.

d. Procedure.

- (1) View the Adult Abdomen protocol image in Module 3 (uniformity image) with a WW \simeq 100 and a WL \simeq 0. Place an ROI of approximately 400 mm² at the center of the image and the four edge positions shown in Figure 5-5.
- (2) For the edge ROIs, place the edge of the ROI approximately one ROI diameter away from the edge.
- (3) Figure 5-5 shows Module 3 showing placement of uniformity center and edge ROIs.

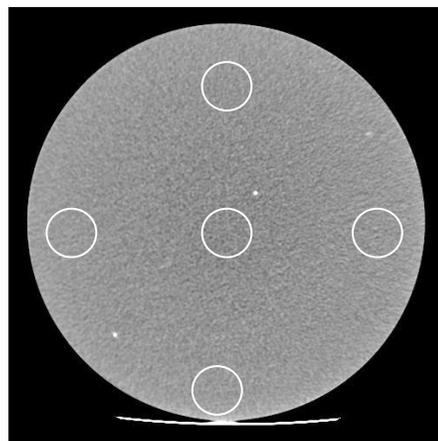


Figure 5-5.

e. Interpretation of Results.

- (1) Uniformity. Record the mean CT numbers for all five ROIs for your records. Additionally, record the standard deviation of the center ROI. Calculate the difference in ROI values between each edge ROI and the center ROI value. If the difference exceeds the criteria, consult a qualified service engineer.
- (2) Artifact. With all graphics turned off, view the same image carefully with the room lighting reduced. Examine the image for artifacts such as rings or streaks and record the presence and appearance of any artifacts. If artifacts are present, consult a qualified service engineer to investigate.
- (3) Scaling Accuracy. Using the scanner's measuring tools, measure the distance between the two very small BBs (0.28 mm each) to assess the accuracy of in-plane distance measurements. Consult a qualified service engineer if measured distance is outside 10% of the nominal distance.

view the image with the room light lowered and, determine the highest spatial frequency for which the bars and spaces are distinctly visualized.

- (2) Repeat this procedure using a high resolution (edge enhanced) adult chest protocol.
- (3) Figure 5-6 shows Module 4, to assess high contrast (spatial) resolution, contains eight bar resolution patterns in line pairs per centimeter (lp/cm).

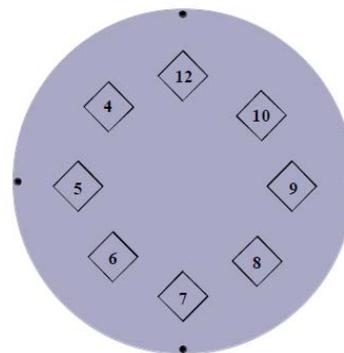


Figure 5-6.

12. High Contrast

- a. Purpose. To evaluate the high contrast resolution capability of the CT system.
- b. Criteria. Manufacturer's specification or ACR recommended standards:
 - (1) ACR recommends that the CT system should be capable of resolving 5 lp/cm using the facility's adult abdomen protocol, and 6 lp/cm for high resolution (edge enhanced) adult chest protocol. ACR does not have pass/fail criteria for this test, but the results should be recorded for baseline purposes.
- c. Equipment. ACR Accreditation Phantom.
- d. Procedure.
 - (1) View the Adult Abdomen protocol image in Module 4 (high contrast resolution) with a WW \approx 100 and a WL \approx 1100. Using the illustration in Figure 4 as reference, note the eight bar patterns, which represent spatial frequencies corresponding to: 4, 5, 6, 7, 8, 9, 10, and 12 lp/cm. Carefully

e. Interpretation of Results.

- (1) The 4 lp/cm bar pattern is the easiest to resolve and appears to have the widest bars and widest spaces.
- (2) The 12 lp/cm bar pattern is the hardest to resolve and, in this image, will likely appear as a uniformly filled square.
- (3) A better resolution should be seen (6 lp/cm) for the high resolution (edge enhanced) adult chest protocol compared to the adult abdomen protocol (5 lp/cm). The results should be recorded for baseline purposes.

13. Slice Thickness Accuracy

- a. Purpose. To verify the accuracy of the actual width of the image slice.
- b. Criteria. Manufacturer's specifications or ACR recommended criteria of ± 1.5 mm of the prescribe slice thickness.
- c. Equipment. ACR Accreditation Phantom

d. Procedure.

- (1) View the images in Module 1 using the adult abdomen protocol obtained from three different slice width scans.
- (2) Count the number of wires visualized in each of the two slice thickness ramps (Figure 5-3).
- (3) Count the number of wires in the top section separately from the number of wires in the bottom section.
- (4) The images should be viewed with a WW \approx 400 and a WL \approx 0.
- (5) Count any wire that appears to be 50% or more as bright as the central wires.
- (6) For both the top ramp and the bottom, divide the total number of wires visualized by 2 and record the resultant top scan width and bottom scan width (both in mm).

e. Interpretation of Results. Refer to manufacturer's specifications for acceptance criteria. In the absence of specifications, ACR recommends that the measured profile width should be within \pm 1.5 mm at the nominal slice width.

14. Radiation Dosimetry

Computed Tomography Dose Index (CTDI)_{VOL}

- a. Purpose. To determine the radiation dose to tissue for several CT clinical protocols and to compare the dose data to reference CTDI_{VOL} levels.
- b. Criteria. ACR Accreditation Standards.

Examination	Pass/Fail Criteria	Reference Levels
	CTDL _{vol} (mGy)	CTDL _{vol} (mGy)
Adult Head	80	75
Adult Abdomen	30	25
Pediatric Head (1 yr)	To be determined	45
Pediatric Abdomen (5 yr, 40-50 lb)	25	20

c. Equipment.

- (1) Phantom Data Form, with average facility protocols for adult head and body, and pediatric head (1 year old) and body (5 year old, 40-50 lbs).
- (2) Calibrated CTDI (pencil) ionization chamber (typically 10 cm in length)
- (3) Calibrated electrometer.
- (4) Acrylic (PMMA) cylindrical phantoms, having cylindrical holes at 1 cm from the edge, and one at the center (Figure 5-7):
 - (a) Head CTDI phantom: 16 cm diameter
 - (b) Body CTDI phantom: 32 cm diameter



Figure 5-7.

- (5) Dose calculation Excel spreadsheet, is available at www.acr.org under the CT Accreditation page.

d. Procedure.

- (1) Position the phantom appropriately at the isocenter of the scanner. Ensure that the phantom is correctly aligned in all three planes (sagittal, axial, and coronal).
 - (a) For the adult position the 16 cm phantom in the head holder.
 - (b) For the adult abdomen scans, position the 32 cm phantom on the table top.
 - (c) For the pediatric abdomen scans, position the 16 cm phantom on the table top.

- (d) For the pediatric head scans, position the 16 cm phantom on the table top.
- (2) Connect the pencil chamber to the electrometer and insert the pencil chamber into the central hole in the phantom. Ensure that all other holes (those at 3, 6, 9, and 12 o'clock positions) are filled with acrylic rods.
- (3) Using the appropriate protocol as entered in the phantom data form, acquire a single axial slice at the center of the phantom, with no table increment. If the protocol is normally scanned helically, change to an axial scan, keeping the remaining technical parameters unchanged. All CTDI dose information must be acquired using axial scans.
 - (a) In multislice CT, CTDI is a function of detector configuration. It is imperative that the detector configuration and total beam width used matches the site's Clinical Protocol (NxT) as closely as possible.
 - (b) If NxT used for dosimetry does not exactly match the clinical value, be sure to modify the table increment used in the calculation to yield the same pitch value as used clinically.
- (4) Record the following in the Excel Dose Spreadsheet for the appropriate examination:
 - (a) kVp
 - (b) mA
 - (c) Exposure time (sec)
 - (d) Z-axis collimation (T, in mm)
 - (e) Number of data channels used
 - (f) Table Increment (mm) used to yield the clinical pitch
 - (g) Active chamber length of pencil chamber
 - (h) Chamber correction factor
 - (i) Exposure in mR
- (5) Repeat the scan two more times and record the measurements from each scan in the Excel Dose Spreadsheet. If the data differ by more than 5%, check your equipment and rescan the data until the three measurements agree within 5%.
- (6) The spreadsheet will calculate the **average** measurement from scans in mR, and the *CTDI at isocenter in phantom* in mGy.
- (7) Move the pencil chamber from the center position to the 12 o'clock peripheral position. Ensure that an acrylic rod is then inserted into the vacated isocenter position.
- (8) Repeat steps 3 through 7 and record the value in mGy as the *CTDI at 12 o'clock position*.
- (9) The spreadsheet will calculate the following:
 - (a) Average of the three measurements from the 12 o'clock position in mR
 - (b) Head CTDI at 12 o'clock position in mGy
 - (c) CTDI_w in mGy
 - (d) CTDI_{vol} in mGy
 - (e) DLP in mGy-cm
 - (f) Effective Dose in mSv
- (10) Repeat steps 1 through 9 for adult head and body, and pediatric head and body clinical CT protocols.
- e. Interpretation of Results.
 - (1) Compare the measured CTDI_{VOL} values with the ACR recommended reference levels.
 - (2) If the measured CTDI_{VOL} values exceed ACR *Pass* threshold criteria, consult the lead interpreting radiologist and senior CT technologist to adjust scanning protocols to acceptable dose levels.

15. Scatter

- a. Purpose. To establish and maintain control of the scatter pattern created by the CT scanner.
- b. Criteria. Refer to manufacturer's isodose area plot for interior room measurements. Exterior room measurements should be less than 100 mrem per year for the general public.
- c. Equipment. CTDI body phantom and electrometer with large (180 sq cm) probe.
- d. Procedure. Center the CTDI phantom in the gantry opening and width of table. Place the probe at the first position to be evaluated. Scan under highest technique clinically used (1 slice) for body mode with the largest slice thickness. Record the electrometer reading. Move the probe to the next location and repeat the procedure.
- e. Interpretation of Results.
 - (1) Exterior walls should not exceed the general public dose limit of 100 mrem per year.
 - (2) If doses within the room are significantly greater than the expected isodose values provided by the manufacturer a service engineer should be consulted.

Table 5-1.—Computerized Tomography Unit Survey Requirements.

	Tests	Frequency	Measurements	Tolerance
1.	Table Loading	A	Loaded, maximum and minimum height, in & out	Manufacturer's specifications
2.	Table Positioning	A	Slice, return to same position, same slice Smallest slice available	± 1 mm
3.	Table, Gantry Alignment	A	Centers: Table and gantry	± 5 mm
4.	kVp Accuracy	A/P	All kVp CT kVp stations	± 5% of nominal kVp setting
5.	Tube Current Linearity	A/P	5 mA stations, covering range of mA stations used clinically	$(X1 - X2) < 0.1(X1+X2)$ Where X1 and X2 are the average mR/mAs values at each consecutive tube current settings.
6.	Beam Quality	A/P	Default kV	Manufacturer's specification
7.	Position Accuracy	A/P	ACR Phantom Module 1	Visualize 4 BBs
8.	CT Number Accuracy	A/P	ACR Phantom Module 1	Water: btwn -7 & +7 HU Air: -1005 & -970 HU See ACR standards
9.	Low Contrast	A/P	ACR Phantom Module 2 ROI HU difference in & out of cylinder	CNR > 1.0 for adult head & abdomen; CNR > for pediatric abdomen
10.	Uniformity Artifact Scaling Accuracy	A/P	ACR Phantom Module 3 ROI measurements at edge & center of image ACR Phantom Module 3 ACR Phantom Module 3 Measure distance between 2 BBs	Difference between edge ROI and center ROI < 5 H Rings or streaking artifacts Measured distance < 10% of nominal distance (100 mm)

Table 5-1.—Computerized Tomography Unit Survey Requirements (continued).

	Test	Frequency	Measurements	Tolerance
11.	High Contrast	A/P	ACR Phantom Module 4 Evaluating limiting resolution (lp/cm) pattern	5 lp/cm for adult abdomen protocol; 6 lp/cm for high resolution adult chest protocol
12.	Slice Thickness Accuracy	A/P	ACR Phantom Module 1 Evaluate 3 different slice thickness and measure the steps in the top and bottom ramps.	Measured slice thickness should be within \pm 1.5 mm of nominal setting.
13.	Radiation Dosimetry	A/P	CTDI volume of adult head & abdomen protocol, and pediatric head & abdomen protocol	Adult Head < 80 mGy Adult Abd < 30 mGy Ped Head < TBD Ped Abd < 25 mGy
14.	Scatter	A	Largest slice thickness Body FOV, standard body algorithm CTDI Body Phantom simulating patient, measure @ occupied locations	< 100 mR/yr to the public in occupied spaces

Abbreviations: A: acceptance, P: periodic, HU: Hounsfield units, NL: Normal, FOV: Field Of Vision, ROI: Region Of Interest, DPSC: Defense Personnel Support Center, MTF: Modulation Transfer Function, RAD: Radiation Absorbed Dose (1 rad = 100 erg/g), MSAD: Multiple Scan Average Dose, CTDI: Computed Tomography Dose Index, mR: millirad = 1/1000 rad, kV: kilovolt, SMPTE: Society of Motion Picture and Television Engineers

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Computerized Tomography Unit Survey

NMCPHC TM 6470.1
JUNE 2013

Facility:	Date:
Room Number/Location:	ECN:
Manufacturer:	
Model Number:	Tube Serial Number:

Test Performed	Pass	Fail	N/A	Comments (failure comments must annotate minor or significant finding)
Table Loading				
Table positioning				
Table, Gantry Alignment				
kVp Accuracy				
Tube Current Linearity				
Beam Quality (HVL)				
Position Accuracy (Laser Alignment)				
CT number Accuracy				
Low Contrast				
Uniformity				
Artifact				
Scaling Accuracy				
High Contrast				
Slice Thickness Accuracy				
Radiation Dosimetry				
Scatter				
Additional Comments:				

Purpose:	Results:
Surveyor Name:	
Surveyor Signature:	

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Chapter 6

Mammographic Units

A. Introduction

The MQSA; Correction; Final Rule, 21 CFR 16 and 900, November 10, 1997, requires any facility that produces, processes or interprets mammograms to be certified by the FDA. To be certified, facilities must meet the federal regulations and must be accredited by a FDA approved private or state accrediting body.

B. Minimum Required Personnel Qualifications

MQSA

C. Testing Periodicity

Annually

D. Equipment

As specified by the MQSA

E. References

1. Code of Federal Regulations, Title 21, Chapter 1, Parts 1020.30, 1020.31, 1020.32; 3 May 1993 edition.
2. Mammography Quality Standards Act (MQSA) of 1992.
3. *Quality Assurance in Mammography*. American College of Radiology (ACR), 1994.

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Chapter 7

Performance Tests for Ultrasound Scanners

A. *Minimum Required Personnel Qualifications*

Advanced Diagnostic Imaging Equipment Ultrasound (US)

B. *Introduction*

There currently exist only recommendations for Quality Control (QC) programs for ultrasound. However, such programs are important for ensuring the accuracy of patient examinations as well as for controlling repair and maintenance costs of the units themselves.

The tests listed in Table 7-1 should be performed using the most clinically used transducers with Time Gain Compensation (TGC) and depth settings as described in ref.4. For acceptance testing, all transducers need to be tested.

This chapter only applies to real-time B-mode operation ultrasound systems. Doppler and any other flow imaging modes quality control test procedures are not cover under this chapter.

C. *Testing Periodicity*

See Table 7-1 for the periodicity of each test.

D. *Equipment*

1. Tissue equivalent phantom with average velocity of sound of $1540 \text{ m/s} \pm 10 \text{ m/s}$ and an attenuation coefficient of 0.5 to 0.7 dB/MHz-cm
2. Ultrasound Scanner System Survey

E. *References*

1. Hendrick, W.R., and Hykes, D.L. 1997 *Journal of Diagnostic Medical Sonography*: 13, pp 68-75.
2. Carson, P.L. and Zagzebski, J.A. 1981. *Pulse Echo Ultrasound Imaging Systems Performance Tests and Criteria*; AAPM Report No 8, American Institute of Physics.
3. Poznanski, A.K. 1988. *Quality Assurance for Diagnostic Imaging*; NCRP Report No. 99, National Council on Radiation Protection.
4. Goodsitt M.M and Carson P.L 1998. *Real-time B-mode ultrasound quality control test procedures Report of AAPM Ultrasound Task Group No. 1*

F. *Performance Tests for Ultrasound (US) Scanners*

1. *Vertical Distance Accuracy*

- a Purpose. To determine the accuracy of distances measured along the beam axis.
- b Regulations. Refer to manufacturer's specifications.
- c Equipment. Tissue-Mimicking (TM) phantom
- d Procedure.
 - (1) Rest ultrasound transducer on scanning surface of the phantom.
 - (2) Adjust the focal zone and depth controls until the vertical pin targets are clearly visualized and freeze the image.
 - (3) Measure the distance between two of the vertical pin targets and compare this measurement with the actual vertical pin distance specified by the phantom. Always measure the distance on the between the same two targets that were used during the baseline tests. Record the

measured distance and compared with known distance.

2. *Horizontal Distance Accuracy*

- a Purpose. To determine the accuracy of distances measured perpendicular to the beam axis.
- b Regulations. Refer to manufacturer's specifications.
- c Equipment. TM phantom
- d Procedure.
 - (1) Repeat step 1.d. (1) thru d. (2).
 - (2) Measure the distance between two of the horizontal pin targets and compare this measurement with the actual horizontal pin distance specified by the phantom. Always measure the distance between the same two targets that were used during the baseline tests. Record the measured distance and compared with known distance.
- e Interpretation of Results. If vertical and or horizontal distance accuracy exceeds tolerance levels specified in Table 7-1 consult a qualified service engineer.

3. *Transducer Sensitivity / Depth of Penetration*

- a Purpose. To determine the sensitivity of an ultrasound instrument's weakest echo signal level that can be detected and clearly displayed.
- b Regulations. Refer to manufacturer's specifications.
- c Equipment. TM phantom
- d Procedure.
 - (1) Rest ultrasound transducer on scanning surface of the phantom.
 - (2) Adjust focal zone to maximum depth, gain and output power to maximum.

- (3) Scan phantom and freeze image. Measure and record the maximum depth of visualization of background echoes from the phantom. This is the distance from the top of the scan window to the deepest cylindrical or spherical object that is barely visible. Record the depth of penetration.

- e Interpretation of Results. The maximum depth of penetration is the point at which usable tissue echoes disappear from the image, i.e. how far one can "see" into the patient. The maximum depth of penetration should remain the constant over time; variations indicated performance degradation. If changes in depth exceed tolerance levels specified in Table 7-1 consult a qualified service engineer.

4. *Dead Zone (Ring Down)*

- a Purpose. To determine the zone were useful data is missing (dead zone).
- b Regulations. Refer to manufacturer's specifications.
- c Equipment. TM phantom
- d Procedure.
 - (1) Adjust focal zone and depth controls to contain a set of filaments targets located very close to the scanning window (dead zone target group) and freeze the image.
 - (2) Determine the closest pin which can be imaged and record its depth.
- e Interpretation of Results: The dead zone is the result of reverberations in the transducer, adjacent tissue, and the scanner's attempts to compensate for these problems. Damage to the transducer or poor acoustic coupling may accentuate this defect. If dead zone exceeds specifications listed in Table 7-1 consult a qualified service engineer or if there is any consistent measurable change from baseline.

5. *General Maintenance*

- a Purpose. To evaluate the integrity of the scanner's mechanical components.

- b Regulations. Visual determination of satisfactory or unsatisfactory per Table 7-1.
- c Equipment. None
- d Procedure.
 - (1) Check unit and transducer cables, housing, and transmitter surfaces for cracks, separations, and discolorations.
 - (2) Transducer(s) plug-ins should be marked if they can be plugged into one of several outlets and check for bent or loose prongs.
 - (3) Verify that transducer(s) within the scan head move(s) smoothly without excessive noise or vibration, and the absence of air bubbles in the scan heads.
 - (4) Check for dirty or broken switches, knobs, and burnt out lights.
 - (5) The video monitor should be clean and free of scratches.
 - (6) Check that all wheels rotate freely and that the unit is easy to maneuver, and that wheels are seated securely and lock properly.
 - (7) Inspect that the dust filters are clean and free of lint and clumps of dirt, as overheating may result and shorten the life of electronic components.
- e Interpretation of Results. Take damaged systems or components out of service and repair them before using the system to image patients.

6. Image Uniformity

- a Purpose. To ensure the absence of image artifacts and non-uniformities.
- b Regulations. Visual determination of satisfactory or unsatisfactory per Table 7-1.
- c Equipment. TM phantom
- d Procedure.
 - (1) Adjust the focal zone and depth controls to scan the region of the phantom with the fewest targets (most commonly the area

opposite the phantom cysts) and freeze the image. Record the settings for future use.

- (2) Print a hard copy, visualize results, and grade the image.

- e Interpretation of Results. The hard copy of the image should be inspected for the absence of non-uniformities. A service engineer should be contacted if noticeable and/or serious non-uniformities are present.

7. Lateral Resolution

- a Purpose. To determine the instrument's ability to distinguish small, adjacent structures perpendicular to the beam's major axis.
- b Regulations. Refer to manufacturer's specifications.
- c Equipment. TM phantom
- d Procedure.
 - (1) Adjust the control settings to obtain a clear image that shows as many of the vertical pin targets as possible and freeze the image.
 - (2) Measure and record the width of the three vertical pin targets in the near, middle, and far field zones, always measuring the pin width from edge-to-edge.

NOTE: Lateral resolution is highly dependent upon machine the settings used to generate an image; therefore be sure to record the baseline settings and use the same settings for all follow up procedures.

- e. Interpretation of Results. Lateral resolution is approximately equal to beam width and varies with depth, transducer focusing characteristics, and the system's gain and sensitivity settings. Objects smaller than the ultrasound beam are displayed with a width equal to the width of the ultrasound beam at that depth. The lateral resolution of transducers with a fixed focus will vary noticeably with depth. Lateral resolution is typically affected by the loss of transducer elements or by problems in the system's beam-forming circuits. Although minor

variations are normal, the pin width should remain relatively constant over time. A service engineer should be contacted if beam width changes by more than 1 mm from baseline values.

8. Axial Resolution

- a Purpose. To determine the instrument's ability to detect and clearly display closely spaced objects that lie on the beam's axis.
- b Regulations. Refer to manufacturer's specifications.
- c Equipment. TM phantom
- d Procedure.
 - (1) For each axial resolution target group (near, middle, and far), adjust the focal zone and depth controls to scan the target group and freeze the image.
 - (2) Determine the axial resolution by finding the two pin targets with the smallest vertical spacing that are visible as distinct objects and have no vertical overlap and record the resolution level.
 - (3) Record machine baseline settings and use the same settings for all follow up procedures.

NOTE: Pin targets larger than 0.15mm in diameter may produce a doubling artifact for transducer frequencies greater or equal to 5 MHz.

- e. Interpretation of Results. Axial resolution depends on the transducer's spatial pulse length or pulse duration, which depend on the center frequency and damping factor. Axial resolution should remain stable over time. A service engineer should be contacted if any consistent measurable change from baseline values.

9. Cyst Imaging (Anechoic Imaging)

- a Purpose. To evaluate the system's ability to display a round, negative contrast object.

- b Regulations. Refer to manufacturer's specifications.

- c Equipment. TM phantom

- d Procedure.

- (1) Adjust the focal zone and depth controls until the target cyst is clearly visualized, the edges of the cyst are sharply defined, and the cyst interior is echo free. Freeze the image.

NOTE: Bright spots at the top and bottom of cysts are specular reflections and are considered normal for some systems.

- (2) Measure and record the height and width of each cyst.

- (3) Rate the cyst for no distortion, minor distortion, and/or major distortion.

- (4) If using a phantom that has cysts of different sizes, determine the smallest cyst at near, middle, and far field zones.

- (5) Repeat steps 1-3 for each phantom cyst. Record settings for future use.

- e Interpretation of Results. Cyst imaging combines aspects of contrast resolution and image uniformity into a single test. Cyst image quality can be affected by electrical noise, side lobes in the transducer beam and problems in the image processing hardware. Flattened cyst indicates geometric distortion. Echoes inside the cyst may be the result of system noise or side lobe contamination. A service engineer should be contacted if you observe any major distortions e.g. height differs from width by 20% or more; are detected or any measurable change from baseline.

10. Display Monitor and Hardcopy Fidelity

- a Purpose. To independently evaluate the monitor and printer capabilities.

- b Regulations. Refer to manufacturer's specifications.

- c Equipment. TM phantom

d Procedure.

- (1) Display grayscale test pattern (or step-wedge) and count number of grayscale steps.
- (2) Make a hard copy and count number of grayscale steps. Record machine settings for future use and save printed image.

NOTE: The number of grayscale steps displayed on the monitor and hardcopy should be the same. The baseline hardcopy can be used as a reference to verify the monitor in all postbaseline tests.

- e Interpretation of Results. If the number of grayscale steps for monitor and /or hardcopy exceeds tolerance levels specified in Table 7-1 consult a qualified service engineer.

Table 7-1.—Ultrasound Imaging System Survey Requirements.

	Test	Frequency	Measurements	Tolerance
1	Display Monitor Fidelity	A/S	Display and count number of grayscale steps visible on monitor Contrast and brightness controls are at baseline positions	#gray bars displayed < control value -2, fuzzy or blooming annotation
2	Hardcopy Fidelity	A/S	Print grayscale pattern and count number of grayscale steps Contrast and brightness controls are at baseline positions	#gray bars displayed < control value -2, fuzzy or blooming annotation
3	Image Uniformity	A/S	Examine image for nonuniformities and artifacts	Nonuniformity> 4dB or , any consistent measurable change from baseline values.
4	Depth Visualization/ Penetration	A/S	Scan phantom and freeze the image. Measure and record the deepest cylindrical or spherical object barely visible.	Change > 0.6 cm from baseline
5	Vertical Distance Accuracy	A/S	Scan phantom and freeze image. Measure distance between most widely separated filament target in vertical column.	Error >1.5 mm or 1.5%
6	Horizontal Distance Accuracy	A/S	Scan phantom and freeze image. Measure distance between most widely separated filament target in horizontal column.	Error >2 mm or 2%, whichever is greater
7	Anechoic Object Imaging	A/Y	Scan phantom and freeze image. Record smallest anechoic object visualized at different depths. Record height and width and ratio for anechoic object larger than smallest perceived. Record cyst image quality.	Major distortion or any consistent measurable change from baseline.
8	Axial Resolution	A/Y	Scan phantom and freeze image. Zoom at each axial target group. Record smallest separation between targets perceived at various depth.	1 mm or 2mm if frequency <4 MHz, or any consistent measurable change from baseline.
9	Lateral Resolution	A/Y	Scan phantom and freeze image. Measure width of the pin targets in the near, mid and far fields of the image.	Change>1 mm from baseline value

Table 7-1.—Ultrasound Imaging System Survey Requirements (continued).

	Test	Frequency	Measurements	Tolerance
10	Dead Zone	A/Y	Scan the region in the phantom containing the dead zone and freeze image. Record the depth of the shallowest visible filament.	7 mm for $f < 3$ MHz 5 mm for $3 \text{ MHz} < f < 7 \text{ MHz}$ 3 mm for $f \geq 7$ MHz
11	Physical and Mechanical Inspection	A/S	Check cables and transducer for cracks, damage, filter cleanliness, housing dents and any other visible damage.	Report findings to staff and/or service personnel as applicable.

Abbreviations: A= acceptance; S= semiannually; Y= yearly.

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Ultrasound Scanner System Survey

NMCPHC TM 6470.1
JUNE 2013

Facility:	Date:
Room Number/Location	ECN:
Manufacturer:	
Model Number:	Tube Serial Number:

Test Performed	Pass	Fail	N/A	Comments (failure comments must annotate minor or significant finding)
Display Monitor Fidelity				
Hardcopy Fidelity				
Image Uniformity				
Vertical Distance Accuracy				
Horizontal Distance Accuracy				
Anechoic Object Imaging				
Axial Resolution				
Lateral Resolution				
Dead Zone				
Physical and Mechanical Inspection				

Additional Comments:

Transducer Model Number:	Serial Number:
Phantom Model Number:	Serial Number:

Purpose:	Results:
Surveyor Name:	
Surveyor Signature:	

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Chapter 8

Magnetic Resonance Imaging (MRI) Units

A. Recommended Performance Tests

These tests follow the recommendations of AAPM Report 100, 2004 ACR MRI Quality Control Manual and 2005 ACR Phantom Test Guidance for the ACR MRI Accreditation Program. Each activity providing and receiving MRI medical physics support should purchase these documents for more detailed instruction regarding MRI information, quality control, and quality assurance. These tests assume that a quality assurance program is in place and that the technologist follows the ACR recommended periodic tests. Needed documentation: Magnetic Resonance Imaging Unit Survey Form.

1. Central Frequency Evaluation

- a. Purpose. To ensure resonance frequency is within manufacturer specifications.
- b. Regulations. None
- c. Equipment. Large uniform spherical phantom
- d. Procedure.
 - (1) Place the uniform, spherical phantom at the center of the magnet. The phantom should have a large spherical volume if possible. Prepare the phantom for a simple T1 weighed spin echo scan.
 - (2) During pre-scan, the system should check the central frequency and transmitter gain attenuation. Record this information.
- e. Interpretation of Results:. Have the facility contact the system field engineer if center frequency drift exceeds prescribed manufacturer tolerances or action limits established by the facility's quality control program (typical expected range = nom freq (Hz) \pm 100 Hz).

2. Magnetic Field Homogeneity

- a. Purpose. To ensure the magnetic field is uniform across the entire imaging FOV.
- b. Regulations. None
- c. Equipment. Large (at least 30 cm diameter) uniform spherical phantom. Generic Digital Imaging and Communications in Medicine (DICOM) capable reading software.
- d. Procedure (Method 1 – Spectral Peak).
 - (1) Obtain a spectrum from the phantom. This can be done by going into manual tuning or pre-scan mode. Ensure that the frequency resolution is much less than the expected peak width.
 - (2) Measure Full Width at Half Maximum (FWHM) of the spectral peak. Convert the FWHM from Hz to ppm of the B₀ field strength by using the following equation:

$$\text{FWHM (ppm)} = \text{FWHM (Hz)} / (42.576 \text{ (Hz/T)} B_0 \text{ (T)})$$

Some manufacturers do not allow analysis of pre-scan or manual shimming. In these cases, you may have to use manufacturer software to provide a line width. Contact your field engineer to find out details.
- e. Procedure (Method 2 – Phase Diff Map).
 - (1) Requires the availability to display phase images, which may not be available on all MRIs.
 - (2) Position the phantom in the center of the large volume (body) Radiofrequency (RF) coil. Scan the phantom using a simple field echo (spoiled gradient echo) sequence. Do not use a RF spin echo to avoid rephasing field inhomogeneity caused of phase differences.
 - (3) Acquire an image using a Echo Time (TE) of approximately 10 – 20 ms (TE₁). Display the image as a phase map.

Acquire a second image using a slightly longer TE (TE₂).

- (4) Subtract the second image from the first to obtain a phase difference image.
- (5) Calculate the difference between the B₀ field at a given voxel and the reference value at the center of the field of view:

$$\Delta B_0 = \frac{\delta\phi}{\gamma} \left(\frac{1}{TE_1} - \frac{1}{TE_2} \right)$$

Where: ΔB₀ is in mT; δφ is the phase difference in radians; γ is the gyromagnetic ratio (42,576 Hz·mT⁻¹ = 267,513 radians·mT⁻¹ for protons); and TE values are in sec.

- (6) Repeat the procedure for to obtain data from the other two planes.
 - (7) Determine the greatest differences in any plane between the values of ΔB₀ within circular regions of interest having specific Diameter of Spherical Volumes (DSOVs). This difference divided by the B₀ field strength will provide the homogeneity in ppm for the specified DSOV.
- f. Procedure (Method 3 – Bandwidth Diff).

- (1) Position the phantom in the center of the large volume (body) RF coil.
- (2) Scan the phantom twice using a Gradient Echo (GRE) sequence appropriate for the scanner (e.g. flip angle = 25, TR = 52 ms, TE = 8.5 ms, thickness = 6 mm, scan time 1:06, 256 x 256 matrix, 400 mm FOV) and alternately with small and large Bandwidths (BW). The low BW should be near minimum (e.g. < 20 Hz pixel⁻¹); the high BW should be near the system's available maximum (e.g. ~ 500 Hz pixel⁻¹).
- (3) Measure and record the displayed phantom diameters for each band width (For axial image, measure in the left to right direction; in coronal and saggital images, measure in the anterior to posterior direction).
- (4) Calculate the difference between the B₀ field at a given voxel and the reference value at the center of the field of view:

$$H_B(\text{ppm}) = \frac{BW_1 \cdot BW_2 \cdot (x'_1 - x'_2)}{\left(\frac{\gamma}{2\pi}\right) \cdot B_0 \cdot FOV_x(BW_2 - BW_1)}$$

Where: H_B is the inhomogeneity in ppm; BW₁ and BW₂ are the low and high bandwidths, respectively in Hz; x'₁ and x'₂ are the measured sphere diameters in mm for the low and high BWs; γ is the gyromagnetic ratio (42,576 Hz·mT⁻¹ = 267,513 radians·mT⁻¹ for protons); B₀ is the center frequency in Hz and FOV is the field of view in mm.

- (5) Repeat the procedure for to obtain data from the other two planes.
- (6) Calculate the total field inhomogeneity as the mean of the inhomogeneities in the three planes.

- g. Interpretation of Results. Homogeneity is specified by the system manufacturer. The values obtained should be compared to those specified. Typical values are approximately 2 ppm for a 30 to 40 cm diameter sphere.

3. *American College of Radiology (ACR) Phantom Image Acquisition*

- a. Purpose. To acquire appropriate cross sectional images of the ACR MRI Phantom to allow for effective image quality testing.
- b. Regulations. None
- c. Equipment. ACR MRI Phantom
- d. Procedure.
 - (1) Place the large ACR MRI phantom in the head coil and align to phantom crosshairs. Advance the table to the magnet isocenter.
 - (2) Acquire a sagittal localizer (scout) image using the following parameters: 1 slice, sagittal spin echo, TR = 200 ms, TE = 20 ms, slice thickness = 20 mm, FOV = 25 cm, matrix = 256 x 256, NEX = 1, scan time = 0:56 sec.
 - (3) Display the resulting sagittal slice. Inspect the image to ensure the entire phantom is visible
 - (4) Acquire axial slices of the relevant phantom sections using 11 slices, starting at the vertex of the crossed 45 degree wedges at the inferior end of the ACR

phantom and ending at the vertex of the crossed 45 degree wedges at the superior end. The ACR T1 series: (11 slices, spin echo, TR = 500 ms, TE = 20 ms, FOV = 25 cm, slice thickness = 5 mm, slice gap = 5 mm, matrix= 256 x 256, NEX = 1).

- (5) As necessary, the ACR T2 series: (11 slices, double echo spin echo, TR = 2000 ms, TE / TE₂ = 20 / 80 ms, FOV = 25 cm, slice thickness = 5 mm, slice gap = 5 mm, matrix= 256 x 256, NEX = 1)
- (6) As necessary, determine and record the facility's Axial Head T1 and T2 weighted sequences.

4. *Slice Position Accuracy*

- a. Purpose. To determine whether locations of acquired axial slices differ excessively from their prescribed locations for a properly operating scanner.
- b. Regulations. None
- c. Equipment. ACR MRI Phantom
- d. Procedure.
 - (1) Display the T1-weighted series. Differences between the prescribed and actual positions of slices #1 and #11 are measured.
 - (2) Display the slice magnified on the monitor by a factor of 2 to 4. Keep the vertical bars of the crossed wedges with the displayed portion of the image.
 - (3) Adjust the display window so that the ends of the vertical bars are clear using a narrow display window. The display level should be set to a level one half that of the signal of the bright portions of the phantom.
 - (4) Use the viewer's measurement tool to measure the difference in length between the left and right bars. If the left bar is longer, then assign a negative value to the number; if the right bar is longer, assign a positive value.
- e. Interpretation of Results. The crossed wedges have a 45 degree slope. Therefore the bar

length difference is twice the actual slice displacement error. The magnitude of the bar length difference should be less than or equal to 5 mm.

5. *Slice Thickness Accuracy*

- a. Purpose. To determine accuracy of specified slice thickness.
- b. Regulations. None
- c. Equipment. Same as above
- d. Procedure.
 - (1) Display slice #1 with a magnification of two to four while keeping the slice thickness insert fully visible (The slice thickness inserts are the two opposed horizontal thick bright lines).
 - (2) Adjust the display level so that the signal ramps are well visualized. Place a rectangular ROI at the middle of each signal ramp. Note the mean signal values for each of the two ROI's and determine a joint ramp mean signal value. If the two ROI mean values differ more than 20%, the ROI's may include some of the area surrounding the ramps. Adjust the ROI sizes to only include the ramps and note the new mean values and joint mean value.
 - (3) Lower the display level to one half of the average ramp signal. Leave the display window set to minimum.
 - (4) Use the display station length measurement tool to measure the lengths of the top and bottom ramps. Record these measurements.
- e. Interpretation of Results. The slice thickness is calculated using the following formula:

$$\text{Slice Thickness} = 0.2 \times (\text{top} \times \text{bottom}) / (\text{top} + \text{bottom})$$

where "top" and "bottom" refer to measured lengths of the top and bottom ramps respectively. This measurement is best for slice thicknesses between 3 mm and 7 mm. For the ACR T1-weighted axial imaging series, the measured slice thickness should be 5.0 mm ± 0.7 mm.

6. RF Coil Checks (Signal to Noise Ratio [SNR], Percent Image Uniformity [PIU], Percent Signal Ghosting [PSG])

- a. Purpose. To ensure that the radio frequency coils are functioning properly.
- b. Regulations. None
- c. Equipment. ACR MRI phantom or a phantom that simulates the geometry body part of interest for the coil being tested.
- d. Procedure.

(1) Volume Coils

- (a) Display slice #7.
- (b) Select an ROI that covers approximately 80% of the phantom cross section (approx 200 cm²). Record the ROI mean signal and standard deviation values.
- (c) Select a second ROI that covers approximately 0.15% of the FOV (for a 256 x 256 matrix, the ROI should be about 100 pixels). Move this ROI to the area of maximum intensity within the “mean signal ROI”. This area can be found by narrowing the window and adjusting the level value to find the brightest area. Determine the ROI mean signal in this area. Record as “high”. Repeat this measurement for the location of lowest signal intensity. This value is “low”.
- (d) Select a third oval ROI (Approx 120 cm²). Using the ROI, measure the mean signal values above, below, and to the left and right of the phantom. Calculate “ghost signal” as (top +bottom) and “background signal” as (left + right). Record all results.
- (e) Calculate SNR:

$$\text{SNR} = \text{Mean Signal} / \text{Noise Standard Deviation}$$

(2) Calculate PIU

$$\text{PIU} = 100 \times [1 - (\text{High} - \text{Low}) / (\text{High} + \text{Low})]$$

- (a) Calculate PSG:

$$\text{PSG} = 100 \times |(\text{Ghost Signal} - \text{Background Signal}) / (2 \times \text{Mean Signal})|$$

- (b) Perform these tests for at least one volume coil using the ACR T1 and T2 sequences during annual inspections and all volume coils during acceptance.

(3) Surface Coils

- (a) Set up the coil of interest with its appropriate phantom in its normal clinical orientation with the phantom centered in the coil. Run a pulse sequence with a slice positioned near the center of the RF coil and in the imaging plane most often used in clinical practice. Scan the phantom using a T1weighted series (the T1-weighted series used by the ACR MRI Accreditation program is a good standard- single spin echo, TR = 500 ms, TE = 20 ms).
- (b) Determine mean and standard deviation values as for the volume coil above, using appropriate proportionalities, or as directed by the manufacturer.
- (c) Calculate SNR:

$$\text{SNR} = \text{Mean Signal} / \text{Noise Standard Deviation}$$
- (d) Observe signal intensity distribution and note whether it generally appears the same as when previous measurements were performed on the coil. During acceptance, save a hard or softcopy image with window settings for future reference.
- (e) Perform this test for at least one volume coil using coil T1 and T2 sequences during annual inspections and all volume coils during acceptance.

- e. Interpretation of Results. Volume and surface RF coil SNRs should match manufacturer’s specifications and be consistent from one annual inspection to the next. Volume coil PIU should be equal to or greater than 87.5% for 1.5 T systems and equal to or greater than

82%. Volume coil PSGs should be less than or equal to 2.5%.

7. Geometric Accuracy

- a. Purpose. To ensure that images are scaled in a manner that is directly related to the true dimensions of the body parts under investigation.
- b. Regulations. None
- c. Equipment. ACR MRI Phantom
- d. Procedure.
 - (1) Display the sagittal localizer image of the ACR phantom. Set the window width to a very narrow value (0 - 2). Adjust the window level until about one half of the phantom is white and the other half is black.
 - (2) Change the window width value to one half of the window level noted above. Change the window level value to one-half of the window width value.
 - (3) Use the measuring tool to measure vertically from one end of the phantom to the other. Record the value as “z direction”. The actual phantom length in this direction is 148 mm.
 - (4) Display slice #5 using the same window and level routine as for the sagittal localizer view.
 - (5) Determine the diameter of the signal producing circular phantom volume measured vertically and horizontally. Record these values as “y direction” and “x direction,” respectively. The actual phantom diameter in both directions is 190 mm.
 - (6) Repeat with sagittal and coronal slices if desired.
- e. Interpretation of Results. The length measurements obtained from a 25 cm FOV should vary less than ± 2 mm from their true values.

8. Spatial Resolution

- a. Purpose. To determine the scanner’s ability to resolve small objects.
- b. Regulations. None
- c. Equipment. ACR MRI Phantom
- d. Procedure.
 - (1) Display slice #1 of the ACR T1 weighted axial image series.

[There are three pairs of not-quite-square hole arrays. They consist of Upper Left (UL) and Lower Right (LR) hole arrays. The UL array is used to assess resolution in the right-left direction. The LR array is used to assess resolution in the top-bottom (anterior-posterior if the phantom were a patient head). The hole diameters differ between the array pairs (left = 1.1 mm, center = 1.0 mm, right= 0.9 mm)]
 - (2) Magnify the image by a factor of 2 to 4, keeping the resolution arrays visible in the display. Reduce window width to a small value. Adjust window level until the holes in the arrays are distinguishable.
 - (3) For each of the arrays, adjust the window and level to best show the holes as distinct from one another. If all four holes in any single row or column (row for UL arrays, column for LR Arrays) are distinguishable from one another, the image is considered resolved.
 - (4) Determine the smallest hole size (1.1 mm, 1.0 mm, 0.9 mm) that can be resolved in the UL (rows resolved) and LR (column resolved) arrays.
 - (5) Repeat with sagittal and coronal slices if desired.
 - (6) Repeat for T2 weighted series, if desired.
- e. Interpretation of Results. Resolution in both directions should be 1.0 mm or better.

9. Low Contrast Detectability (LCD)

- a. Purpose. To assess the extent to which low contrast objects are discernible in the images.
- b. Regulations. None
- c. Equipment. ACR MRI Phantom
- d. Procedure.

- (1) Using images 8, 9, 10 and 11 of the T1 weighted axial series, display each one at a time and adjust the display window and width and level settings for best visibility of the low contrast spokes.

[Each slice has 10 low contrast disk spokes. Each spoke is made of 3 disks. All of the spokes of a given slice have the same contrast level (Contrast is 1.4%, 2.5%, 3.6%, and 5.1% for slices #8 to #11, respectively)]

- (2) Count the number of complete spokes in each slice. The number of complete spokes counted is the score for this slice. The ACR recommends choosing a single slice in which all of the spokes are not normally observable as the slice to score. However, for an annual check it is easy to score all the slices and add them together.
- (3) Repeat for T2 weighted series, if desired.

- e. Interpretation of Results. Low contrast detectability should be equal to or greater than or equal to 9 spokes (total) for 1.5 T systems and equal to or greater than 37 spokes (total) for 3 T units.

10. Image Artifact Assessment

- a. Purpose. To ensure that overall MRI system performance is remaining stable.
- b. Regulations. None
- c. Equipment. ACR MRI phantom
- d. Procedure.

- (1) Adjust the display window and level to show the full range of pixel values for

each slice of the T1 weighted ACR axial series.

- (2) Check to make sure that the phantom appears circular, there are no ghost images in the background or overlying the phantom, there are no streaks or artifact bright or dark spots visible and there are no unusual or new features in the image.
- (3) Repeat for T2 weighted series, if desired.

- e. Interpretation of Results. There should be no artifacts visible in any of the images.

11. Soft Copy Display Evaluation

- a. Purpose. To determine if the system monitors are operating within manufacturer's specifications. Soft copy display device quality control is defined in accordance with DICOM Part 14
- b. Regulation. None
- c. Equipment. Precision luminance meter
- d. Procedure.

Without full implementation of the DICOM Part 14 standard, the following limited set of tests is recommended:

- (1) Luminance Maximum and Minimum. Display a uniform image. Adjust window/level to the brightest available level. Record this value as "maximum". Adjust window/level to display all black (lowest available). Record this value as "minimum".
- (2) Luminance Uniformity. Display a uniform image. Measure the luminance at the center and each of the four corners of the image display. Record these values. Calculate the average value of the four corners. Record this value. Calculate the percentage difference of the luminance values measured in the image display area as follows:

$$\% \text{ diff} = 100\% \times |(\text{center} - \text{corners ave.}) / \text{center}|$$

- (3) Resolution. Display a SMPTE test pattern with a magnification factor that is appropriate for the monitor being tested. Evaluate the high resolution patterns in the

image center and in each of the corners. (SMPTE patterns vary depending on design, so be careful to use one with appropriate resolution and patterns).

- (4) Spatial Accuracy. A SMPTE test pattern that displays a rectangular grid is typically displayed with a magnification factor that allows it to fill the entire screen. Display a similar grid pattern over the screen. Compare the displayed SMPTE pattern to the overlaid grid.
- e. Interpretation of Results. Luminance uniformity percentage difference should be less than or equal to 5%. Verify that the 5% patch can be distinguished in the 0 / 5% patch, the 95% patch can be distinguished in the 95 / 100% patch and that all gray level steps around the ring of gray levels are distinct from adjacent steps. Maximum luminance, minimum luminance and luminance uniformity should not vary by more than 15% from levels measured at acceptance.

12. Hard Copy Image Quality Control

- a. Purpose. To assess the stability of the Hard copy imager
- b. Regulations. None
- c. Equipment. Densitometer
- d. Procedure.

Necessary if the facility uses film for primary interpretation.

- (1) Display the SMPTE pattern and visually confirm that the gray levels on the display are subjectively correct. Verify that the 0% patch can be distinguished in the 0 / 5% patch, the 95% patch can be distinguished in the 95 / 100% patch and that all gray level steps around the ring of gray levels are distinct from adjacent steps.
- (2) Print the SMPTE pattern using a 6-on-1 format and capture the same image on all six frames.
- (3) Using a film densitometer, measure the optical density of the 0%, 10%, 40%, and

90% gray level patches. Record these values

- e. Interpretation of Results. Action levels should be established by the quality control program. If the action levels are exceeded, double check phantom positioning before seeking other action.

13. B₀ Field Room Survey

- a. Purpose. To map out the magnetic field inside the magnet room and in adjacent areas to ensure patient and staff safety.
- b. Regulation. None
- c. Equipment. Gauss meter
- d. Procedure.
 - (1) Using a calibrated Gauss meter perform a survey inside the magnet room. Record these measurements using a room diagram.
 - (2) Take additional readings in areas directly adjacent to the magnet room and record these values as well.

e. Interpretation of Results. The 5 Gauss line should be marked by signs to warn people (e.g. patients, staff and visitors) with pacemakers and other restrictive devices to avoid being in the area. In most modern MRI suites, the 5 Gauss line lies within the scanner room.

14. Physical and Mechanical Inspection

- a. Purpose. To assess the physical and mechanical integrity of the MRI unit and associated equipment.
- b. Regulations. None
- c. Equipment. None
- d. Procedure.
 - (1) Visually inspect the MRI magnet for obvious defects, damage or other safety hazards. Visually inspect the cryogen venting system to ensure there are no obvious impediments to its proper function.

- (2) Visually inspect the magnet equipment room for general and missile effect safety hazards. Inspect ancillary equipment and supplies in the magnet room and adjacent spaces for MR compatibility (items should be appropriately labeled as MRI safe or MRI conditional at the relevant magnetic field strength).
- (3) Visually inspect the magnet equipment room for electrical, trip and falling object hazards.
- e. Interpretation of Results. MRI equipment should be physically and mechanically stable, showing no obvious mechanical or electrical conditions that suggest patient or operator safety concerns. All ancillary equipment (e.g. surface coils, phantoms, power injectors, anesthesia machines, etc should be in good working order and compatible for the unit strength being used. Report violations to staff for corrective action (some items may require immediate removal from the magnet room to prevent missile hazards).

15. Patient Monitoring Evaluation

- a. Purpose. To ensure that the facility maintains appropriate patient / unit operator communication capability.
- b. Regulation. None
- c. Equipment. None
- d. Procedure. Test patient communication devices (e.g. intercom and hand held operator notification devices) for proper operation. Record any deficient devices.
- e. Interpretation of Results. All patient communication devices should function properly.

16. Ferromagnetic detector system operation

- a. Purpose. To ensure that the facility maintains appropriate patient / unit operator communication capability.
- b. Regulation. None
- c. Equipment. None

- d. Procedure. Test fixed and portable (e.g. fixed frame, stand alone and wand) detector systems for proper operation. Record any deficient devices.
- e. Interpretation of Results. The detector should operate according to the manufacturer's specifications.

17. ACR MRI Safety Recommendations Compliance

- a. Purpose. To evaluate facility compliance with ACR MRI safety zone and procedure recommendations.
- b. Regulation. None
- c. Equipment. Gauss meter
- d. Procedure.
 - (1) Walk about the MRI spaces to determine whether the layout meets the ACR's most recent safety zone scheme. Does the arrangement make sense and are its instructions and intent obvious to an untrained member of the general public? Are the various zones posted correctly?
 - (2) Review the facility's MRI policy and procedures manual to determine if it is operating in conformance with the ACR's safety guidelines with respect to: safety zones, patient screening, public access, contrast administration, patient consent, fire and code blue safety.
 - (3) Review MRI staff and non-staff MRI safety training records.
- e. Interpretation of Results. The facility's design should conform to the ACR's four zone configuration to maximize patient safety. All personnel expected to enter the MRI spaces should have current magnet specific safety training on file. The MRI Policy and procedures manual should be current and contain necessary elements. Advise the facility on what steps it can take to meet the ACR's current safety criteria if elements are missing or inadequate.

18. Quality Control (QC) Program Review

- a. Purpose. To ensure that adequate daily/weekly quality control
- b. Regulation. None
- c. Equipment. None
- d. Procedure. Review the facility's existing quality control program to ensure that the following elements are included:
 - (1) Setup/positioning accuracy
 - (2) Center frequency
 - (3) Transmit gain/attenuation
 - (4) Geometric accuracy
 - (5) Spatial resolution
 - (6) Low contrast detectability
 - (7) Artifact analysis
 - (8) Visual Checklist
 - (9) Film QC (if used for primary interpretation)
- e. Interpretation of Results. A proper functioning program should contain these elements; ideally performed as prescribed by the ACR. ACR accredited facilities must follow ACR guidelines. Review QC results and advise MRI staff on how to establish baselines define pass/fail criteria (acceptance), evaluate results and respond to test failures.

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Magnetic Resonance Imaging Unit Survey

NMCPHC TM 6470.1
JUNE 2013

Facility:	Date:
Room Number/Location:	ECN:
Manufacturer:	
Model Number:	Tube Serial Number:

Test Performed	Pass	Fail	N/A	Comments (failure comments must annotate minor or significant finding)
Central Frequency Evaluation				
Magnetic Field Homogeneity				
ACR Phantom Image Acquisition				
Slice Thickness Accuracy				
RF Coil Checks				
Geometric Accuracy				
Spatial Resolution				
Low Contrast				
Image Artifact				
Soft Copy Display Evaluation				
Hard Copy Display Evaluation				
B0 Field Room Survey				
Physical and Mechanical Inspection				
Patient Monitoring Evaluation				
Ferromagnetic Detector System Operation				
ACR MRI Safety Recommendations				
Quality Control Program Review				
Additional Comments:				

Purpose:	Results:
Surveyor Name:	
Surveyor Signature:	

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Chapter 9

Nuclear Medicine Imaging

A. Introduction

The modern gamma camera is a highly sophisticated imaging system but its underlying principle of operation is still the same as the original Anger camera. The evolution of the gamma camera has led to improved performance by optimizing the various sub systems as new technology was implemented. Today the most of the imaging degrading problems associated with the original camera have been either engineered out or sophisticated methods have been devised to correct data prior to generating the image.

As the gamma camera evolved so did the methods of collecting and displaying images. Today the gamma camera can provide cross sectional images of patient anatomy as well as general planar images. The cross sectional imaging places far greater demands on the camera performance than does planar imaging and subsequently increase demands on quality control of the systems.

To ensure the best possible imaging, all gamma camera systems should be tested when first purchased to establish that the system meets its claimed performance and to collect data to be used to verify continued system performance over the life of the system. The tests provided in this document are based on several reports prepared by the AAPM. Although the documents are somewhat dated, the fact that the gamma camera's underlying principle of operation and its general design have not changed much over time, makes these reports still relevant. The performance gains have been achieved by improved engineering of components,

implementation of computer chips, and a better understanding of the underlying problems and the procedures in the reports still test the end result of these improvements.

B. Minimum Required Personnel Qualifications

Advanced Diagnostic Imaging Equipment (NMI)

C. Testing performances

The testing required of a system will be dependent on how the system will be used -planar imaging, Single Photon Emission Computed Tomography (SPECT) imaging or both -and whether it is a single head system or a multi-head system. Multi-headed system used for both planar and SPECT imaging will require substantially more testing and more time than a single headed planar system. Needed documentation: Nuclear Medicine Camera Survey Form.

D. References

1. AAPM Report No. 6, "Scintillation Camera Acceptance Testing and Performance Evaluation," 1980
2. AAPM Report No.9, "Computer-Aided Scintillation Camera Acceptance Testing," 1982
3. AAPM Report No. 22, "Rotating Scintillation Camera SPECT Acceptance Testing and Quality Control," 1987
4. AAPM ReportNo.52, "Quantitation of SPECT Performance," 1995
5. National Electrical Manufacturers Association Standard NU 1,"Performance Measurement of Scintillation Cameras," 1994

E. Planar Gamma Camera

The planar gamma camera only generates planar emission images. These systems do not have the capability to collect data while rotating around the patient and therefore cannot produce cross sectional images. Only the following tests are required to be performed to evaluate the performance of these systems. If more than one imaging head all must be tested.

1. Installation Check

Prior to performing any of these tests evaluate the installation of the system by observing the following:

- a. Check the integrity of the system looking for any loose fitting or inappropriately aligned components.
- b. Look at all the cables and ensure they are properly supported and will not interfere with any of the systems motion or patient movement. Ensure the cables and cable connections are all secure.
- c. Move the camera in all its directions to ensure that it moves smoothly. The system should start and stops smoothly and without any significant time delay. This is particularly important on stopping since a patient could be injured if the camera is being lowered on to the patient.
- d. Verify the alignment of the system as appropriate. If the system has indicator noting when it is horizontal or perpendicular check these with a level. If the system indicates angles of the head check this using a level and protractor.
- e. The gamma camera head should be appropriately shielded to prevent interference from extraneous radiation. This should be checked the $^{111}\text{g;hest Plnp}>'(\text{nl}$ radioisotope used in the area of the gamma camera. The source (5 to 10 millicuries for $^{99\text{mTc}}$) should be slowly moved around the back and sides of the head at about one to two feet and the count rate noted. Excessive background will reduce the contrast of the images acquired with the camera. If the manufacturer quotes a shielding performance ensure the system meets the standard. Repeat using a high energy source (^{67}Ga or ^{131}I) is such sources are used in the

clinic. These should be approximately 200 uCi.

- f. Check all collimators for any sign of physical damage.
- g. Check the scan table for stability and ensure there are no sharp edges that could injure the patient or technologist. If the table is designed to be locked into place then check that the locking is secure and snug. Check the alignment of the table in the vertical and horizontal direction.

2. Temporal Resolution

The performance of the gamma camera is highly dependent on the timing characteristics (system dead time) of the system. The maximum count rate will define the activity that can be administered to a patient. Excessive count rate (excessive activity) will degrade the image quality and at the same time increase the unnecessary dose to the patient. The timing characteristics for the intrinsic (bare crystal-no collimator) and the extrinsic (collimated crystal) should be measured.

a. Intrinsic Temporal Resolution.

- (1) Remove any collimator from the camera head.
- (2) Select a 20% energy window width (or use the manufacturers recommended window width for measuring $^{99\text{mTc}}$).
- (3) Ensure that the background radiation level is less than 500 counts per second.
- (4) Make two $^{99\text{mTc}}$ sources (#1 and #2) each with between 2 and 7 mCi activity. Place the sources in container with at least 6 mm lead shielding on sides and bottom. Place at least 6 mm of Cu on top of the container to absorb scatter from the container.

- (5) Place the source at a distance that gives a count rate of approximately 30,000 cps or if the dead time is quoted by the manufacturer use the following equation to calculate the count rate:

$$\text{Count Rate} = \frac{0.1}{\tau} + 1.2$$

Ensure that the entire crystal is being irradiated by the source.

- (6) Using a preset time of 100 sec and a fixed time between each measurement measure the sources in the following order.
- Measure source #1 and record counts.
 - Place source #2 next to source #1 and record counts.
 - Remove source #1 and measure source #2 alone and record counts.
 - As a control the sources can be re-counted in the reverse order.

NOTE: If the count is displayed at the camera head and on the computer console record both.

- (7) Calculate the dead time using the following equation:

$$\tau = \left[\frac{2 \times R_{12}}{(R_1 + R_2)^2} \right] \ln \left[\frac{R_1 + R_2}{R_{12}} \right]$$

In the counts recorded at the camera head and the computer console are different; calculate the dead time for each. A larger τ at the computer console indicates additional count losses at the computer interface. This is rare but if it does occur the difference should small.

- (8) Calculate the count rate at which the count loss is 20% due to the dead time (τ).

$$R_{20\% \text{ loss}} = \frac{1}{\tau} \times \ln \frac{10}{8} = \frac{0.23311}{\tau}$$

Compare this value with the manufacturers specification. Note that this method of measure dead time eliminates

scatter and the NEMA method does not. Therefore the NEMA method gives a larger τ (~1.3x).

- b. Maximum Intrinsic Count Rate. This measurement is dependent on the dead time of the system and is the maximum count rate the system will record. At this level the count rate will not increase with increasing activity and may in fact decline.

- (1) With the collimator removed and using the energy window as the dead time test; place approximately 4 mCi of ^{99m}Tc in container shielded on the bottom and sides by 6mm of lead and with 6mm Cu on top at a distance of 1.5 meters. Move the source and or camera head until a maximum count rate is observed. See Figure 9-1.

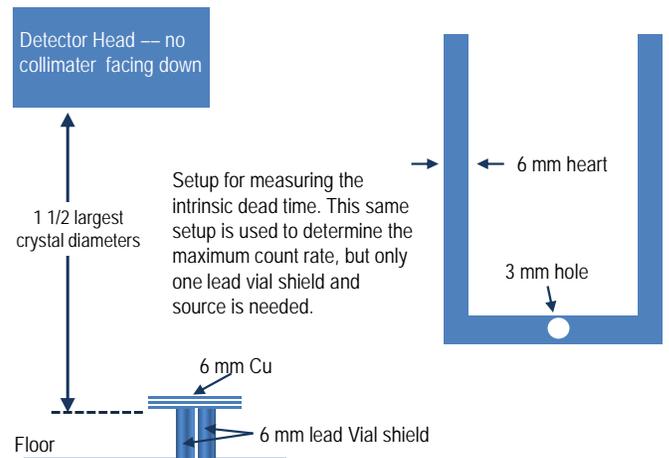


Figure 9-1.

- (2) Record the maximum count rate and compare to any published manufacturers specification.
- c. Extrinsic Temporal Resolution. The above measured is for the non clinical situation where no collimator is installed on the camera head. This test measures the dead time in a more clinical situation and requires the use of a scatter phantom. If such a phantom is not available then skip this test.
- (1) Select the most common collimator used clinically (usually a general purpose or high sensitivity collimator).

- (2) Adjust the energy window to 20% or to the value indicated by the manufacturer in their collimator performance specifications.
- (3) Prepare two sources (#1 and #2) that give a count rate of approximately 20,000 cps or if the extrinsic dead time is known a count rate determined by

$$Count\ Rate = 1.2 \times \frac{100,000}{\tau_{extrinsic}}$$

where the source is in the scatter phantom. The expected range of activity is 1 to 7 mCi and the source volume should be around 5ml.

- (4) Orient the gamma camera head so it point horizontally and place the scatter phantom against the collimator face with the sources closest to the collimator and centered.
- (5) Using a count time of 100 sec record the counts from the sources as follows:
 - (a) count source #1 alone
 - (b) count source #1 and source #2
 - (c) count source # 2 alone

- (6) Calculate the intrinsic dead time.

$$\tau_{extrinsic} = \left[\frac{2 \times R_{12}}{(R_1 + R_2)^2} \right] \ln \left[\frac{R_1 + R_2}{R_{12}} \right]$$

- (7) Calculate the observed counting rate that will generate a 25% count loss.

$$R_{extrinsic-25\% loss} = \frac{1}{\tau_{ext}} \left(\ln \frac{4}{3} \right) = \frac{0.216}{\tau_{ext}}$$

During imaging, the recommended upper limit for count loss due to dead time is 25%. Use of activities in patients in excess of that which gives this count rate merely increases the dose to the patient with no gain in image quality of imaging time. See Figure 9-2.

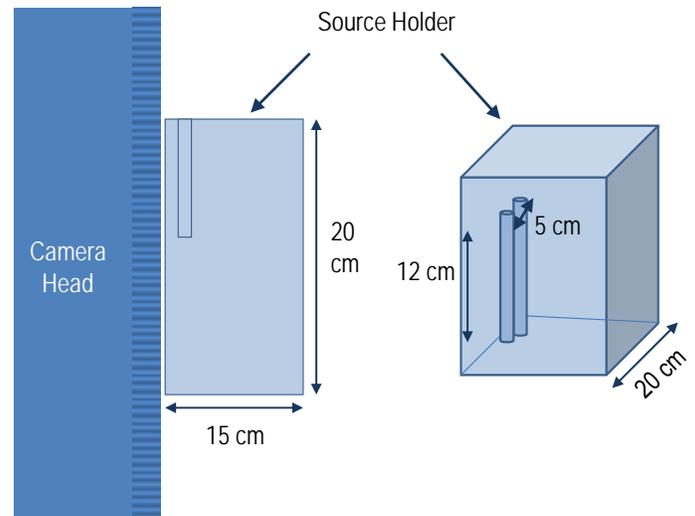


Figure 9-2.

3. Uniformity Testing

Uniformity is one of the most important performance parameters of the modern gamma camera and can be influenced by many factors such as energy window, count rate, correction circuitry, etc.

a. Intrinsic Uniformity (no collimator).

- (1) Install the 3 mm lead mask if available on the gamma camera head to limit the FOV to the Useful Field Of View (UFOV) as defined by the manufacturer. Disable the uniformity correction circuitry if possible.
- (2) Obtain a ^{99m}Tc point source (1 cc or less) with an activity that will give a count rate (~30,000 cps) that generates more than a 10% count loss for the energy window used clinically (15% or 20%) at a distance of five times the UFOV diameter. Use the intrinsic dead time value previously calculated to verify that the count loss does not exceed 10% (see chart below). Record the activity and time it was measured.
- (3) Place the source centered over the crystal at a distance of 5 UFOV diameters. Be extremely careful not to drop the source on the detector as this could damage the crystal (a thin sheet of styrofoam placed on the crystal face is good protection). Record the count rate indicated on the

console and/or camera gantry. See Figure 9-3.

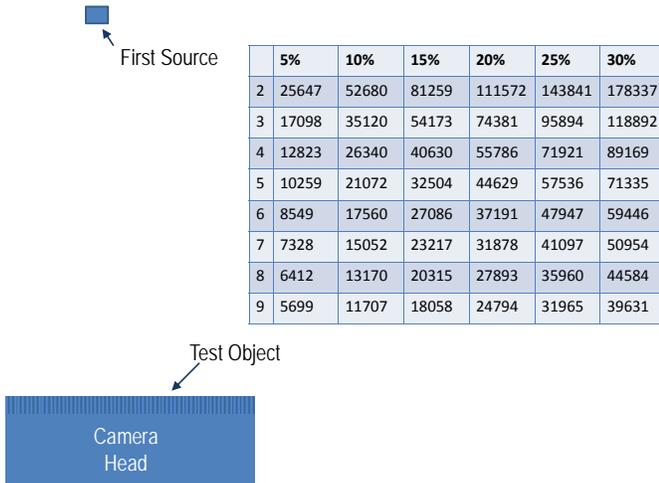


Figure 9-3.

- (4) Acquire an image with in a 64x64 (or smallest matrix size available) matrix and a bit depth of 16 bits.
- (5) Collect a minimum of 10,000 counts in the center pixel to generate a 1% standard deviation. Record the time.
- (6) Using a window of 200 counts observe the image for any lines of pixels in the horizontal or vertical direction. If seen they should be corrected before further analysis of the image uniformity is done.
- (7) Compare the recorded count rate from (3) above to the calculated count rate based on the total counts recorded divided by the time in (5). These should agree to within 1%.
- (8) Average the counts in the center 100 pixels and draw a ROI to include all pixels with counts greater than Y:z of this average.
- (9) If able smooth the image using a 9 point filter function:

121
242
121

or if not available then use the standard smoothing function provided by the manufacturer.

- (10) Calculate the “integral uniformity” (maximum deviation of the counts in the pixels as a percent) using

$$Int\ Uniformity = \pm 100 \times \left[\frac{Max - Min}{Max + Min} \right]$$

where Max and Min are the minimum and maximum counts in pixel.

- (11) Calculate the “differential uniformity” (max rate of change over a specified number of pixels) using

$$Diff\ Uniformity = \pm 100 \times \left[\frac{Hi - Low}{Hi + Low} \right]$$

where Hi and Low are the highest and lowest counts in a five pixel series.

- (12) Calculate the integral and differential uniformity for the Central Field Of View (CFOV) using the same formulae but with the periphery of the previously defined ROI moved in 4 pixels per size.

NOTE: Many modern gamma camera systems have QC functions that calculate these uniformity parameters automatically and can be used for testing if desired.

- (13) Repeat the above measurement using a count rate of 75,000 cps and evaluate the effect of the high count rate on the uniformity of the image.
- (14) Repeat the uniformity measurements after adjusting the energy window up and down by an amount that reduces the observed count rate by 10%/t). This should not make the flood images unacceptable.
- (15) Repeat the uniformity measurements using a low energy radioisotope (70-80 keY) and a high energy radioisotope (300-400 keY) if these are used in the clinic.
- (16) If the uniformity correction circuitry was disable, re-enable it and repeat the intrinsic uniformity correction measurements.

b. Extrinsic Uniformity.

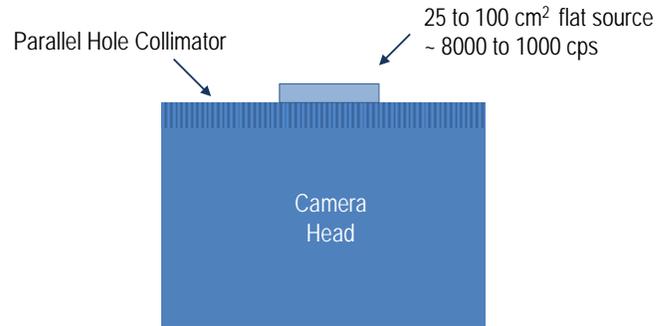
- (1) For all commonly used collimators, repeat the uniformity measurements using each collimator and a flood source that does not give a count rate in excess of 30,000 cps.

4. Systems Sensitivity and Relative Collimator Efficiency

The sensitivity of a system defines how efficiently it uses the radiation emitted from the patient. Since nuclear medicine imaging is geometrically inefficient due to general geometry of the imaging process, it is desirable to maximize the use of any photons that intersect the face of the gamma camera imaging head.

a. System Sensitivity.

- (1) Install a general purpose parallel hole collimator on the camera. Record the identity of the collimator.
- (2) Prepare a flat disc source of ^{99m}Tc with a surface area of around 25 to 100 cm. Use an activity that will generate a count rate of 8,000 to 10,000 cps with a 20% energy window. Record the activity in the source and the time it was assayed.
- (3) Place the source at the center of the collimator and collect 100,000 counts. Record the time and the indicated count rate. Verify the calculated count rate and the indicated count rate are the same.
- (4) Remove the source and record the indicated background count rate.
- (5) Determine the system sensitivity in cps per microcurie (SI units of cps per Becquerel). See Figure 9-4.



$$\text{System Sensitivity} = \frac{R_{\text{source}}(\text{cps}) - R_{\text{background}}(\text{cps})}{\text{Act}(\mu\text{Ci})}$$

Figure 9-4.

b. Relative Collimator Sensitivity.

- (1) For each clinically used collimator, determine the decay corrected count rate (cps) using the technique above.
- (2) Record the background count rate for each collimator.
- (3) Calculate the relative sensitivity of the collimators using the general purpose collimator (or the one specified by the manufacturer) as the reference. Relative sensitivity is the

$$\text{Sens}_{rel} = \frac{R_{col}}{R_{reference\ col}}$$

Compare these to the manufacturer's specifications.

5. Spatial Linearity

Modern gamma cameras have elaborate correction circuitry to correct the mis-positioning of point of photon interaction which led to non linearity. Although elaborate methods are available to determine linearity, a simple visual check is considered adequate with today's systems.

- a. Remove the collimator from the gamma camera and place a linearity bar phantom (or an orthogonal hole phantom) on the crystal face. Be very careful not to drop or bump the exposed crystal as this can lead to damage to the crystal. See Figure 9-5.

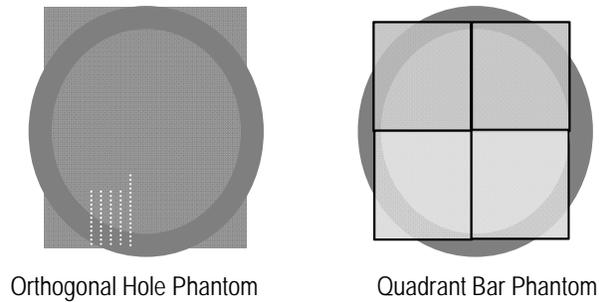


Figure 9-5.

- b. Prepare a point source of about 100 to 200 μ ci and place it six or so away from the camera head. If the count rate exceeds 30,000 cps move the source further away to reduce the count rate.
- c. Start the camera and collect approximately 1 million counts.
- d. Review the image with attention to the linearity of the bars or of the holes. There should be little if any wavy or curved distortion of the lines in the center or the periphery of the image. If the computer console has a line tool, draw a straight from one end of the bar to the other or from the centroids of the first and last hole of the orthogonal hole phantom. The deviation of bar image or the centroids of the hole images from this straight line should be minimal.
- e. If the system has an automated linearity calculation tool then this tool can be used to evaluate the system but a visual check should also be done. If the image shows significant deviations on observation and the program does not then further analysis should be done to determine the reason for the discrepancy.

6. Point Source Sensitivity

This test is performed to determine the uniformity of the sensitivity of the crystal at various locations. Ideally, the crystal should have the same sensitivity at all points.

- a. Disable the uniformity correction circuitry of the system if allowed.
- b. A lead container at least 6 mm in thickness with a 3 mm hole in the bottom will be required. This can be made from a lead vial

holder that is no longer needed or can be purchased from a nuclear medicine supply source. See Figure 9-6.

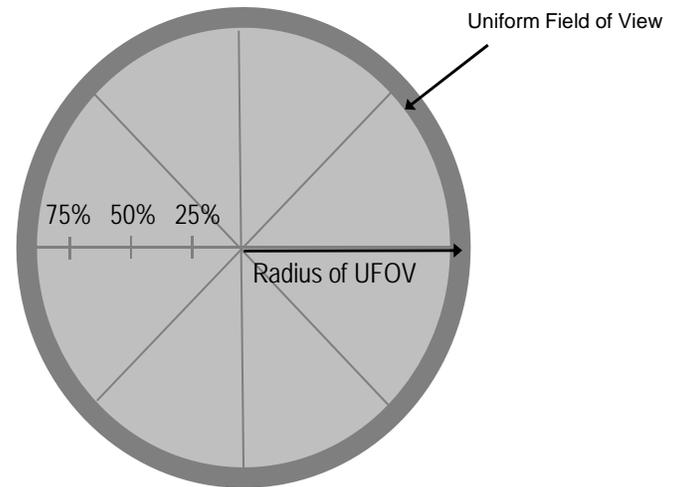


Figure 9-6.

- c. Remove the collimator from the gamma camera head and rotate the head so the face of the detector is facing up. Be very careful not drop or bump the unprotected detector as severe damage can occur
- d. Place a 20% energy window (or whatever the manufacturer recommends for ^{99m}Tc) centered on the ^{99m}Tc peak energy-140 keV.
- e. Place a vial containing ^{99m}Tc in the vial shield. Adjust the source activity to give no more than 10,000 cps when placed on the face of the uncollimated gamma camera head.
- f. Adjust the system to collect a 128 x 128 by 16 bit image and place the vial at the center of the detector. Collect an image for about 5 sec. Note the time since all subsequent images will have to be collected for the same period of time for the results to be valid. Observe the image to ensure there is no pixel overflow. If so then reduce the time for image collection until no overflow is seen. Record the counts in the image.
- g. Using the time determined above repeat the measurement with the vial located at 25%, 50% and 75% of the radius in both the plus and minus direction of the X axis. Repeat the measurement in the Y axis and then along the 45° angle between the X and Y axes for a total

of 25 measurements. At each measurement record the time and counts collected.

- h. Determine the average and standard deviation of the measurements and the maximum deviation from the mean. The coefficient of variation (avg/sd) should not exceed 2%.
- i. Review the data and note any local deviations (between two points) of more than 1%.

7. Spatial Resolution

To accurately measure intrinsic resolution requires a slit mask made of 3 mm lead with a 1 mm wide slit extending for a distance equal to the UFOV of the camera being tested. If such a slit mask is not available, a more straight forward but less accurate method is to use a line bar phantom that has a set of bars just below and just above the intrinsic resolution. Extrinsic resolution can be measured by imaging a simple line source or a bar phantom.

a. Intrinsic Resolution (slit mask method).

- (1) Remove the collimator for the camera head and orient the crystal facing up. Select a 20% energy window center on the 140 keV peak of ^{99m}Tc and use the maximum matrix size available (at least 512 by 512 by 16 bits).
- (2) Place the slit mask along the X axis flush against the detector and suspend a point source approximately five crystal diameters away from the mask.
- (3) Collect an image with at least 10,000 counts in the central pixel of the image of the slit.
- (4) Determine the FWHM from the image of the slit by direct measurement using linear interpolation. This is most accurate if the pixel is approximately 1/10th the FWHM. If this is the case then also estimate FWTM. See Figure 9-7.

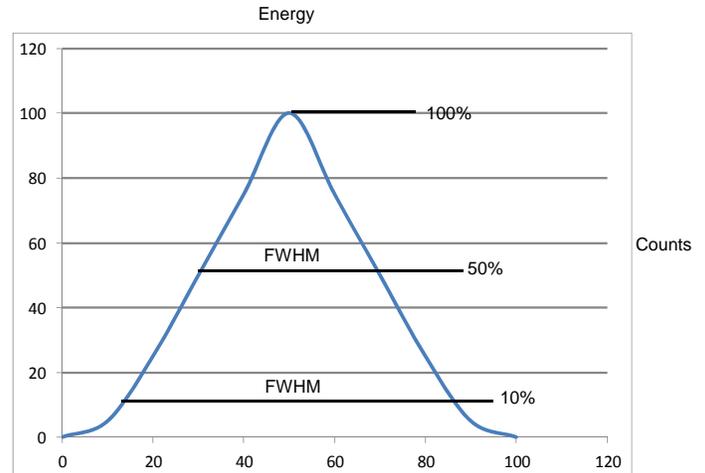


Figure 9-7.

- (5) Repeat this measurement along the X and Y axes at points 25%, 50%, and 75% of the distance from the edge of the UFOV to the center point for a total of 13 measurements.
- (6) Optionally repeat this measurement using radioisotopes of interest eIOTI etc.).

b. Intrinsic Resolution (bar pattern method).

NOTE: For this test to be useful at least one of the bar patterns must be smaller than the intrinsic resolution of the system (~3-4 mm).

- (1) Remove the collimator for the camera head and orient the crystal facing up. Select a 20% energy window center on the 140 keV peak of ^{99m}Tc and use the maximum matrix size available (at least 512 by 512 by 16 bits)
- (2) Mask the outer edge of the crystal physically or electronically to limit the image to the UFOV of the system.
- (3) Place a ^{99m}Tc point source at a distance of 5 UFOV distances from the crystal face.
- (4) Place the bar phantom flush against the crystal face aligned carefully in the X and Y directions.
- (5) Acquire an image of 3 million counts.

- (6) Repeat the above rotating the bar phantom 90° each time until each quadrant has been tested with the highest frequency (smallest bar size).
 - (7) Observe the images to assess the uniformity of resolution across all quadrants.
- c. Extrinsic Resolution.
- (1) Install a general purpose or the most frequently used collimator to the camera head and orient the crystal facing up. Select a 20% energy window center on the 140 keV peak of ^{99m}Tc and use the maximum matrix size available (at least 512 by 512 by 16 bits).
 - (2) Fill two capillary tubes (inner diameter less than 1mm and at least 5 cm long) with high concentration ^{99m}Tc to give no more than 10,000 cps.
 - (3) Place the capillary tube along the X axis at a distance of 5 cm from the face of the collimator.
 - (4) Acquire an image with at least 10,000 counts in the central pixel of the Line Spread Function (LSF) image.
 - (5) Place the second capillary tube 5 cm away from the first and parallel to it and collect a second image. Calculate the pixel size by dividing 5 cm by the number of pixels between the peaks of the two LSF images.
 - (6) Repeat with the tubes aligned along the Y axis.
 - (7) Calculate the FWHM and FWTM for both the X and Y directions.
 - (8) Optionally, repeat using other collimators and higher count rates.
- a. The collimator will be removed from the camera and the camera oriented facing up.
 - b. The source to be used is ⁶⁷Ga (93 keV, 184 keV and 296 keV energy peaks). The source will be placed in a vial shield (at least 6 mm lead) with a 3 mm hole in the bottom. The activity will be adjusted to give no more than 10,000 cps for all energy windows being tested.
 - c. The vial containing the source will be placed on the-X axis at 75% of the UFOV radius
 - d. Use a zoom that will ensure that at least 10 pixels are included in the FWHM of the image. An image for each of the energy windows will be acquired (minimum of 1000 counts in the central pixel).
 - e. Move the source a known distance along the X axis and repeat the measurement
 - f. Determine the pixel size by measuring the number of pixels between the two peaks and dividing this in to the known distance.
 - g. For each of the images (one at each image) determine the location of the center of the peak.
 - h. Calculate the difference between the position of the 93keV peak and each of the other peaks.
- $$diff_{x \text{ direction}} = [Centerpixel_{93keV \text{ xaxis}} - Centerpixel_{otherenergy \text{ xaxis}}] \times pixelsize_{x \text{ axis}}$$
- $$diff_{y \text{ direction}} = [Centerpixel_{93keV \text{ yaxis}} - Centerpixel_{otherenergy \text{ yaxis}}] \times pixelsize_{y \text{ axis}}$$
- $$diff = \sqrt{diff_x^2 + diff_y^2}$$
- i. Repeat in the Y axis direction.
 - j. Record both the X and Y deviation ($diff_x$ and $diff_y$) and the mixed deviation (diff).

F. SPECT Gamma Camera

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The test procedure in this section is based on key system performance parameters which most strongly influence image quality. These tests are designed to measure the clinical acceptability of the system and not necessarily to verify the stated performance by the vendor.

8. Energy Registration

For maximum image quality when imaging radioisotopes that emit several photons of different energy, the positioning of the point at which the radiation interacts with the crystal cannot be dependent on the energy of the photon.

1. Rotational Uniformity and Sensitivity

This will test the system's sensitivity to stray magnetic fields and to the thermal changes in the detector heads.

- a. Prepare a flood source with ^{99m}Tc ensuring the activity is uniformly disbursed throughout the phantom. Alternatively and preferably use a solid ^{57}Co flood source with a uniformity of at least +/-5% or better.
- b. Secure the flood source to the face of the collimator (a low energy general purpose collimator) so that it does not move during motion of the imaging head.
- c. Center a 20% energy window on the photopeak energy of the radioisotope being used and collect a 5 million count flood in a 64x64 matrix with the detector at 0 degree position. Record the time necessary to acquire the 5 million counts.
- d. Repeat the flood image at 90, 180, 270 and 360 degrees, using the time recorded for the first flood image.
- e. Calculate the maximum sensitivity variation:

$$\text{Max Sens Var}(\%) = \frac{\text{Counts}_{\text{max}} - \text{Counts}_{\text{min}}}{\text{Counts}_{\text{max}} + \text{Counts}_{\text{min}}} \times 100$$

In the absence of vendor performance criteria, the sensitivity variation should not exceed 1%.

- f. Using the system's computer, subtract the 90 degree flood image from the 270 degree image. Review each of the subtracted images for indications of structure noise and other non random noise. Save the images for reference.

2. Spatial Resolution

This test will use a line source which is at least 30 cm in length and no more than 2 mm inside diameter. These can be made from catheters.

- a. Fill the line source with ^{99m}Tc with a concentration of 1 mCi/cm³. If the line source is not rigid, then attach it to a rigid support which will not generate catter (tape the catheter to a piece of cardboard or Styrofoam)

- b. Suspend the line source over the end of the imaging table so that it is over the detector without any interfering objects.
- c. Adjust the table so that the line source is at the center of rotation and then set the radius of rotation to 20 cm or the smallest that is achievable. Make sure the line source and the collimator face are parallel to the axis of rotation and level.
- d. Peak the system on the photopeak energy using a 20% window, select a 128x128 matrix and 128 views over 360 degrees.
- e. A pixel size in the range of 3-3.5 mm is desirable (a 16 inch crystal with a 128 matrix will give a pixel size of 3.2 mm). If necessary, select a magnification mode that will deliver this pixel size or smaller.
- f. Acquire the tomographic study using a time that will deliver at least 100k counts in the first projection image.
- g. Reconstruct the data using a ramp filter into 10 mm transverse sections, starting at the top of the line. Uniformity and attenuation correction do not need to be applied. Consult the vendor to determine the appropriate filter to use if in doubt.
- h. Using the first section, draw a one pixel wide profile in the X direction through the hottest pixel in the reconstructed image of the line source. From the profile, calculate the FWHM by linear interpolation.
- i. Repeat the above for the Y direction and then for a slice at the bottom of the stack and in the middle.
- j. Acquire a planar image of the line source containing 500k counts with the collimator 20 cm from the line source.
- k. At approximately the same positions as the three tomographic resolution results were determined, use a ~10 mm(3 pixel) wide count profile through the planar image of the line source to calculate FWHM.
- l. Record the ratio of the SPECT/Planar FWHM to the three locations. These should not exceed 1.1. If so, then the Center of Rotation (COR) may be incorrect. Collect a new COR and

repeat the test. Large errors can be due to the X or Y axis' being out of alignment with reference to the line source.

- m. In the absence of vendor performance criteria, the ratio should not exceed 10% and must not exceed 15%.

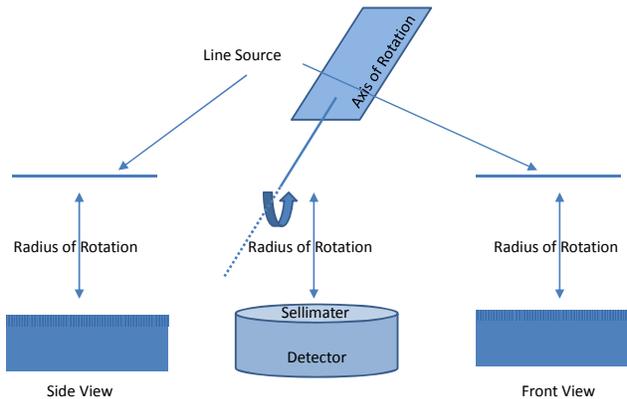


Figure 9-8.

3. System Performance

To evaluate the system performance a Jaszczak SPECT phantom is used. Other phantoms that include sections with just water and sections with other test objects to measure contrast can also be used by modifying this procedure.

a. Tomographic Data Collection.

- (1) Install a low energy general purpose collimator or the one used most often clinically.
- (2) Fill the SPECT phantom with 8 to 10 mCi if a high resolution collimator is being used and mix the solution to ensure uniform distribution of the activity.
- (3) Position the phantom on the end of the imaging table with the long axis parallel to and aligned with the axis of rotation. Fasten the phantom in place using tape or Velcro strips.
- (4) Peak the system on the photopeak energy using a symmetrical 20% window, set the radius of rotation to 20 cm or the smallest radius attainable and select a 64x64 matrix with 64 projection views over 360 degrees.

- (5) Use a magnification factor that will give a pixel size in the range of 6 to 7 mm if needed.
- (6) Acquire the tomographic study using a time sufficient to give at least 500k counts in the first projection image.
- (7) Reconstruct the data without system flood correction applied if possible, using a Hann filter and a one Nyquist cutoff. If the filter is not readily available ask the vendor to provide the name of the filter that most closely matches it.
- (8) Repeat the above, but apply linear attenuation correction using 0.11/cm attenuation coefficient or the system default value.
- (9) Repeat 1 thru 8 with flood correction turned on.

b. Attenuation Correction Analysis.

- (1) Using the uniformity corrected tomographic data set, select a transverse slice through the uniform part of the phantom image and draw 5 pixel wide horizontal count profile through the center of the section. Look at the plot for flatness.
- (2) Repeat for the vertical direction.
- (3) Any over or under correction for attenuation can be due to miscalibration of the pixel size, inappropriate attenuation coefficient selected, incorrect selection of the boundary for attenuation correction or there is a software error.

c. Uniformity and Root Mean Square Noise Analysis.

- (1) Display the entire set of tomographic images generated from the data not corrected for uniformity. Look for artifacts such as profound ring artifacts.
- (2) Select one uniform slice close to the center of the uniform slices and draw a 15x15 pixel ROI at the center and record this information from the region.

Mean Counts per pixel
Maximum count

Minimum count
 Standard Deviation

Manually determine the maximum and minimum counts in pixel if this information is not provided automatically.

$$Int\ Uniformity = \frac{\text{max count} - \text{min count}}{\text{max count} + \text{min count}} \times 100$$

$$rms\ noise(\%) = \frac{\text{Standard Deviation}}{\text{mean counts}} \times 100$$

- (3) Calculate the integral uniformity and the root mean square(rms) noise.
- (4) Repeat the above using the data set corrected for uniformity.
- (5) In the absence of vendor provided performance criteria, the following values are considered acceptable:

Without uniformity correction:

Integral uniformity: 9.9–18.3%
 rms noise: 4.5–5.7%

With uniformity correction:

Integral uniformity: 10.7–18.8%
 rms noise: 3.6–7.2%

d. Contrast Analysis.

- (1) Using the tomographic slice image set generated from the data set not corrected for uniformity, select the image that most clearly displays the cold spheres and record the number of spheres visible.
- (2) For each of the spheres, record the counts from the “coldest” pixel and determine the contrast.
- (3) Repeat (2) using the tomographic image set generated from the data corrected for uniformity.
- (4) If there are not vendor provided performance criteria then use the following values as a guide. The data in Table 9-1 is from a Jaszczak phantom.

Table 9-1.—Data from Jaszczak Phantom.

Sphere Size (mm)	Min. Contrast	Max. Contrast
31.8	0.53	0.73
25.4	0.35	0.56
19.1	0.21	0.38
15.4	0.11	0.27

Nuclear Medicine Camera Survey

NMCPHC TM 6470.1
JUNE 2013

Facility:	Date:
Room Number/Location:	ECN:
Manufacturer:	
Model Number:	Serial Number:

Test Performed	Pass	Fail	N/A	Comments (failure comments must annotate minor or significant finding)
Uniformity				
System Resolution				
Multi-Energy Registration				
Pixel Size				
Count Rate				
System Sensitivity				
System Linearity				
Center of Rotation SPECT only				
Slice Uniformity SPECT only				
Slice Thickness SPECT only				
In Place Resolution SPECT only				
Image Contrast SPECT only				
Additional Comments:				

Purpose:	Results:
Surveyor Name:	
Surveyor Signature:	

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Chapter 10

Linear Accelerators (LINACs) and Diagnostic Imaging Equipment Used in Radiotherapy

A. *Minimum Required Personnel Qualifications*

Each Navy radiation oncology department should establish local qualification standards for personnel performing performance and safety evaluations of Linear Accelerators (LINACs) and diagnostic imaging equipment used in radiotherapy. These personnel should be either Medical Physicists with board-certification in radiation therapy physics (such as certification by the ABR or ABMP as a Therapeutic Radiologic Physicist), a board-eligible Medical Physicist as determined by the certification board, or an individual under the direct supervision of one of the above.

B. *Policies and Procedures*

1. It is highly recommended that performance and safety evaluation procedures provided by the equipment manufacturer and/or by nationally-recognized protocols are followed when applicable, such as Task Group (TG) reports published by the AAPM, as well as reports published by the National Council on Radiation Protection and Measurements (NCRP), International Council on Radiation Protection (ICRP), and other nationally-recognized organizations.
2. Local policies and procedures should specify facility-specific requirements and periodicities, or at a minimum, indicate the use of specific nationally-recognized protocols.
3. A Medical Physicist specialized in Radiation Therapy should determine which acceptance tests and periodic quality assurance tests should be performed for therapeutic x-ray units (e.g., superficial x-ray and orthovoltage units) and radiotherapy LINACs.
4. A Medical Physicist specialized in Radiation Therapy should determine which acceptance tests and periodic quality assurance tests should be performed on diagnostic imaging equipment

associated with radiation therapy. These tests should be determined in consultation with a Diagnostic Medical Physicist. Diagnostic imaging equipment includes but is not limited to the following:

- a. Rad/fluoro radiotherapy simulators;
 - b. CT, Photon Emission Tomography (PET), CT/PET, and MRI units utilized as radiotherapy simulators;
 - c. X-ray film portal imaging;
 - d. Electronic portal imaging (EPI);
 - e. Cone beam CT (i.e., Kilovoltage Computed Tomography [KVCT] and MegaVoltage Computed Tomography [MVCT]); and,
 - f. Other Onboard Imaging (OBI) devices.
5. Policies and procedures in other chapters in this manual should be followed as applicable regarding acceptance and periodic testing of diagnostic imaging equipment used within the practice of Radiation Therapy. A Medical Physicist specialized in Radiation Therapy should determine which of the policies and procedures are applicable.

C. *Testing Periodicity*

LINACs and Tomotherapy: Annually, monthly, daily Quality Assurance (QA) test per AAPM TG-40, TG-51, and TG-142, upon acceptance and after major repairs per TG-45.

Additional QA tests (if applicable) for LINACs and Tomotherapy: Intensity-Modulated Radiation Therapy (IMRT) QA prior to patient treatment and Stereotactic RadioSurgery/Stereotactic Beam Radiation Therapy QA according to TG-142.

CT-simulator: Annually, monthly, and daily QA tests per TG-40 and TG-66, upon acceptance and after major repairs per TG-66.

D. Equipment

LINACs: Phantom (solid for monthly or distilled water for annual/monthly QA tests), MapCheck (if applicable), ionization chamber, electrometer, QA mechanical device (if applicable), other equipment as specified by the physicist per TG-142.

CT simulator: Laser alignment tool, head/body water phantom, radiographic/radiochromic film (when available), laser QA device, other equipment as specified by the physicist per TG-66.

Tomotherapy: Phantoms (solid/liquid water) for weekly or monthly quality assurance (QA), radiochromic film (if available) or MapCheck for dose Delivery Quality Assurance (DQA) – i.e. IMRT QA prior to treatment, specified by the physicist per TG-148.

E. References

1. AAPM TG-21, “A Protocol for absorbed dose from high-energy beams,” Med. Phys. 10(6)(1983).
2. AAPM TG-40, “Comprehensive QA for Radiation Oncology: Report of AAPM Radiation Therapy Committee Task Group 40,” Med. Phys. 21(4)(1994).
3. AAPM TG-45, “AAPM Code of Practice for Radiotherapy Accelerators: Report of AAPM Radiation Therapy Task Group No. 45,” Med. Phys. 21(7)(1994).
4. AAPM TG-51, “Protocol for Clinical Reference Dosimetry of High-Energy Photon and Electron Beams: Report of AAPM Radiation Therapy Committee Task Group 51,” Med. Phys. 26(9)(1999).
5. AAPM TG-66, “Quality assurance for computed-tomography simulators and the computed-tomography-simulation process: Report of the AAPM Radiation Therapy Committee Task Group No. 66,” Med. Phys. 30(10)(2003).
6. AAPM TG-142, “Quality Assurance of Medical Accelerators,” Med. Phys. 36(9)(2009).
7. AAPM TG-148, “QA for helical Tomotherapy: Report of the AAPM Task Group 148,” Med. Phys. 37(9)(2010).
8. NCRP Report No. 151, *Structural Shielding Design and Evaluation for Megavoltage X-and Gamma-Ray Radiotherapy Facilities*, National Commission on Radiation Protection and Measurements, 2006

Chapter 11

High Dose Rate (HDR) Brachytherapy

A. Minimum Required Personnel Qualifications

Each Navy radiation oncology department should establish local qualification standards for personnel performing performance and safety evaluations of High Dose Rate (HDR) brachytherapy used in radiotherapy. These personnel should be either Medical Physicists with board-certification in radiation therapy physics (such as certification by the ABR or ABMP as a Therapeutic Radiologic Physicist), a board-eligible Medical Physicist as determined by the certification board, or an individual under the direct supervision of one of the above.

B. Policies and Procedures

1. It is highly recommendation that performance and safety evaluation procedures provided by the equipment manufacturer and/or by nationally-recognized protocols (e.g. Nuclear Regulatory Commission) are followed when applicable, such as TG) reports published by the AAPM) as well as reports published by the NCRP, ICRP, and other nationally-recognized organizations.
2. Local policies (e.g. the applicable Navy Radioactive Materials Permit) and procedures should specify facility-specific requirements and periodicities, or at a minimum, indicate the use of specific nationally-recognized protocols.
3. A Medical Physicist specialized in Radiation Therapy should determine which acceptance

and periodic quality assurance tests should be performed for the specific HDR unit

4. Policies and procedures in other chapters in this technical manual should be followed as applicable regarding acceptance and periodic testing of HDR equipment utilized within the practice of Radiation Therapy. A Medical Physicist specialized in Radiation Therapy should determine which of the tests are applicable, and which additional tests should be performed.

C. Testing Periodicity

Remote afterloader: Upon acceptance and after major repairs, annual QA, quarterly QA, and daily QA per AAPM TG-59.

D. Equipment

Radiochromic (Gafchromic) film, applicators, source guide tubes, and radioactive source

E. References

1. AAPM TG-41, “*Remote Afterloading Technology: Report of AAPM Task Group No. 41.*”
2. AAPM TG-59, “*High dose-rate brachytherapy treatment delivery: Report of AAPM Radiation Therapy Committee Task Group No. 59,*” Med. Phys. 25(4)(1998).
3. NCRP Report No. 151, *Structural Shielding Design and Evaluation for Megavoltage X-and Gamma-Ray Radiotherapy Facilities*, National Commission on Radiation Protection and Measurements, 2006.

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Chapter 12

Entrance Skin Kinetic Energy Released in Material (KERMA) (ESK)

A. Introduction

One of the largest contributors to total population radiation exposure from man-made radiation sources is from diagnostic (dental and medical) radiography. One of the goals of the Conference of Radiation Control Program Directors (CRCPD) is to reduce the unnecessary component of dental and medical x-ray exposure to a level As Low As Reasonably Achievable (ALARA).

Reference 3, lists recommended patient exposure guides which reflect "State of current practice" in a cross section of radiography facilities across the United States. They are to be used as a tool for reducing unnecessary radiation exposure to patients, while maintaining or improving image quality. Calculated Entrance Skin KERMA (ESK) should be compared to these average values.

Exposures that significantly exceed the levels indicated in the guides for routine examinations are likely to represent unnecessary patient doses and causes for such excessive exposure should be investigated. A reasonable but arbitrary range of acceptability is $\pm 20\%$ of a guide value.

B. Minimum Required Personnel Qualifications

Basic Diagnostic Imaging Equipment

C. Testing Periodicity

Acceptance, annual, or after major repair

D. Equipment

1. Ion chamber
2. Patient-Equivalent Phantoms
3. Tape measure

E. References

1. AAPM Report 31. "Standardized Methods for Measuring Diagnostic X-Ray Exposures," 1990.
2. "Average Patient Exposure/Dose Guides. A report by Committee n Quality Assurance in Diagnostic Radiology (H-7)." Conference of Radiation Control Program Directors, Inc. CRCPD Publication 92-4, 1992.
3. "Nationwide Evaluation of X-Ray Trends (NEXT)," Conference of Radiation Control Program Directors, Inc. Frankfort: CRCPD. 1974 - 1994.
4. AAPM Report 70. Cardiac Catheterization Equipment Performance, 2001.

F. Entrance Skin Kinetic Energy Released in Material (KERMA) (ESK) for General Radiographic Equipment

1. Purpose

To ensure that ESK also formally known as entrance skin exposure for standard radiographic techniques is within standards.

2. Regulations

Joint Commission for Accreditation of Healthcare Organizations (JCAHO, 1994) requires ESK's, for techniques used most commonly, be evaluated on an annual basis.

3. Procedure

a. Manual Mode.

- (1) In addition to the procedures outlined below, the following parameters must be known for each tube head to obtain specific organ doses:

- (a) Source to skin distance (SSD)

- (b) Source to Image Distance (SID)
 - (c) Technique factors for the selected projection
 - (d) HVL of the unit in question for the selected projection
- (2) Set the clinically used SID. Center the ion chamber in the x-ray field at approximately 23 cm above the tabletop to minimize backscatter. Record the distance from the focal spot to the center of the ion chamber.
 - (3) Collimate the light field on the ion chamber using narrow beam geometry.
 - (4) Set the desired technique factors at the control panel.
 - (5) Place the ion chamber in the center of the useful beam, measure, and record SSD, SID, and the ESK.
 - (6) Repeat as necessary for other commonly used projections and technique factors.
 - (7) Calculate the entrance skin KERMA for each projection using the patient thickness guidelines in Table 2 of HHS Publication (FDA) 89-8031 and the inverse square law. The inverse square calculation is as follows:

$$ESK(mGy) = \left(\frac{x_1}{x_2} \right)^2 \times AirKERMA$$

Where:

ESK = corrected x-ray beam intensity at the skin entrance without backscatter

x_1 = focal spot to center of ion chamber distance

x_2 = distance from the focal spot to the surface of the skin ($x_2 = x_1 -$ patient thickness)

Air KERMA = Air KERMA at the center of the ion chamber

NOTE: Exposure in air (mR) may be converted to ESK (mGy) by multiplying by 0.00876 mGy/mR.

- (8) Interpretation of Results. Compare exposures received for standard techniques with the NEXT published national guidelines and rate as satisfactory or unsatisfactory. If exposures are not within recommended ranges, an evaluation of image quality should be conducted in consultation with the clinical staff. Factors that can cause variations are backscatter, collimation, phantom material, location of ion chamber, x-ray beam, etc. A qualified service engineer should be consulted for equipment adjustment.
- (9) To determine tissue/organ doses for projections common in diagnostic radiology, use the ESK for each projection, the additional information in item 3.1 above and refer to HHS Publication (FDA) 89-8031.
- (10) To estimate the dose to the embryo-fetus from radiographic examinations, refer to reference HHS Publication (FDA) 79-8079 and NCRP Report 54.

b. Automatic Exposure Control Mode.

- (1) Measure and record the HVL of the x-ray beam.
- (2) Set up x-ray unit for commonly used radiographic projections: chest, abdomen, and extremity.
- (3) Place the patient-equivalent phantom over the selected AEC detectors. (see figures 12-1a and 12-1b, shown for a chest unit).
- (4) Place the ion chamber in the useful beam, measure, and record the SSD, SID, and ESK values. Ensure that the detector does not cover the AEC sensor.
- (5) Follow the steps in 3.(a)(7) through 3.(b)(4) above to calculate ESK, interpret results and to estimate organ dose/embryo-fetal doses.

G. Entrance Skin Kinetic Energy Released in Material (KERMA) (ESK) for Dental Intraoral Units

1. Procedure

- a. Place the probe about ½-inch from end of cone.
- b. Use a technique commonly used on the dental unit to make an exposure. This is the ESK which should be recorded along with all settings used.
- c. Record focal spot to chamber distance which represents the source to skin distance and approximates the source to image distance. Use the actual kVp as determined.

H. Entrance Skin Kinetic Energy Released in Material (KERMA) Rate (ESKR) for Fluoroscopy Units

1. Procedure

Refer to Chapter 4. for Entrance Skin KERMA Rate (ESKR) for fluoroscopic measurement procedures.

NOTE: 1100 alloy Al sheets are less suitable as a fluoroscopy ESKR phantom than acrylic slabs since the Al represents significantly different equivalent patient thicknesses at different kVp values. Al also does not provide the same amount of scatter as the thicker acrylic block. Experimental data has demonstrated up to 2X higher ESKR using acrylic. However, not all evaluators will have acrylic phantoms in their equipment inventories. To maintain consistency, clearly identify the type of phantom used, record the testing conditions, and perform subsequent evaluations using the original phantom and conditions.

I. Digital Spot Entrance Skin Kinetic Energy Released in Material (KERMA) Rate (ESKR)

1. Introduction

- a. Fluoroscopy is routinely used as a localization mechanism for radiographic images that are analyzed at a later time. In many fluoroscopic examinations, the digital spot exposure component can be substantial, especially if the use of contrast is involved. Therefore, accurate digital spot ESKR measurements are essential to maintaining a database for determining patient exposures.
- b. Digital spot exposure measurement assumes proper generator calibration and satisfactory operation of the imaging chain components. Image intensifier entrance exposure rate (μRfr^{-1}) must be properly set to the manufacturer's recommendation. Digital spot exposure testing is typically performed last during an acceptance inspection or annual performance evaluation.

2. Procedure

- a. Arrange the fluoroscopy unit and ion chamber in the configuration appropriate to the machine type; i.e. undertable tube, overtable tube, or c-arm. Ensure that if a grid is used in clinical studies, it is in the beam path during testing.
- b. Place a 4 cm Al or 15 cm acrylic phantom in the beam in the same manner as for measuring ESKR. Ensure that the phantom sits between the ion chamber and the image intensifier tube.
- c. If the unit provides specific digital spot settings for different anatomical applications, program the system for non-contrast abdominal studies. If different dose levels are also provided, select an average setting. If anatomical or dose programming are not provided, use the system's ABC) to determine the kVp to be used during testing. For manual only systems, program the unit for 80 kVp. Select an appropriate medium level current (e.g. 200 mA). Program a digital spot film system to operate at its minimum frame rate (1 frs⁻¹ is most desirable). If appropriate, set the

digital spot device to terminate exposure using AEC.

- d. Set the image intensifier to minimum size, collimating to the phantom dimensions if necessary. Fluoro the phantom briefly, allowing ABC to select an appropriate kVp. Several systems apply the ABC selected voltage directly to the digital spot technique. For those that do not, the fluoro kVp serves as a useful baseline for manual digital spot technique programming.
- e. Irradiate the phantom and ion chamber using digital spot mode, recording the measured ESKR and technique factors. During acceptance, repeat for all available II sizes and dose settings, as applicable. During annual evaluations, test at the most commonly used dose setting using the largest II size.
- f. Repeat the procedure for each phantom thickness and field of view for which fluoroscopic exposure is clinically used.
- g. If digital spot exposures are made with and without a grid in the beam, repeat the procedure with the grid removed from the beam.

3. Interpretation of Results

- a. Calculate ESKR as a function of mAs. Determine maximum, minimum, and average exposure/mAs. If current values differ from their acceptance or historical counterparts by more than $\pm 10\%$, refer the system for adjustment by a qualified service engineer.

Chapter 13

Radiation Shielding Design and Evaluation for Medical and Dental X-Ray Facilities

A. Introduction

Shielding design for medical facilities must protect workers and members of the public from excessive exposure to ionizing radiation from radiographic and nuclear imaging, and radiation therapy. In Title 10, Code of Federal Regulations Part 20, the United States Nuclear Regulatory Commission requires that the effective dose does not exceed 1mSv (100 mrem) per year for a member of the general public and 50 mSv (5 rem) per year for radiation workers from radioactive materials.

The National Council on Radiation Protection and Measurements has established similar recommendations for ionizing radiation exposure from other sources of ionizing radiation including x-rays. The concept of ALARA mandates that the exposure be kept below these limits. Thus when designing shielding, the target limit should be lower to ensure that the regulatory limits are not likely to be exceeded.

The current recommended design criteria is 0.02 mSv (2 mrem) per week for members of the general public and 0.1 mSv (10 mrem) per week for radiation workers. It is the responsibility of the shielding designer to keep abreast of changes in these limits. Magnetic Resonance Imaging facilities will also require shielding designs that reduce magnetic and radiofrequency interference. The design of these shields are typically beyond the capabilities of site personnel and will generally be included as part of the purchase contract for such units.

B. Minimum Required Personnel Qualifications

Board certification from ABR in the appropriate subspecialty or American Board of Health Physicists (ABHP) is the normal pathway for obtaining the Advanced Radiological Systems Shielding Design qualification. This is in line with the NCRP 147 and NCRP 151 recommendation that only "Qualified Experts" should perform shielding designs.

On a case by case basis, NMCPHC may evaluate individual shielding design experience as an exemption to board certification. Shielding experience in these cases should include a minimum of 2 designs of the applicable type(s): linear accelerators, HDR therapy units, nuclear medicine suites, computed tomography, fluoroscopy, and radiographic units.

Designs used to demonstrate competency may be example shielding problems approved and reviewed by any individual who has been granted a shielding design qualification from the MPAB.

C. Design and Evaluation Periodicity

Shielding design is required for all new radiographic, nuclear medicine, therapy installations, and after major renovations to existing facilities. As recommended in NCRP Report No. 147, sites designed using the previous NCRP Report No. 49 standard do not need to be upgraded as long as the room has not changed in functionality.

D. Equipment

1. Large volume ion chamber (≥ 180 cm nominal volume) to check radiation levels

E. References

1. United States Nuclear Regulatory Commission. Standards for Protection Against Radiation. Washington D.C.: Chapter 10 Part 20;2007.
2. National Council on Radiation Protection and Measurements. Structural Shielding Design for Medical X-Ray Imaging Facilities. Bethesda, MD: NCRP; Report No. 147; 2004.
3. American Association of Physicists in Medicine. Task Group Report 108: Shielding for PET/CT Facilities. 2006
4. National Council on Radiation Protection and Measurements. Structural Shielding Design for Megavoltage Radiotherapy Facilities. Bethesda, MD: NCRP; Report No. 151; 2005.

5. National Council on Radiation Protection and Measurements. Radiation Protection in Dentistry. Bethesda, MD: NCRP; Report No. 145; 2003.
6. American Association of Physicists in Medicine. Task Group Report 100: Acceptance Testing and Quality Assurance Procedures for Magnetic Resonance Imaging Facilities. 2010
7. American College of Radiology. ACR Guidance Document for Safe MR Practices: June 2007
8. National Council on Radiation Protection and Measurements. Limitations of exposure to ionizing radiations. Bethesda, MD: NCRP; Report No. 116; 1993.
9. Dixon, RL and Simpkin DJ: Application of new concepts for radiation shielding of medical diagnostic x-ray facilities. RSNA 1998.
10. Simpkin DJ: Evaluation of NCRP report 49 assumptions and use factors in diagnostic radiology facilities. Med Physics 23:577-584; 1996
11. Simpkin DJ: Transmission data for shielding diagnostic x-ray facilities. Health Phys. 68:704-709; 1995.
12. Suleiman OH, Conway BJ, Fewell TR, Slayton RJ, Rueter FG, and Gray J: Radiation Protection requirements for medical x-ray film. Med. Physics 22:1691-1693; 1995.
13. Dixon RL: On the primary barrier in diagnostic x-ray shielding. Med Physics 21: 1785-1794; 1994.
14. Archer BR, Fewell TR, Conway BJ, and Quinn PW: Attenuation properties of diagnostic x-ray shielding materials. Med Physics 21: 1499-1507; 1994.
15. Simpkin DJ: Shielding requirements for mammography. Health Phys. 53:267-179; 1987.
16. National Council on Radiation Protection and Measurements. Structural shielding design and evaluation for medical use of x-rays and gamma rays of energies up to 10 MeV. Bethesda, MD: NCRP; Report No. 49; 1976.

Chapter 14

Performance Tests for Monitors in Picture Archiving and Communication System (PAC)

A. Introduction

Display testing in the form of acceptance testing or frequent QC provides a means by which the user can be assured that the display quality is adequate and is maintained throughout the useful life of the device. It will also determine when a display device should be decommissioned before diagnosis is adversely affected. Furthermore, a comprehensive display.

QC program ensures the consistency and integrity of image presentations throughout the clinic, reducing possible inconsistencies in clinical decisions based on images displayed on different devices.

The purpose of this section is to provide guidance for visually testing display systems. For more comprehensive quantitative or advanced testing, refer to the primary reference, AAPM TG 18.

This section does not cover performance testing for mammography monitors. Refer to the manufacturer's manual for specific testing requirements for these monitors.

B. Testing Periodicity

Acceptance, annually, and after major repairs

C. Reference

AAPM Online Report No. 3, Imaging Informatics Subcommittee Task Group #18, Assessment of Display Performance for Medical Imaging Systems, 2005.

D. General Performance Tests for Picture Archiving and Communication System (PACS) Monitor Equipment

Prior to acceptance of the monitor, the ambient lighting level should be measured and documented and a DICOM luminance calibration should be performed. The calibration of the DICOM luminance should be done by the manufacturer of the monitor or

software used to perform quality control tests. Prior to the annual evaluation of the monitor the ambient lighting level should be measured and documented and a verification of the DICOM luminance calibration should be done (to include verifying the L_{max} and L_{min}). Most monitors have software installed to perform the verification of the DICOM luminance calibration.

1. Geometric distortion

- a. Purpose. To ensure the display of the monitor is free from geometric distortions.
- b. Equipment. AAPM TG18-QC test pattern
- c. Procedure.
 - (1) The pattern should be maximized to fill the entire display area. For displays with rectangular display areas, the patterns should cover at least one orientation of the display area and be placed at the center of the area used for image viewing.
 - (2) The linearity of the pattern should be checked visually at a viewing distance of 30 cm across the display area and at the edges.
- d. Interpretation of Results. The patterns should appear straight without significant geometrical distortions. The pattern should be properly scaled to the aspect ratio of the video source pixel format so that grid lines represent squares. The lines should appear straight without any curvature or waviness, indicative of proper linearity. Some small barrel and pincushion distortions are normal for Cathode Ray Tube (CRT) devices but should not be excessive.

2. Display Reflection

- a. Purpose. Assess and minimize display reflection.
- b. Description. Reflections can have two general forms, specular and diffuse. Specular reflection is said to occur when the angle of the incident light rays equals that of the emerging rays as dictated by geometrical optics. Such a reflection produces a virtual image of the source as would a mirror. In diffuse reflection, the light is randomly scattered out of the specular direction and no virtual image of the source is produced. There are two types of diffuse reflection. One is where the scattering angles of the emergent light are broadly distributed and poorly correlated with the angle of the incident light such as with a Lambertian reflector where the direction of the incident light has little affect on the observed reflected luminance. The other type of diffuse reflection is where light is randomly scattered into a narrow distribution of angles in the vicinity of the specular direction.
- c. Equipment. AAPM TG18-AD test pattern
- d. Procedure.
 - (1) Turn the display device off or put in power save mode. Ensure the ambient lighting in the room is the same as when the radiologist is interpreting images.
 - (2) Examine the display's faceplate at a distance of 30-60 cm with an angular view of +/-15 degrees for specularly reflected light sources or illuminated objects.
 - (3) Load the TG18-AD test pattern and view the low contrast patterns with normal ambient lighting.
 - (4) Turn off all lights and view the test pattern in total darkness.
- e. Interpretation of Results. In examining the display's faceplate under normal ambient light condition, no specularly reflected patterns of high contrast objects should be seen. If light sources such as that from a film illuminator or window are seen, the position of the display device in the room is not appropriate. If high

contrast patterns are seen such as an identification badge on a white shirt or a picture frame on a light wall, then the ambient illumination in the room should be reduced. The threshold of visibility for low-contrast patterns in the TG18-AD test pattern should not be different when viewed in total darkness and when viewed in ambient lighting condition. If the ambient lighting renders the "dark-threshold" not observable, the ambient illuminance on the display surface is causing excess contrast reduction and the room ambient lighting needs to be reduced.

3. Luminance Response

- a. Purpose. To ensure the luminance of the display device is consistent and uniform.
- b. Equipment. AAPM TG18-CT and TG18-MP test patterns
- c. Procedure.
 - (1) The TG18-CT pattern should be evaluated for visibility of the central half-moon targets and the four low-contrast objects at the corners of each of the 16 difference luminance regions at a viewing distance of 30 cm.
 - (2) The TG18-MP test pattern should be viewed to evaluate the bit-depth resolution of the display. The evaluation includes ascertaining the horizontal contouring bands, their relative locations, and grayscale reversals at a viewing distance of 30 cm.
- d. Interpretation of Results.
 - (1) The appearance of the TG18-CT test pattern should clearly demonstrate the low contrast target in each of the 16 regions. Since this pattern is viewed in one state of visual adaptation, it is expected that the contrast transfer will be better at the brightness for which the visual system is adapted as opposed to the darkest or the brightest regions. A common failure is not to be able to see the targets in one or two of the dark regions.

- (2) In the evaluation of the TG18-MP pattern, the relative location of contouring bands and any luminance levels should not be farther than the distance between the 8 bit markers (long markers). No contrast reversal should be visible.

4. Luminance Uniformity

- a. Purpose. To ensure the luminance across the display area is uniform.
- b. Equipment. AAPM TG18-UN10 and TG18-UN80 test patterns
- c. Procedure. Display each of the test patterns and assess the uniformity of the image visually.
- d. Interpretation of Results. The patterns should be free of gross non-uniformities from center to the edges. Typical CRTs show symmetrical nonuniformities and LCD displays are associated with non-symmetrical ones. No luminance variations with dimensions on the order of 1 cm or more should be observed.

5. Display Resolution

- a. Purpose. To ensure the display system is capable of producing separable images of different points of an object with high fidelity.
- b. Equipment. AAPM TG18-QC test pattern and magnifying glass
- c. Procedure.
 - (1) Display the test pattern ensuring one display pixel per image pixel is displayed.
 - (2) Using the test pattern and magnifier, inspect the displayed "Cx" patterns at the center and four corners of the display area and score the appearance using the provided scoring scale (from 1, the sharpest reference pattern to 12, the blurriest reference pattern).
 - (3) Evaluate the line pair patterns at the Nyquist and half-Nyquist frequencies in the horizontal and vertical directions in terms of visibility of lines.

d. Interpretation of Results

- (1) The visual evaluation should render all the targets except the smallest one visible. It should be pointed out that failure of a device in this test can also be an indication of improper luminance response. That can be ruled out by first verifying the proper luminance response of the device. However, the results are independent of the absolute luminance value of the pattern's background; since the mean value and the standard deviation of the background are linearly dependent on the luminance, their ratio, i.e., signal to noise, remains independent of luminance.
- (2) The Cx elements should be scored between 0 and 4 at all locations. The horizontal and vertical line pair patterns at Nyquist frequency should be discernable at all locations and for all directions.
- (3) In CRTs, it is normal for the performance at the center to be better than any corner due to normal deflection distortions. Also, the horizontal line pair patterns at Nyquist frequency usually appear overall slightly brighter than the vertical patterns because the vertical patterns contain a higher percentage of rise/fall time per pixel, delivering less beam energy to the phosphor screen. At the Nyquist frequency, the difference in the average luminance should be less than 30%. A difference more than 50% indicates a slow video amplifier not well suited for the matrix size. The line pair pattern at half-Nyquist frequency should show less luminance difference since the vertical patterns contain two pixels/line providing more dwell time for the electronic beam. A significant difference between the thicknesses of the black and white lines is also indicative of a poorly shaped pixel with excessive spread of the pixel, which diminishes the black content.

6. Display Noise

- a. Purpose. To visually quantify the spatial noise of the display system.
- b. Equipment. AAPM TG18-AFC test pattern

c. Procedure.

- (1) Each quadrant of the test pattern contains a large number of regions with varying target position. In each quadrant the contrast and size of the target is constant. The contrast-size values for the four quadrants are 20-2, 30-3, 40-4, and 60-6. The observer views the patterns from a distance of 30 cm.
- (2) Evaluate each of the quadrants and establish the contrast-size for which the observer can confidently place the position of all targets.

d. Interpretation of Results. The visual evaluation should render all the targets except the smallest one visible for primary monitors and the second largest targets should be visible for secondary monitors.

7. *Veiling Glare*

a. Purpose. To assess the veiling glare of the display system.

b. Equipment. AAPM TG18-GV and TG18-GVN test patterns

c. Procedure.

- (1) Display the test patterns such that the white region is 20 cm in diameter.
- (2) Observe the visibility of the low contrast objects in each of the test patterns with the bright region masked from view. Because the human visual system will change adaptation if it views the bright field, it is imperative that the bright field is fully blocked from view and that no reflected light from the bright field be observable.

d. Interpretation of Results. No significant reduction in the contrast of the target object should be observed between the two patterns with and without the bright field. This test is sensitive to the perceived contrast of the target with a black surrounding region. If this is exactly at the just noticeable threshold, then any reduction in contrast will render the pattern not visible. The third object should be visible in either pattern for primary monitors and at least one target for secondary monitors.

8. *Display Chromaticity*

a. Purpose. To verify the color of the display system is uniform.

b. Equipment. AAPM TG18-UN80 test pattern

c. Procedure.

- (1) Display the test pattern on all monitors associated with the workstation.
- (2) Look for color uniformity of the test pattern across the display area of each monitor.

d. Interpretation of Results. No significant perceivable color difference should be present among the monitors. With monochrome phosphor-based displays such as CRTs, any perceivable differences can be attributed to the use of different phosphors, different batches of phosphor materials in the manufacturing process, aging of multiple component phosphors, or differences in faceplate's anti-reflection/glare treatments.

Chapter 15

Guidance for the Use, Care, Evaluation, and Disposal of Lead Aprons

A. Background

The Environment of Care standards set forth by the JCAHO require performance inspections on medical equipment. Lead aprons are considered medical equipment. In addition, all state radiation control programs require evaluations of lead aprons. In recent years, references (a) and (b) have addressed the topic of the proper care, evaluation and disposal of lead aprons.

B. Guidance

The Bureau of Medicine and Surgery (BUMED) guidance for the use, care, evaluation and disposal of lead aprons (including thyroid and gonadal shields) utilized in medical facilities is as follows:

C. References

1. Implementation of an X-ray Radiation Protective Equipment Inspection.
2. Program, Operational Radiation Safety; 82(2): S51-S53, 2002.
3. Inspection of Lead Aprons: A Practical Rejection Model,
4. Operational Radiation Safety; 95(Supplement 2): S133-S136, 2008.

D. Use, Care, Evaluation, and Disposal

1. Use of Lead Aprons

Based on NCRP recommendations, lead aprons of a minimum of 0.5 mm lead-equivalency should be used for fluoroscopic applications and for shielding direct gonadal exposures. Lead aprons of a minimum of 0.25 mm lead-equivalency should be sufficient for all other radiographic applications.

2. Care of Lead Aprons

Properly cared for lead aprons have a life expectancy of approximately 10 years. They should be properly hung on hooks/racks when not in use. They should never be folded, creased or draped across another piece of equipment. They should be kept clean of dirt, grease and other contaminants.

3. Evaluation of Lead Aprons

Pursuant to references (a) and (b), lead aprons should be evaluated at least annually. This evaluation should consist of a visual inspection and physical evaluation. If a suspicious area is found, i.e. tears, perforations, or thinning creases at the time of the annual check or on any other occasion, an x-ray evaluation should be performed. Depending on the availability of the facility, the x-ray evaluation may be done with either fluoroscopy or x-rays. A record of the date of the check, the type of check (visual, tactile, and/or x-ray), the results, and who performed the check, should be kept for three years. It is expected that an inspector will be able to verify that the evaluations have been done by either looking at the aprons and/or the documentation system.

4. Rejection Criteria

Whole body lead aprons should be rejected and replaced if the tear length exceeds 2 in. for the single layered material or 10 in. for the double layered material. If the defect(s) occur in an area that would cover the reproductive organs, and the area exceeds 1.5 in., the apron should be replaced. If the defect(s) occurs on a thyroid shield and the area exceeds a ½ in., the lead thyroid shield should be replaced. See Table 15-1 below.

5. Disposal of Lead Aprons

Lead aprons contain hazardous materials, and it is illegal to dispose of lead aprons in a landfill. For the disposal of lead aprons that remain in a condition to warrant their re-use, it is recommended that commands contact their nearest Defense Reutilization & Marketing Office (DRMO) through their host or

activity Environmental Department. For lead aprons damaged beyond their safe use as defined in the paragraphs above, it is recommended that commands process the aprons for disposal through their Hazardous Materials (HAZMAT) office. Alternately, some manufacturers of lead aprons may take them back for recycling or disposal.

Table 15-1.—Apron Rejection Criteria.

Type of Apron	Definition Area	Length of Defect	
		Lead Equivalency (mm)	
		0.25	0.50
Double Layered	Whole Body	13.5 cm	27 cm
	Gonads	4.4 cm	8.7 cm
Single Layered	Whole Body	5.9 cm	5.4 cm
	Gonads	1.9 cm	1.7 cm
	Thyroid	1.9 cm	1.8 cm

Chapter 16

Direct Digital Radiography Systems

A. Introduction

Digital Radiography (DR) consists of specialized equipment using Photoconductors (Direct DR or DDR) to replace the cassette and cassette tray altogether with a specialized digital detector system. The photoconductor material – Selenium – is placed on top of a Thin Film Transistor (TFT) array. The detector captures ionizations and measures the charge deposited directly. The data from the detector are directly digitized and sent out as a picture to the PACS.

This document describes a series of tests to assess digital detector performance. The tests are intended to detect artifacts and test image quality and sensitivity. All images should be acquired with a minimal amount of pre-processing and a linear Look Up Table (LUT) applied, unless otherwise stated. Some of the images should be assessed on either a reporting quality monitor or printer. These devices should be monitored as part of a QA program. Ambient lighting conditions should be consistent and appropriate.

B. Minimum Required Personnel Qualifications

Basic Diagnostic Imaging Equipment

C. Testing Periodicity

Annually, upon acceptance, and applicable portions after major repairs

D. Equipment

1. Tape measure
2. Adhesive tape
3. 1.0 mm copper filtration (> 10 x 10 cm)
4. TO20 threshold contrast test object
5. Resolution test object (e.g. Huttner 18)
6. M1 geometry test object
7. Contact mesh
8. Ionization chamber
9. Small lead or copper block (~ 5 x 5 cm)
10. Direct Digital Radiography System Survey

E. Reference

1. KCARE DDR Commissioning and Annual QA Protocol Manual, January 2005. 2. The Essential Physics of Medical Imaging. Bushberg, Jerrold, Anthony Seibert, Edwin Leidholdt, John Boone. Philadelphia, 2002.

F. General Requirements for Radiographic Equipment

1. Dosimetry

- a. Purpose. To measure entrance detector exposures.
- b. Regulations. Measures dose required for later tests 3, 4, 5, 6, 10.
 - a. Equipment. Ionization chamber, 1.0 mm Cu filter.
 - b. Procedure. Set a Focus to Detector Distance (FDD) of at least 150 cm (see Figure 16-1). Record this distance. Position a chamber at least 30 cm in front of the detector (away from backscatter). If possible either point the tube away from the detector or shield the detector with a lead apron. Collimate to the chamber. Expose the chamber such that the inverse square law corrected receptor entrance air KERMA is approximately 10 uGy, using 70 kVp and 1.0 mm Cu filtration. Record the measured dose and repeat twice. Under the same beam conditions determine the mAs required to deliver 1 uGy, 4 uGy, 12 uGy, and 50 uGy.

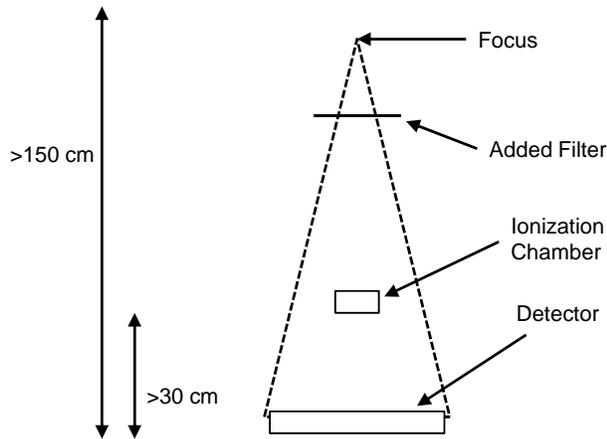


Figure 16-1.

- c. Interpretation of Results. Data collected here is used in tests 3, 4, 5, 6, 10.

2. Dark Noise

- a. Purpose. To assess the level of noise inherent in the system.
- b. Regulations. Test is used to set a baseline for future QA tests. On future annual tests, the tolerance should be +/- 50% exposure equivalent.
- c. Equipment. None
- d. Procedure. If possible, remove the grid from the system. Close the collimators and cover the detector with a lead apron. Set a low exposure (e.g. 50 kVp and 0.5 mAs). This will give an effectively zero dose, or 'dark noise' image. Record the detector dose indicator value, and pixel value.
- e. Interpretation of Results. Used to establish a baseline for future QA tests. If tolerance outside of +/- 50% of baseline is observed, consult with qualified service engineer.

3. Linearity, System Transfer Properties, and Dark Noise

- a. Purpose. To establish relationship between receptor dose and pixel value, and establish exposure index varies linearly with the increasing exposure.
- b. Regulations. The trend-line plotted in Excel should have an R^2 fit value > 0.95 . There is

no tolerance for the system transfer properties (STP) equation; however the pixel value to dose relationship should be a simple relationship (e.g. log, linear, or square root). There is also no tolerance for the dark noise image; however the data may be useful as a baseline when rechecking the dark noise in the event of other image quality problems.

- c. Equipment. 1.0 mm Cu filter
- d. Procedure. If possible, remove the grid from the system. Open the collimators and expose the entire area of the detector at 10 kVp with 1.0 mm Cu filter at the tube head. Set a mAs and FDD to deliver a dose of order 1 uGy (as determined in test 1 – Dosimetry). Record the detector dose indicator value. Repeat for doses of order 4 uGy, 12 uGy, and 50 uGy. Record a pixel value from the center of each image from the acquisition workstation. If ROI analysis is not available at the acquisition workstation the images should be transferred to the reporting workstation to perform this task. Plot a graph of pixel value versus receptor dose using a graph plotting package (e.g. Microsoft Excel). A zero dose point can be obtained using the result of test 2 – Dark Noise. Obtain the equation of the trend line for this graph. This equation is the STP equation and is used for making corrections in tests 4 and 6. An equation of the form $\text{dose} = f(\text{pixel value})$ where f is some arbitrary function, is required.
- e. Interpretation of Results. Establishes relationship between receptor dose and pixel value, and establish exposure index varies linearly with the increasing exposure. Consult with qualified service engineer for relationships outside of tolerance.

4. Image Retention.

- a. Purpose. To test that any detectable residual signal (ghosting) that remains in subsequent images is minimal.
- b. Regulations. If no evidence of ghosting is found from visual inspection of the images then the test is passed and there is no need to perform ROI analysis. There should be $<5\%$ (remedial) difference between the STP corrected pixel values in the ghosted region and the surrounding areas.

- c. Equipment. Attenuating material – either copper or lead 5 x 5 cm.
- d. Procedure. Ensure the grid is removed from the system if possible and there is no attenuation in the beam. Set the FDD to be approximately 180 cm. Close the collimators and cover the detector with a lead apron. Set a low exposure (e.g. 50 kVp and 0.5 mAs). Open the collimators and place the attenuating material (Cu or Pb 5 x 5 cm) on the detector such that it covers part of the field. Make an exposure at 70 kVp and mAs to deliver a receptor dose of order 4 uGy. Obtain another blank image as described above. This exposure should be made 1 minute after the previous one. Set a very narrow window and adjust the level. Visually inspect the image for any remnant of the previous image. If a remnant is visible, use ROI analysis to quantify the difference in pixel value between the ghosted and unghosted areas. See Figure 16-2. If ROI analysis is not available the image should be transferred to a reporting workstation. The ROI values should be used to calculate indicated receptor doses using the STP equation established in test 3 – Linearity, STP, and Dark Noise.

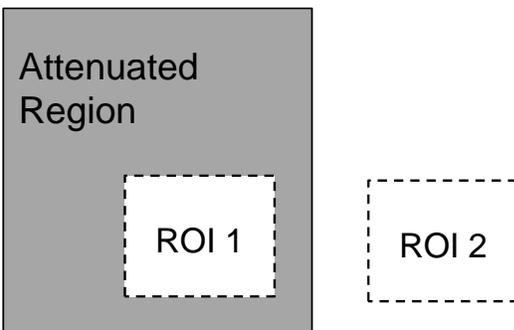


Figure 16-2.

- e. Interpretation of Results. If evidence of ghosting present, consult with qualified service engineer.

5. Detector Dose Indicator Consistency

NOTE: This test can only be performed if the unit has a form of detector dose indicator.

- a. Purpose. To assess the variation of sensitivity between exposures, and set a baseline for

monitoring system sensitivity for future QA testing.

- b. Regulations. The measurements should be used to set a baseline for future QA tests. The indicated sensitivity indices should not differ by greater than 20% of equivalent exposure, between exposures.
- c. Equipment. 1.0 mm Cu filter
- d. Procedure. If possible, remove the grid from the system. Set a field size to cover the entire detector and a FDD as for test 1 – Dosimetry. Expose the detector to a known dose of 10 uGy at 70 kVp with 1.0 mm Cu at the tube head. Set a mAs as established from test 1 – Dosimetry. Record the organ program, LUT name and detector dose indicator, without changing the window and leveling. Repeat at least 3 times. Also repeat for 1 uGy and 12 uGy (1 image for each).
- e. Interpretation of Results. If indices differ by greater than 20% of baseline, consult with qualified service engineer.

6. Uniformity

- a. Purpose. To assess the uniformity of the recorded signal from a uniformly exposed detector. A non-uniform response could affect clinical image quality.
- b. Regulations. The images should not have obvious artifacts. The ratio of the standard deviation of the 5 STP corrected ROI values to their mean (the coefficient of variation) should be less than 10%.
- c. Equipment. None
- d. Procedure. Visually inspect all images obtained in test 5 – Detector Dose Indicator Consistency for uniformity and artifacts. The uniformity of one of images should be assessed using ROI analysis if available; to measure the mean and standard deviation of the pixel values in position a-e, as indicated in Figure 16-3 (i.e. the center of the image and the center of the four quadrants). For detectors that are tiled detectors an ROI should be drawn at the centre of all tiles. The ROIs should be of order 10000 pixels. If ROI analysis is not available at the acquisition workstation then images should be transferred

to a reporting workstation. If uniformity is poor in the direction of the anode cathode axis this is likely to be a result of the anode heel affect. To confirm this, the test should be repeated with the tube rotated through 90°. The five values obtained from ROI analysis should be used to calculate five indicated receptor dose values using the STP equation obtained in test 4 – Image Retention.

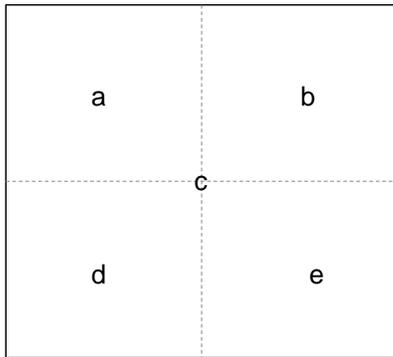


Figure 16-3.

- e. Interpretation of Results. If ratio of corrected values to mean is greater than 10%, consult with qualified service engineer.

7. Scaling Errors

- a. Purpose. To assess the accuracy of software distance indicators and check for distortion.
- b. Regulations. See in Figure 16-4 that measured distances x and y should agree within 3% of the actual distances at the center or 5% at the corners. All calculated aspect ratios should be within 1.00 +/- 0.03 at the center or 5% at the corners.

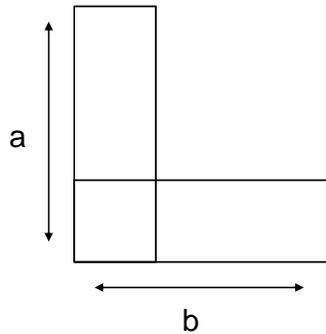


Figure 16-4.

- c. Equipment. M1 test object

- d. Procedure. Ensure the grid is removed from the system, if possible. Position the M1 test object directly onto the detector with an FDD of 150 cm. Expose the detector at 50-60 kV with no attenuation in the beam and 10 mAs. Using the distance measuring software tools measure the dimensions (x and y) of five central squares in both the horizontal and vertical directions. Calculate the aspect ratio x/y. Select any corner of the image and measure the horizontal (a) and vertical (b) sizes of two squares as indicated in Figure 4. Calculate the aspect ratio a/b. Repeat this for one other corner. If possible download the image as a DICOM file. Open the image using a DICOM viewer such as Santeviewer. Hold the cursor over a corner of a square in the grid. Record the position within the image (i.e. the x and y coordinates). Move the cursor to the corner of the square of the grid 10cm from the first corner in the x direction. Record the coordinates again. Calculate the pixel pitch, $p(\text{mm})=100/n$ where n =number of pixels covering 10cm of the grid. Repeat for the y direction. This test is only necessary for commissioning. Compare the pixel pitch to that stated by the manufacturer. The difference should be no greater than the estimated measurement error.

- e. Interpretation of Results. If distances measure outside of tolerances, consult with qualified service engineer.

8. Blurring and Stitching Artifacts

- a. Purpose. To test for any localized distortion or blurring and to highlight any stitching artifacts if the system is formed from more than one detector element.
- b. Regulations. No blurring should be present. If stitching artifacts are present there should be no loss of information.
- c. Equipment. Contact mesh MS4 or MS5 test object
- d. Procedure. The test should be made with the grid both in and out of the detector. Ensure there is no attenuation in the beam and that the FDD is set as large as possible. With a contact mesh on the detector, make an exposure at 50-60 kVp and 10 mAs using fine focus. An MS4 or MS5 test object is appropriate. Visually inspect the image for

blurring and stitching artifacts. Repeat with a finer mesh if available.

- e. Interpretation of Results. If blurring or stitching artifacts with loss of information are present consult with qualified service engineer.

9. Limiting Spatial Resolution

- a. Purpose. To test the high contrast limit of the system's ability to resolve details.
- b. Regulations. These measurements should be used to set a baseline for future QA tests. Print or save the images for future reference, if possible. Future annual QA testing should be +/- 20% of baseline.
- c. Equipment. Resolution test object
- d. Procedure. Ensure the grid is removed from the system, there is no attenuation in the beam and the FDD is set as large as possible. Place the resolution test object onto the detector aligned at 45° to its edges. Set 50-60 kV and expose the cassette using 10 mAs on fine focus. Adjust the window level and magnification to optimize the resolution. Score the number of resolvable groups of lines from the screen. The image should be scored at a magnification of order x 5. If this facility is not available on the review workstation then images should be transferred to the reporting workstation for scoring. Look up the corresponding resolution. Repeat the measurement twice with the resolution test object placed at a slight angle to the lateral or longitudinal axis. If the system has more than one detector element, measurements at 45° should be made for each element.
- e. Interpretation of Results. Compare acceptance test to future QA test results. Significant divergences in limiting spatial resolution (outside of 20% of baseline) require consultation with qualified service engineer.

10. Threshold Contrast Detail Detectability

- a. Purpose. To monitor image quality by assessing the visibility of low contrast details.
- b. Regulations. The results of this test are used to set a baseline for future QA tests. Results

could be compared to those from other similar systems if available. Print or save the images for future reference, if possible. Future annual QA testing should be performed only at 4 uGy and be +/- 30% of baseline.

- c. Equipment. 1.0 mm Cu filtration
- d. Procedure. Ensure the grid is removed from the system, if possible. With the tube, detector, and 1.0 mmCu filtration in the same positions as for test 5 – Detector Dose Indicator Consistency. Place the TO20 (or equivalent) test object on the detector. Collimate down to the size of the test object. Set 70 kVp and the appropriate mAs to deliver ~4 µGy. Ascertain whether clinical images are most commonly viewed soft or hard copy. If images are viewed softcopy, score them on a reporting workstation optimizing window and level settings for each detail size. If they view hardcopy, adjust the window to optimize the visibility of the details, ensuring that background noise is perceptible, and print the image out on the largest film size. View the image on a masked light box. Calculate an image quality factor, IQF,

$$IQF = \frac{1}{n} \sum_{i=1}^n \frac{H_T(A_i)}{H_T^{ref}(A_i)} \left[\frac{D_{ref}}{D} \right]^{0.5}$$

where:

$H_T(A)$ = threshold contrast detail index values calculated from the image,
 $H_T^{ref}(A)$ = threshold contrast detail index values calculated from a reference image of a system known to be in good adjustment,
 D = the dose to the image plate,
 D_{ref} = the dose to the image plate for the reference image
 n = the number of details in the test object.

Repeat this test for exposures of ~1 µGy and ~12 µGy.

- e. Interpretation of Results. Compare acceptance test to future QA test results. Significant divergences (outside of 30% baseline) in image quality require consultation with qualified service engineer.

Table 16-1.—Direct Digital Radiography Systems Survey Requirements.

Test	Frequency	Measurements	Tolerance
1. Dosimetry	A/P	Set FDD at 150 cm and chamber 30 cm from detector. Collimate to chamber, expose at 70 kVp using 1.0 mm Cu to 10 uGy. Repeat twice. Determine mAs required to deliver 1 uGy, 4 uGy, 12 uGy, and 50 uGy.	Measured dose required for later tests 3, 4, 5, 6, 10.
2. Dark Noise	A/P	Close collimator, cover detector with lead apron. Expose at 50 kVp and 0.5 mAs, record detector dose indicator value and pixel value.	Used as baseline for future QA tests. On future annual tests, the tolerance should be +/- 50% exposure equivalent.
3. Linearity, System Transfer Properties, and Dark Noise	A	Open collimators and expose entire area of the detector at 10 kVp with 1.0 mm Cu filter at the tube head. Set a mAs and FDD to deliver a dose of 1 uGy (as determined in test 1 – Dosimetry). Record detector dose indicator value. Repeat for doses of 4 uGy, 12 uGy, and 50 uGy. Record pixel value from the center of each image from the acquisition workstation or reporting workstation. Plot a graph of pixel value versus receptor dose (e.g. with Microsoft Excel). A zero dose point can be obtained using the result of test 2 – Dark Noise. Obtain equation of the trend line for this graph.	The trend-line plotted in Excel should have an R^2 fit value > 0.95. There is no tolerance for the STP equation; however the pixel value to dose relationship should be a simple relationship (e.g. log, linear, or square root). There is also no tolerance for the dark noise image; however the data may be useful as a baseline when rechecking the dark noise in the event of other image quality problems.
4. Image Retention	A	Set the FDD to 180 cm. Close collimators and cover the detector with a lead apron. Set a low exposure (e.g. 50 kVp and 0.5 mAs). Open collimators and place the attenuating material (Cu or Pb 5 x 5 cm) on the detector such that it covers part of the field. Make an exposure at 70 kVp and mAs to deliver a receptor dose of 4 uGy. Obtain another blank image as described above. This exposure should be made 1 minute after the previous one. Set very narrow window and adjust the level. Visually inspect the image for any remnant of the previous image. If a remnant is visible, use ROI analysis to quantify the difference in pixel value between the ghosted and unghosted areas. See Fig 2. The ROI values should be used to calculate indicated receptor doses using the STP equation established in test 3 – Linearity, STP, and Dark Noise.	If no evidence of ghosting is found from visual inspection of the images then the test is passed and there is no need to perform ROI analysis. There should be <5% (remedial) difference between the STP corrected pixel values in the ghosted region and the surrounding areas.

Table 16-1.—Direct Digital Radiography Systems Survey Requirements (continued).

Test	Frequency	Measurements	Tolerance
5. Detector Dose Indicator Consistency	A/P	Set a field size to cover the entire detector and a FDD as for test 1 – Dosimetry. Expose the detector to a known dose of 10 uGy at 70 kVp with 1.0 mm Cu at the tube head. Set a mAs as established from test 1 – Dosimetry. Record the organ program, LUT name and detector dose indicator, without changing the window and leveling. Repeat at least 3 times. Also repeat for 1 uGy and 12 uGy (1 image for each).	The measurements should be used to set a baseline for future QA tests. The indicated sensitivity indices should not differ by greater than 20% of equivalent exposure, between exposures.
6. Uniformity	A/P	Visually inspect all images obtained in test 5 – Detector Dose Indicator Consistency for uniformity and artifacts. The uniformity of one of images should be assessed using ROI analysis if available; to measure the mean and standard deviation of the pixel values in position a-e, as indicated in figure 3 (i.e. the center of the image and the center of the four quadrants). For detectors that are tiled detectors an ROI should be drawn at the centre of all tiles. The ROIs should be of order 10000 pixels. If ROI analysis is not available at the acquisition workstation then images should be transferred to a reporting workstation. If uniformity is poor in the direction of the anode cathode axis this is likely to be a result of the anode heel affect. To confirm this, the test should be repeated with the tube rotated through 90°. The five values obtained from ROI analysis should be used to calculate five indicated receptor dose values using the STP equation obtained in test 4 – Image Retention.	The images should not have obvious artifacts. The ratio of the standard deviation of the 5 STP corrected ROI values to their mean (the coefficient of variation) should be less than 10%.

Table 16-1.—Direct Digital Radiography Systems Survey Requirements (continued).

Test	Frequency	Measurements	Tolerance
7. Scaling Errors	A	Position the M1 test object directly onto detector with FDD of 150 cm. Expose the detector at 50-60 kV with no attenuation in the beam and 10 mAs. Using distance measuring software tools measure the dimensions (x and y) of five central squares in both the horizontal and vertical directions. Calculate the aspect ratio x/y. Select any corner of the image and measure the horizontal (a) and vertical (b) sizes of two squares as indicated in Figure 4. Calculate the aspect ratio a/b. Repeat this for one other corner. If possible download the image as a DICOM file. Open image using a DICOM viewer such as Santeviewer. Hold the cursor	(See Figure 4: Scaling Errors Test) The measured distances x and y should agree within 3% of the actual distances at the center or 5% at the corners. All calculated aspect ratios should be within 1.00 +/- 0.03 at the center or 5% at the corners.
7. Scaling Errors (continued)	A	over a corner of a square in the grid. Record the position within the image (i.e. x and y coordinates). Move cursor to the corner of the square of the grid 10cm from the first corner in the x direction. Record the coordinates again. Calculate the pixel pitch, $p(\text{mm})=100/n$ where n=number of pixels covering 10cm of the grid. Repeat for the y direction. This test is only necessary for commissioning. Compare the pixel pitch to that stated by the manufacturer. The difference should be no greater than the estimated measurement error.	
8. Blurring and Stitching Artifacts	A/P	The test should be made with the grid both in and out of the detector. Ensure there is no attenuation in the beam and that FDD is set as large as possible. With a contact mesh on the detector, make an exposure at 50-60 kVp and 10 mAs using fine focus. An MS4 or MS5 test object is appropriate. Visually inspect the image for blurring and stitching artifacts. Repeat with a finer mesh if available.	No blurring should be present. If stitching artifacts are present there should be no loss of information.

Table 16-1.—Direct Digital Radiography Systems Survey Requirements (continued).

Test	Frequency	Measurements	Tolerance
9. Limiting Spatial Resolution	A/P	<p>Ensure the grid is removed from the system, there is no attenuation in the beam and the FDD is set as large as possible. Place the resolution test object onto the detector aligned at 45° to its edges. Set 50-60 kV and expose the cassette using 10 mAs on fine focus. Adjust the window level and magnification to optimize the resolution. Score the number of resolvable groups of lines from the screen. The image should be scored at a magnification of order x 5. If this facility is not available on the review workstation then images should be transferred to the reporting workstation for scoring. Look up the corresponding resolution. Repeat the measurement twice with the resolution test object placed at a slight angle to the lateral or longitudinal axis. If the system has more than one detector element, measurements at 45° should be made for each element.</p>	<p>These measurements should be used to set a baseline for future QA tests. Print or save the images for future reference, if possible. Future annual QA testing should be +/- 20% of baseline.</p>
10. Threshold Contrast Detail Detectability	A/P	<p>Ensure the grid is removed from the system, if possible. With the tube, detector, and 1.0 mmCu filtration in the same positions as for test 5 – Detector Dose Indicator Consistency. Place the TO20 (or equivalent) test object on the detector. Collimate down to the size of the test object. Set 70 kVp and the appropriate mAs to deliver ~4 µGy. Ascertain whether clinical images are most commonly viewed soft or hard copy. If images are viewed softcopy, score them on a reporting workstation optimizing window and level settings for each detail size. If they view hardcopy, adjust the window to optimize the visibility of the details, ensuring that background noise is perceptible, and print the image out on the largest film size. View the image on a masked light box. Calculate an image quality factor, IQF,</p> $IQF = \frac{1}{n} \sum_{i=1}^n \frac{H_T(A_i)}{H_T^{ref}(A_i)} \left[\frac{D_{ref}}{D} \right]^{0.5}$ <p>where: $H_T(A)$ = threshold contrast detail</p>	<p>The results of this test are used to set a baseline for future QA tests. Results could be compared to those from other similar systems if available. Print or save the images for future reference, if possible. Future annual QA testing should be performed only at 4 uGy and be +/- 30% of baseline.</p>

Table 16-1.—Direct Digital Radiography Systems Survey Requirements (continued).

Test	Frequency	Measurements	Tolerance
		<p>index values calculated from the image, $H_T^{ref}(A)$ = threshold contrast detail index values calculated from a reference image of a system known to be in good adjustment, D = the dose to the image plate, D_{ref} = the dose to the image plate for the reference image n = the number of details in the test object.</p> <p>Repeat this test for exposures of ~1 μGy and ~12 μGy.</p>	

Abbreviations: A: acceptance; P: periodic/annual; ROI: Region Of Interest; FDD: Focus to Detector Distance; STP: System Transfer Properties; μ Gy: micro-gray

Direct Digital Radiography System Survey

NMCPHC TM 6470.1
JUNE 2013

Facility:		Date:
Room Number/Location:		ECN:
Manufacturer:		
Model Number:	Tube Serial Number:	

Test Performed	Pass	Fail	N/A	Comments (failure comments must annotate minor or significant finding)
Uniformity				
System Resolution				
Energy Resolution				
Multi-Energy Resolution				
Pixel Size				
Count Rate				
System Sensitivity				
System Linearity				
Center of Rotation SPECT Only				
Slice Uniformity SPECT Only				
Slice Thickness SPECT Only				
In Plane Resolution SPECT Only				
Image Contrast SPECT Only				

Additional Comments:

Purpose:	Results:
Surveyor Name:	
Surveyor Signature:	

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Chapter 17

Computed Radiography (CR) Systems

A. Introduction

CR is a marketing term for photostimulable phosphor detector systems. CR utilizes a phosphor plate based vice screen/film combination to retain and ultimately generate a diagnostic image. The technology uses conventional radiographic acquisition geometry to deposit x-ray energy in a photostimulable phosphor screen with delayed luminescence properties. Stored x-ray energy is released via photostimulable emission of the imaging plate as it is scanned by a laser beam located within the reading unit. Phosphorescent light with intensity proportional to the absorbed x-ray energy is emitted as the trapped electrons transition back to the valence band. The emitted light is captured, amplified within a Photomultiplier Tube (PMT) and then converted into a digital format for manipulation. The digital data may be converted into analog format for viewing on a CRT laser/thermal film or flat panel monitor.

It is highly recommended upon acceptance, that the field service engineer for the given product be on site for administrative access and training on use of the system.

The testing protocols covered in this manual may not be the only way to test the equipment and may require adjustment from time to time. Three vendors (Kodak, Fuji, and Agfa) are covered in this chapter. Other manufacturers may have more or fewer requirements for testing their systems.

The imaging chain consists of both the CR device (and plates) and the radiographic system used. The radiographic room used for the testing must have passed all of its physics testing sometime within the prior twelve months.

For acceptance testing use all guidelines of Reference 1 listed below, or the most up to date report from the AAPM.

B. Minimum Required Personnel Qualifications

Basic Diagnostic Imaging Equipment

C. Testing Periodicity

All reading units and each plate used in clinical applications: Annually, upon acceptance and applicable portions after major repairs (i.e. replacement of laser).

D. Equipment

1. X-ray system which passed all testing within last 12 months
2. Calibrated ion chamber with a test stand
3. 0.1 - 0.01 mm Pb line pair phantom
4. Low contrast digital phantom, 14 x 17 inch screen-film contact test tool
5. Metal ruler (straight metal edge)
6. Copper/aluminum filters per manufacturer's recommendation
7. Variable thickness Lucite step wedge
8. Lead block or sheet
9. Measuring tape
10. Stopwatch
11. Computed Radiography System Survey

E. References

- 1 AAPM TG Report 93: Acceptance Testing and Quality Control of Photostimulable Storage Phosphor Imaging Systems. October 2006

F. General Requirements for Computed Radiographic Equipment

1. Phosphor Plate Throughput

- a. Purpose. To verify the manufacturer's plate throughput.
- b. Regulations. The throughput should be within 10% of the manufacturer's stated rate.
- c. Equipment. Watch with a second sweep hand (stopwatch).
- d. Procedure. If needed, pre-identify the plates. Choose a processing type appropriate for the plate size / type. Start the time when the first plate is placed either in the buffer (multi-plate system) or into the single reader slot. Run at least ten plates (max available if this is not possible) or four plates each exposed to ~ 2 mR. Stop the time when the image is displayed on the vendor processing station and extrapolate to an hourly rate. Repeat this for all plate sizes and types.
- e. Interpretation of Results. If the measured rate does not meet the vendor's specifications, consult with a qualified service engineer and the local networking staff. Some vendors' specifications are network dependent.

2. Phosphor Plate Uniformity (Reproducibility)

- a. Purpose. To verify that the plates respond in a uniform manner and that all respond in a similar manner as a group. To verify that artifacts will not obscure the clinical image.
- b. Regulations. The pixel values should be within 10% of the average pixel value for all of the plates. The standard deviation of each average pixel value amongst all plates should be less than 25 for Agfa, less than 20 for Fuji and Kodak. The standard deviation of the exposure indicator values (IgM-Agfa, Sensitivity-Fuji, EI-Kodak) should be less than 0.02 for Agfa, less than 5% for Fuji (standard deviation / mean sensitivity) and less than 20 for Kodak. The images should also be artifact free.
- c. Equipment. 180 cc ion chamber, 1.5 mm Copper filter (Agfa)

- d. Procedure. Pre-expose the ion chamber free in air to approximately 5 - 10 mR at 72" SID using 80 kVp with 0.5 mm Cu and 1.0 mm Al filtration. Expose the full plate in the same fashion. If unable to obtain 72" SID, expose the plate to half the value necessary for the exposure and rotate the plate in between exposures. All plates / cassettes should be tested. Process the plate with the vendor recommended algorithm (system diagnosis / flat field / 200 speed-Agfa, Test / sensitivity, Semi EDR- Fuji, Pattern-Kodak). Take global ROIs of each image and record the average pixel values and standard deviation. Record the proprietary exposure indicator values for each image.
- e. Interpretation of Results. If artifacts appear on the image, clean the plate with the appropriate cleaner. If the artifact is still visible after re-exposure, consider taking the plate out of service (the technologists should also be making this decision between annual evaluations). If the pixel values are not appropriate, consider taking the "guilty plate / plates" out of service. Plates should be replaceable to the activity at no cost.

3. Exposure Indicator

- a. Purpose. To verify that system is calibrated in the manner intended by the manufacturer.
- b. Regulations. The values should be within 2% of the manufacturer's programmed value. The values must be within 10% of manufacturer's programmed value (Agfa IgM = $2.2 < \pm 0.045$; Fuji S = $200 < \pm 20$; Kodak EI = $2000 < \pm 45$).
- c. Equipment. Same as for previous test.
- d. Procedure. Expose three plates of each size to approximately 1 mR at 72" SID with the appropriate vendor energy, filter as per Table 17-1. Process the plate with the appropriate vendor algorithm (Fuji test / sens (L = 1) semi-EDR; Agfa-previous; Kodak-pattern).
- e. Interpretation of Results. If values are outside of the 2% range, pay closer attention to this throughout the year. If they fall outside of 10%, consult the vendor for proper calibration. This value is crucial in daily use by the technologist in monitoring dose and determining the need for repeat images.

4. Linearity

- a. Purpose. To verify that the calibration is linear.
- b. Regulations. Noise should decrease with increased exposure. Proprietary values and average pixel values versus Log (exposure) should have linearity coefficients greater than 95%. See Table 17.1 for vendor specific values.
- c. Equipment. Same as in previous test.
- d. Procedure. Pre-expose the ion chamber free in air to 0.1, 1 and 5 or 10 mR at 72" SID to a beam with 80 kVp in the same fashion as in the previous test. Expose the same plate nine times (three using each exposure level) in the same fashion. Process per previous test - Agfa (Fuji- Test / ave 4.0 Semi-EDR). Place ROIs on the images to get pixel values; technologists should also be making this decision in between annual evaluations. Plot the average pixel value of the three, and the proprietary indicators versus Log of the exposure in Roentgens.
- e. Interpretation of Results. Consult the field service engineer if values vary greater than expected.

5. Laser Beam Evaluation

- a. Purpose. To ensure that the CR reader unit laser is sampling all plate data points and is not skipping data lines.
- b. Regulations. There should be no signal drop out and no more than occasional jitters.
- c. Equipment. Metal coated or steel straight edged ruler and 180 cc ion chamber
- d. Procedures. Pre-expose an ion chamber free in air at 72" SID to a beam with 80 kVp, no added filtration and enough mAs to deliver 5 mR. Expose a single cassette in the same fashion with the ruler centered perpendicularly to the scan lines (scan lines are in direction of plate opening) at a slight angle. Process with vendor specific algorithm as in previous test-Agfa (Fuji-test / sens semi-EDR). View the image using the magnifying glass tool.

- e. Interpretation of Results: If significant jitter is seen, consult with the qualified service engineer.

6. Spatial Resolution

- a. Purpose. To ensure that the system meets the manufacturer's stated sampling rate (expected resolution of Nyquist limit).
- b. Regulations. The resolution must be within 10% of the manufacturer's expected resolution.
- c. Equipment. Line pair resolution pattern (0.01 - 0.1 mm Pb) and 180 cc ion chamber
- d. Procedure. Pre-expose an ion chamber free in air at 72" SID to a beam using 60 kVp, no added filtration and enough mAs for 5 mR. Expose a cassette of each size in the same fashion. If multiple test patterns are available, you may expose each size once. If not, the pattern must be exposed two times each (center x (y-acceptance), periphery x). Collimation is necessary to avoid wash out, but too much collimation may cause the software to misjudge auto collimation. It may also misjudge if multiple patterns are on a small cassette. Process the plates with an appropriate algorithm for the plate size (as in the throughput test). View the image with the magnification tool (10 X on narrow window) on a 2 K workstation (if not available at the site, consider printing on film, or viewing on a 1 K workstation).
- e. Interpretation of Results. If the resolution is below the expected value, first ensure that the resolution for the radiographic tube is adequate and then consult with a qualified service engineer. The laser may need to be replaced.

7. Low Contrast Resolution

- a. Purpose. To ensure that contrast detail is satisfactory.
- b. Regulations. The low contrast sensitivity should be comparable to that of film / screen systems. The low contrast sensitivity should also be similar to that seen in the previous annual evaluation.

- c. Equipment. Low contrast test pattern and 180 cc ion chamber.
- d. Procedure. Pre-expose an ion chamber in a tabletop 40" SID free in air mode using 75 kVp, 1.5 mm added copper filtration, and enough mAs for 0.1, 1 and 5(Agfa) 10(Fuji) mR respectively. Expose three cassettes in the same manner with the test tool on top of each cassette. Process the image using a general low contrast algorithm (Agfa-flat field, 200 speed Fuji-test / sensitivity, semi-EDR, Kodak-pattern). View using window and level as appropriate on a 2K/printer/1K workstation (depending on availability).
- e. Interpretation of Results. Consult with the qualified service engineer if low contrast resolution is noticeably degraded. Consider using a DSA step wedge phantom to compensate for anode-heel effect.

8. Erasure Thoroughness

- a. Purpose. To ensure that vestiges of previous images do not appear in the current image.
- b. Regulations. Ghost images of prior exposures should not appear in a current image.
- c. Equipment. High contrast tool (Pb or line pair phantom)
- d. Procedure. Expose a plate at 72" SID to an 80 kVp beam with a high incident exposure and

the test tool in the image center (i.e. apply collimation). Process the plate with an appropriate algorithm for the plate size. Re-expose at a very low exposure without the test tool and using slightly smaller collimation. View on the image processing station.

- e. Interpretation of Results. Consult a qualified service engineer if a residual image is seen,.

9. Phosphor Plate Dark Noise

- a. Purpose. To ensure that electronic artifacts do not exist.
- b. Regulations. There should be no visible artifacts. (Agfa- $IgM < 0.28$ / $SAL < 130$, average pixel value < 350 and stand dev < 5 , Fuji- Average pixel value < 280 , stand dev < 4 , Kodak EI < 80 , stand dev < 4).
- c. Equipment. None
- d. Procedure. Process three newly erased plates per the manufacturer's specified algorithms (Agfa-system diagnosis / flat field / speed 200, Fuji-Test / sensitivity (L = 1), fixed EDR (S = 10,000)). Perform ROIs on the resulting images. Record average pixel values, standard deviation and proprietary values.
- e. Interpretation of Results. Consult with the qualified service engineer if values are not below the specified limit or artifacts are seen.

Table 17-1.—Computed Radiography Systems Survey Requirements.

Test	Frequency	Measurements	Tolerance
1. Phosphor Cassette Throughput	A/P	If possible, at least ten of each cassette size, or four of each size exposed to ~ 2 mR then extrapolate to hourly rate	Should be within $\pm 10\%$ of manufacturer's spec.
2. Phosphor Plate Uniformity (Reproducibility)	A/P	Expose each plate to 10 mR at 80 kVp with 0.5 mm Cu and 1 mm Al filtration and 72" SID. Gather pixel data with global ROIs and vendor specific values	Agfa PVSD < 25, Fuji and Kodak PVSD < 20 or all PVs within 10%, other values vendor specific, all plates should be artifact free
3. Exposure Indicator	A/P	Expose three plates of each size to 1 mR at 72" SID, gather pixel data with global ROIs and vendor specific values (Agfa: 75 kVp, 1.5 mm Cu, no delay; Fuji: 80 kVp no filter, 10 minute delay; Kodak: 80 kVp, 0.5 mm Cu + 1 mm Al, 15 minute delay)	Exposure Indicator should be within $\pm 2\%$ of manufacturer's programmed, absolutely must be within 10% (Agfa IgM = 2.2 < +/- 0.045, Fuji S = 200 < +/- 20, Kodak EI = 2000 < +/- 45)
4. Linearity	A/P	Expose the same plate three times each to 0.1 mR, 1 mR and 5-10 mR(if can get to 10 with an exposure indicator) with 80 kVp beam; gather pixel data with ROIs and vendor specific values; plot the vendor specific values and pixel values versus lg (exposure)	Noise should decrease with exposure, the linearity coefficients and slope values are vendor specific; all plots should result in a straight line (Agfa-Slope _{IgM} - 1 < +/- 0.1, Fuji-Slope _S +1 < +/- 0.1 or Slope _{PV} /256 - 1 < +/- 0.1, Kodak-Slope _{EI} /1000 - 1 < +/- 0.1 or Slope _{PV} /1000 - 1 < +/- 0.1)
5. Laser Beam Evaluation	A/P	Expose a plate to 5 mR with ruler centered on cassette and perpendicular to the scan lines (slight angle)	There should be no signal drop out or no more than an occasional \pm jitter
6. Spatial Resolution	A/P	Expose a line pair phantom on each plate size to 5 mR using an unfiltered 60 kVp beam at 72" SID in the x and y directions and at 45°, for both center and periphery	The resolution must be within 10% of the manufacturer's stated ($R_{hor} / f_{Nyquist} > 0.9$, $R_{ver} / f_{Nyquist} > 0.9$, $R_{45^\circ} / (1.41 f_{Nyquist}) > 0.9$)
7. Low Contrast	A/P	Expose a low contrast phantom on a single plate to 0.1 mR, 1 mR and 5-10 mR	The low contrast should improve with increased exposure, it should be comparable to film/screen, if annual, should be similar to previous year's
8. Erasure Thoroughness	A/P	Expose a large cassette to 50 mR with high contrast object and process (72" SID, no filter). Re- expose processed plate to 1 mR without object and ~ 5 cm reduced collimation; reprocess one more time using "dark noise" settings for quantitative data	There should not be a ghost image in second image; Agfa PV < 630, PVSD < 5; Fuji PV < 280, PVSD < 4; Kodak PV < 80, PVSD < 4
9. Phosphor Plate Dark Noise	A/P	Take three recently processed (erased) plates and process per manufacturer's recommendations	The plates should not show any visible artifacts, ROI values vary by vendor

Abbreviations: A: acceptance, P: periodic, ROI: Region Of Interest, mR: milliroentgen

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Computed Radiography System Survey

NMCPHC TM 6470.1
JUNE 2013

Facility:		Date:
Room Number/Location:		ECN:
Manufacturer:		
Model Number:	Tube Serial Number:	

Test Performed	Pass	Fail	N/A	Comments (failure comments must annotate minor or significant finding)
Phosphor Cassette				
Phosphor Plate Uniformity				
Exposure Indicator				
Linearity				
Laser Beam Evaluation				
Spatial Resolution				
Wire Mesh Test				
Low Contrast				
Beam Central / Mechanical Spot Film Alignment				
Distance Accuracy and Aspect Ratio				
Erasure Thoroughness				
Phosphor Plate Dark Noise				
Additional Comments:				

Purpose:	Results:
Surveyor Name:	
Surveyor Signature:	

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