Designation: E2445/E2445M − 20

Standard Practice for Performance Evaluation and Long-Term Stability of Computed Radiography Systems[1]

This standard is issued under the fixed designation E2445/E2445M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice describes the evaluation of Computed Radiography (CR) systems for industrial radiography. It is intended to ensure that the evaluation of image quality, as far as this is influenced by the CR system, meets the needs of users of this standard, and their customers, and enables process control and long-term stability of the CR system.

1.2 This practice specifies the fundamental parameters of CR systems to be measured to determine baseline performance, and to track the long term stability of the system. These tests are for applications up to 320 kV. When greater than 320 kV or when a gamma source is used, these tests may still be used to characterize a system, but may need to be modified as agreed between the user and cognizant engineering organization (CEO).

1.3 The CR system performance tests specified in this practice shall be completed upon acceptance of the system from the manufacturer and at intervals specified in this practice to monitor long term stability of the system. The intent of these tests is to monitor the system performance degradation and to identify when an action needs to be taken when the system degrades by a certain level.

1.4 The use of gauges provided in this standard is mandatory for each test. In the event these tests or gauges are not sufficient, the user, in coordination with the CEO shall develop additional or modified tests, test objects, gauges, or image quality indicators to evaluate the CR system. Acceptance levels for these ALTERNATE tests shall be determined by agreement between the user and CEO.

1.5 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system are not necessarily exact equivalents; therefore, to ensure conformance with the standard, each system shall be used independently of the other, and values from the two systems shall not be combined.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.7 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E746 Practice for Determining Relative Image Quality Response of Industrial Radiographic Imaging Systems
E1316 Terminology for Nondestructive Examinations
E1647 Practice for Determining Contrast Sensitivity in Radiology
E2002 Practice for Determining Total Image Unsharpness and Basic Spatial Resolution in Radiography and Radioscopy
E2007 Guide for Computed Radiography
E2033 Practice for Radiographic Examination Using Computed Radiography (Photostimulable Luminescence Method)
E2446 Practice for Manufacturing Characterization of Computed Radiography Systems

3. Terminology

3.1 *Definitions*—The definition of terms relating to gamma- and X-radiology, which appear in Terminology E1316, Guide E2007, and Practice E2033 shall apply to the terms used in this practice.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *aliasing, n*—artifacts that appear in an image when the spatial frequency of the input is higher than the output is capable of reproducing.

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[1] This practice is under the jurisdiction of ASTM Committee E07 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.01 on Radiology (X and Gamma) Method.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.2.1.1 *Discussion*—This will often appear as jagged or stepped sections in a line or as moiré patterns (see Fig. 1).

3.2.2 *banding, n*—linear striping aligned parallel to the IP transport direction, which may be caused by improper scanner normalization (see Fig. 2).

3.2.3 *computed radiography system (CR system), n*—a complete system of a storage phosphor imaging plate (IP) type, corresponding read out unit (scanner or reader) including pertinent equipment settings (for example, sampling resolution, laser power, photomultiplier tube (PMT) gain, etc.), image acquisition and processing software, and image display monitor.

3.2.4 *CR phantom, n*—a device containing an arrangement of test targets used to evaluate the image quality of a CR system, as well as monitoring the image quality of the chosen system.

3.2.5 *fading, n*—the reduction of intensity of the stored image in the imaging plate over time.

3.2.6 *gain, n*—overall signal amplification of the scanning system.

3.2.7 *laser beam jitter, n*—a lack of smooth movement of the laser scanning device, which results in jagged scan lines on the image (see Fig. 3).

3.2.8 *linear pixel value, n*—a numerical value of a picture element (pixel) of the digital image, which is proportional to the radiation dose.

3.2.8.1 *Discussion*—Example: for conversion of 12 bit log to 16 bit linear:

$$PV_{16\ bit\ linear} = 65535 \times 10^{\left(\frac{PV_{12\ bit\ log}}{1024} - 4\right)} \quad (1)$$

The linear pixel value is zero if the radiation dose is zero.

3.2.9 *long-term stability, n*—performance measurements of a CR system over the life-cycle of the devices, used to evaluate relative system performance over time.

3.2.10 *manufacturer, n*—CR system manufacturer, supplier for the user of the CR system.

3.2.11 *PMT, n*—photomultiplier tube or other light capture device used by the specific scanner.

3.2.12 *PMT non-linearity, n*—deviation from a linear response of the PMT at high light input values or from step changes in light.

3.2.12.1 *Discussion*—At high light input values, the PMT may under-respond; also the PMT may over-shoot or under-shoot in response to a step change in light (see Fig. 4).

3.2.13 *scan column dropout, n*—a zero PV linear image artifact created parallel to the transport direction when the path of the scanner's laser beam is prevented from reaching the imaging plate, often due to an internal obstruction (contaminates, for example) (see Fig. 5).

3.2.14 *scan line integrity (or line ripple), n*—fluctuation of line intensity appearing perpendicular to the IP transport direction.

3.2.15 *scanner normalization, n*—as used in this document, scanner normalization refers to a process performed to ensure a flat field image is produced when an imaging plate is exposed without an absorber.

3.2.15.1 *Discussion*—Scanner normalization procedures are dependent on the scanner model, and may or may not be able to be performed by the user.

3.2.16 *scanner slippage, n*—the slipping of an IP in a scanner transport system resulting in fluctuations of PV or distortion of geometric linearity, or both, appearing perpendicular to the IP transport direction (see Fig. 6).

3.2.17 *shading, n*—non-uniform pixel values perpendicular to the IP transport direction, which may also be caused by improper alignment of the light guide or photomultiplier tube assembly or improper scanner normalization.

3.2.18 *user, n*—the user and operating organization of the CR system.

3.2.19 *wait time, n*—time between end of exposure and beginning the scan of the imaging plate.

NOTE 1—Aliasing is more pronounced as lines pair spacing decreases.

FIG. 1 Example of Aliasing on a Line Pair Gauge Image

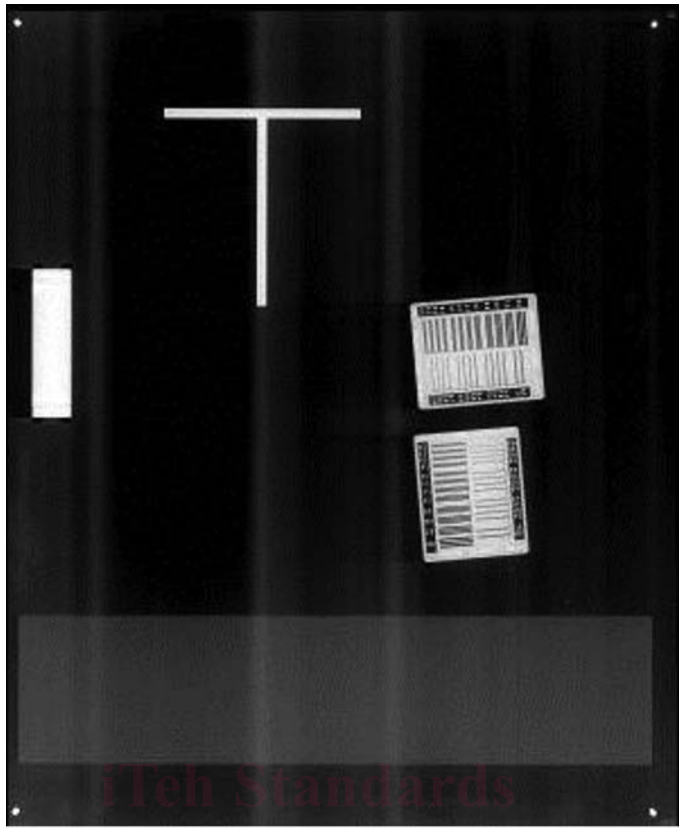

FIG. 2 Example of Banding (Parallel to IP Transport Direction) in a Computed Radiograph of a Prototype Test Phantom

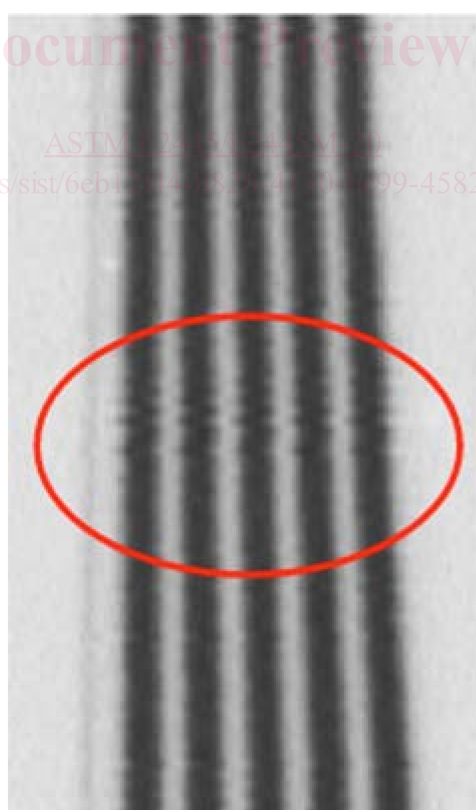

FIG. 3 Example of Laser Beam Jitter as Observed in a Computed Radiograph of a Converging Line Pair Gauge

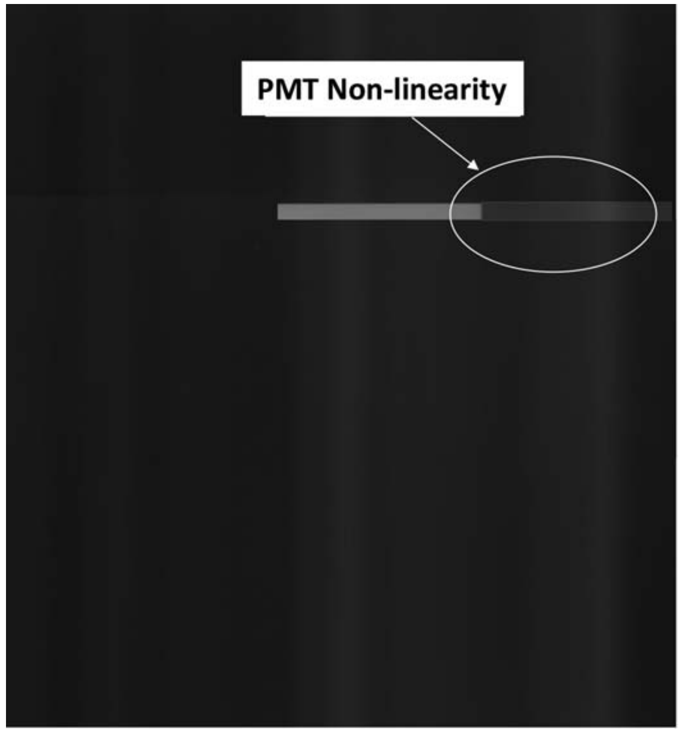

FIG. 4 Example of PMT Non-Linearity as Observed in a Computed Radiograph of a USAF Process Control Standard

FIG. 5 White Arrows Highlight a Simulated Example of Scan Column Dropout

4. Significance and Use

4.1 This practice is intended to be used by the NDT using organization to measure baseline performance of the CR system and to monitor its performance throughout its service as an NDT imaging system. For purposes of this document, the CR System is defined as:

4.1.1 Storage phosphor imaging plate (IP) type and manufacturer,

4.1.2 Read out unit (scanner or reader) manufacturer and model, including applicable scanner settings (for example, sampling resolution, PMT gain, pixel value (PV) look up table, etc.),

4.1.3 Image acquisition and processing software, and

4.1.4 Image display monitor.

4.2 It is to be understood that the CR system has already been selected and purchased by the user from a manufacturer based on the inspection needs at hand. The user shall accept the CR scanner based on manufacturer's results of Practice E2446 on the specific CR scanner as provided in a data sheet for that serialized CR scanner or other acceptance test agreed to between the user and manufacturer (not covered in this practice). This practice is not intended to be used as an

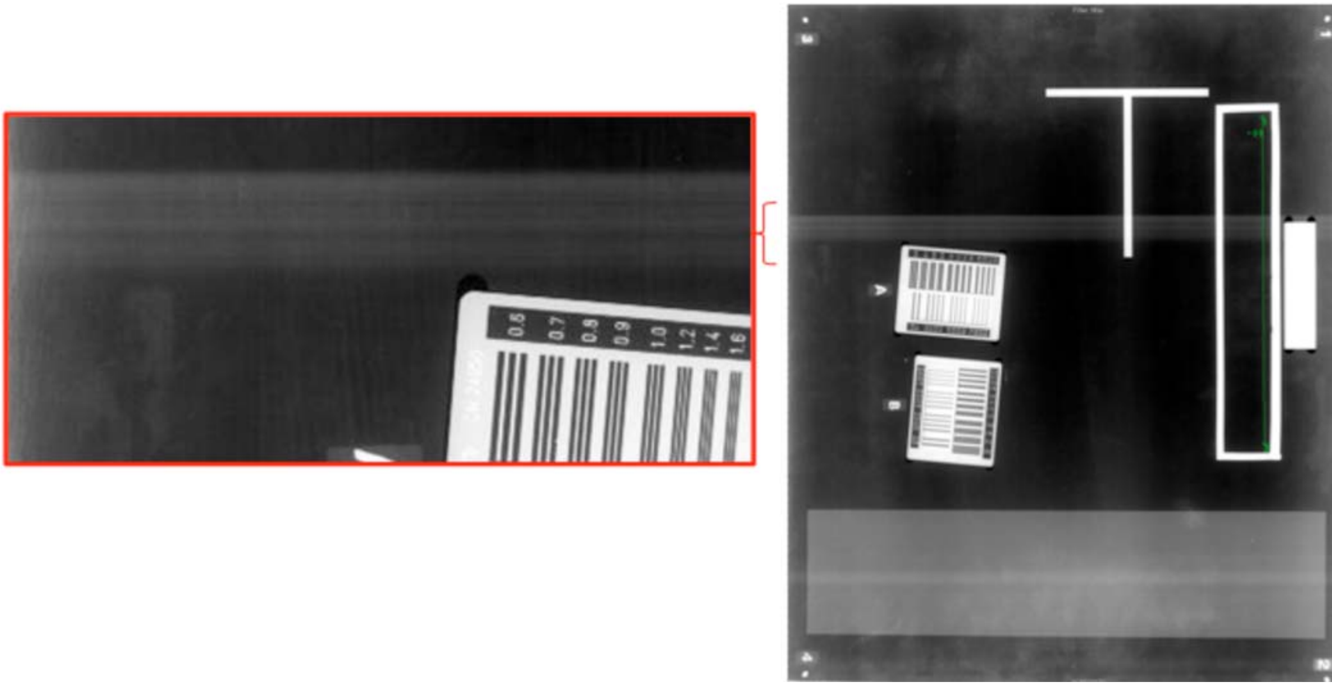

FIG. 6 Example of Scanner Slippage (Parallel to Laser Scan Direction) in a Computed Radiograph of a Prototype Process Control Standard

"acceptance test" of the CR system, but rather to establish a performance baseline that will enable tracking while in-service.

4.3 Although many of the properties listed in this standard have similar metrics to those found in Practice E2446, data collection methods are not identical, and comparisons among values acquired with each standard should not be made.

4.4 This practice defines the tests to be performed and required intervals. Also defined are the methods of tabulating results that CR users will complete following the baseline of the CR system. These tests will also be performed periodically at the stated required intervals to evaluate the CR system to determine if the system remains within acceptable operational limits as established in this practice.

4.5 There are several factors that affect the image quality of a CR image. Factors which are dependent on the CR system performance include basic spatial resolution, relative contrast, and signal-to-noise ratio (SNR) which yield the contrast sensitivity (CS) and Equivalent Penetrameter Sensitivity (EPS). There are several additional factors that are dependent on how well the CR system is functioning (that is, resulting from normal wear and tear, inadequate maintenance, improper setup/calibration, etc.), such as slippage, laser jitter, geometric distortion, etc. Other factors which are related to the specific applications (for example, geometric unsharpness, scatter, etc.) are not evaluated in these tests.

5. General Testing Procedures

5.1 The tests performed herein can be completed either by the use of the Type I CR Phantom (Appendix X1) for applications up to 320 kV, Type II CR Phantom (Appendix X2) for applications up to 160 kV, or individual test targets described in Section 7. When greater than 320 kV or when a gamma source is used, these tests may still be used to characterize a system, but may need to be modified as agreed by the user and CEO. The CR phantoms incorporate many of the basic image quality assessment test targets into a single test device, but some tests cannot be performed with both phantoms. See Table 1 to see which tests can be performed by each phantom.

5.2 To ensure consistent PVs for calculation of test results, the wait time between end of exposure and scanning of the imaging plate should be a consistent time of at least 5 min.

5.3 Tests are divided into two categories: *(1)* Core Image Quality Tests, and *(2)* Supplemental (optional) Tests.

5.3.1 Core Image Quality Tests shall be performed on each CR scanner. If more than one combination of CR system components and scanner settings are used in production, the user shall select one combination to be used for the Core Image Quality Tests.

5.3.2 Supplemental (optional) Tests may be performed at the discretion of the user and may provide useful information for some applications.

5.4 The technique shall be established for each test and documented. The technique information shall include, at a minimum where applicable:

5.4.1 Drawing sketch or photograph of the setups, showing the location and orientation of the phantom or test target with respect to the x-ray source, and imaging plate (IP),

5.4.2 Kilovoltage (kV),

5.4.3 Tube current (mA or microA),

5.4.4 Exposure time,

5.4.5 Wait time,

TABLE 1 System Performance Tests and Process Checks of the CR System

System Performance Test		Unit	Test Type		Test Target				Acceptance Criteria
Parameter			Baseline	Long-term Stability	Type I Phantom	Type II Phantom	Alternate Test Target Required	No Test Target Required	
Core Image Quality Tests									
Contrast Sensitivity	CS	%	x	x	x	x			2 % contrast step
Basic Spatial Resolution	SR_b	µm	x	x	x	x			± one wire/line pair from baseline
Geometric Distortion			x	x	x	x			< 2 % distortion
Laser Jitter			x	x	x	x			straight and continued edges
PMT Non-linearity			x	x	x	x			not be visible at typical window width settings
Laser Beam Scan Line Integrity			x	x	x	x			none visible
Scan Column Dropout			x	x	x	x			none visible
Scanner Slippage			x	x	x	x			< noise (Type I) < 2 % distortion (Type II)
Shading			x	x	x			x (Type II)	± 15 % or none visible[B]
Banding			x	x				x	± 15 % or none visible[B]
Erasure			x	x			see 8.3.1	x	≤ 2 % PV or none visible[B]
Equivalent Penetrameter Sensitivity[A]	EPS	%	x	x			see Appendix X3		± one hole set from baseline[C]
Signal-to-Noise Ratio[A]	SNR		x	x				x	SPC[D]
Supplemental Tests (optional)									
Burn-In			x	x			see 8.3.2		≤ 2 % PV or none visible[B]
Spatial Linearity			x	x	x				≤ 2 % distortion
Central Beam Alignment			x	x	x				regularly spaced spiral
Image Plate Artifacts			x	x				x	n/a
Image Plate Response Variation			x					x	< 10 % PV variation
Image Plate Fading			x					x	n/a

[A] Only EPS or SNR is required (not both).
[B] Acceptance criteria depends on evaluation method selected in Section 9.
[C] For the Practice E746 configuration, ± one hole set on a plaque IQI equates to approximately 15 % total variation.
[D] Statistical Process Control (SPC) is required to establish acceptance criteria limits and tolerances.

5.4.6 X-ray tube manufacturer, model, and focal spot size used (includes variable focal spot size settings),

5.4.7 Source to Detector Distance (SDD),

5.4.8 Source to Object Distance (SOD),

5.4.9 Geometric unsharpness (Ug),

5.4.10 Detector screens and filters and usage,

5.4.11 Imaging plate manufacturer and type/size,

5.4.12 Cassette type,

5.4.13 CR scanner settings (for example, gain setting, resolution setting, and other parameters if available), and

5.4.14 X-ray beam filtration (at tube), collimator, diaphragm and part masking.

6. Application of Baseline Performance Tests and Test Methods

6.1 *CR System Baseline Performance Tests:*

6.1.1 The user shall baseline the CR scanner along with the complete CR system (as defined in 4.1) by performing the Core Image Quality Tests listed in Table 1. Supplemental Tests may be used to baseline the system if desired. Additional tests beyond those defined in this practice are to be defined by the using organization in terms of specific tests to perform, how the data are presented, and the frequency of the testing. This approach does the following:

6.1.1.1 Provides a quantitative baseline of performance.

6.1.1.2 Provides results in a defined form that can be viewed by the CEO.

6.1.1.3 Offers a means to perform process checking of performance on a continuing basis.

6.1.2 Acceptance values, and tolerances thereof, obtained from these tests shall be established by this practice.

6.1.3 When the test produces a result outside the requirement tolerances, the CR scanner is not to be placed in service unless it is repaired, replaced, or some other change is instituted that will assure the image quality of the inspection as stated in the agreement between contracting parties. This assumes that the other elements of the CR system are within their tolerances including the X-ray source/generator, the imaging plates, the image acquisition and processing software, the image display monitor, and the inspection itself (for example, severe X-ray scatter in the inspection is controlled).

6.1.4 The results of the baseline performance test of the new CR system shall be documented as delineated in Table 2 and taken as reference values "Results (baseline)" for further use.

6.1.5 Maximum deviations from "Results (baseline)" as tolerances and limits are established in this document, documented in Table 2, and taken as reference values "Limit" for further use.

6.1.6 When any CR system component is changed, by definition the "CR system" has changed (see 4.1); therefore, the Core Image Quality Tests shall be performed to establish the baseline for this new CR system.

6.2 *User Tests for Long Term Stability*—Image quality assurance requires periodic tests of the CR system to ensure the proper performance of the system.

6.2.1 *Test Intervals*—The frequency shall be at least quarterly unless otherwise approved by the CEO.

TABLE 2 Test Report of CR System

System Information				
Test Component		Manufacturer/Model/Serial Number		
CR System	IP Type			
	Software			
	Viewing Monitor			
	Scanner			
	Scanner Settings	Sampling Resolution (µm)		
		PMT Gain (if applicable)		
		Other (specify):		
Radiation Source		Manufacturer/Model		
		Focal Point (mm)		

Exposure Conditions	Core Image Quality Tests (8.2)	Erasure Test (8.3.1)	Burn-In Test (8.3.2)	IP Artifacts (8.5.4)	IP Response (8.5.5)	IP Fading (8.5.6)
Date						
Tube Filter Material						
Tube Filter Thickness						
kV						
mA						
Time (sec)						
SDD (specify units)						
Test	EPS (8.4.1)	SNR (8.4.2)				
Date						
Tube Filter Material						
Tube Filter Thickness						
kV						
mA						
SDD (specify units)						

Exposure #	1	2	3	4	5	6	7	8
Time (sec)								
EPS								
SQRT (1/SNR)								

Results									
Test		Baseline Test							
		Test after Repair or New Software							
		Long Term Stability							
Test Phantom Type									
Test Procedure Section	Test Metric	Test Target (Method)	Evaluation Procedure Section: Type I Phantom	Type II Phantom	Other	Result (baseline)	Limit	Result	Remarks
			Core Image Quality Tests						
8.2	Contrast Sensitivity	E1647 gauge (line profile)	9.2.1	9.3.1			2 % contrast step		
	Basic Spatial Resolution	Duplex Wire E2002 (line profile)	9.2.2				± one wire/line pair from baseline		
		Parallel Line Pairs (line profile)		9.3.2					
	Geometric Distortion	Linear Quality Indicator (linear measurement)	9.2.3				≤ 2 % distortion		
		Point Measurement Target (linear measurement)		9.3.3					
	Laser Jitter	T-target (visual)	9.2.4				straight and continuous edges		
		Long Strip Target (visual)		9.3.4					
	PMT Non-Linearity	T-target (visual)	9.2.5				not visible at typical window width settings		
		Short Strip Target (visual)		9.3.5					
	Scan Line Integrity	Image Background (visual)	9.2.6	9.3.6			none visible		
	Scan Column Dropout	Image Background (visual)	9.2.7	9.3.7					
	Scanner Slippage	Homogeneous Strip (line profile)	9.2.8				≤ noise		
		Point Measurement Target (linear measurement)		9.3.8			≤ 2 % distortion		
	Shading	Shading Image Quality Targets (PV measurement)	9.2.9.1				± 15 % of target EC		
		Image Background (visual)	9.2.9.2				none visible		
		Image Background (PV measurement)		9.3.9.1			± 15 % of center measurement		
		Image Background (visual)		9.3.9.2			none visible		
	Banding	Image Background (PV measurement)	9.2.10.1	9.3.10			± 15 % of background		
		Image Background (visual)	9.2.10.2	9.3.10			none visible		
8.3.1	Erasure	Image Background (PV measurement)	9.2.11.1	9.3.11			≤ 2 % PV		
		Image Background (visual)	9.2.11.2	9.3.11			no residual image visual		
8.4	Sensitivity Tests (only one of the following methods is required: EPS or SNR)								

TABLE 2 *Continued*

8.4.1	EPS	EPS Test Standard – Appendix X3 (visual)			9.4		± one hole set from baseline		
8.4.2	SNR	Image Background (SNR calculation)			9.5		(by SPC)		
Supplemental Tests (optional)									
8.3.2	Burn-In	Image Background (PV measurement)	9.2.12.1	9.3.12			≤ 2 % PV		
		Image Background (visual)	9.2.12.2	9.3.12			no residual image visual		
8.5.2	Spatial Linearity	Linear Quality Indicator (linear measurement)	9.2.12				≤ 2 % distortion		
8.5.3	Central Beam Alignment	BAM snail (visual)	9.2.13				regularly spaced spiral		
8.5.4	IP Artifacts	n/a			9.6.4		n/a		
8.5.5	IP Response	Image Background (PV measurement)			9.6.5		< 10 % PV variation		
8.5.6	IP Fading	Image Background (PV measurement)			9.6.6		n/a		
Date of Tests									
Conclusion									
Operator									

6.2.2 *Acceptance Criteria and Tolerances*—Table 1 lists the minimum acceptance criteria for all long-term stability tests. For SNR, limits and tolerances shall be established using statistical process control (SPC) per 9.5.

6.3 *Supplemental (Optional) Tests*—Supplemental (optional) tests may be performed at the user's discretion in addition to the tests in 6.1 and 6.2. Where applicable, recommended acceptance criteria are provided in Table 1 and Section 9.

6.4 *Retesting Requirements:*

6.4.1 New CR System Baseline Performance Tests should be performed when any system hardware or software component is repaired, replaced, or upgraded.

6.4.2 Long Term Stability Tests should be performed after routine maintenance.

7. Apparatus

7.1 The tests described in Table 1 and in Section 6 require the usage of either the Type I CR Phantom (see Appendix X1) or the Type II CR Phantom (see Appendix X2). However, this document does not preclude the use of alternate gauges or phantoms which can measure the same parameters listed in Table 1. The use of alternate gauges must be approved by the CEO.

7.2 *Description of CR Image Quality Indicators for User Tests*—The following is a description of CR image quality indicators, which will be identified by reference to this practice.

7.2.1 *Contrast Sensitivity Image Quality Indicator*—The description of the contrast sensitivity test target corresponds to Practice E1647. For use with this practice, three test targets are made from aluminum (Material Group 2), copper (Material Group 4), and stainless steel (Material Group 1). The test target thickness is 12.5 mm [0.50 in.] aluminum, 6.3 mm [0.25 in.] copper and stainless steel. Each test target contains a contrast area for 1, 2, 3, and 4 % wall-thickness contrast sensitivity and is implemented in both the Type I (aluminum, copper, and stainless) and Type II (aluminum only) CR Phantoms (Fig. X1.1 and Fig. X2.1).

7.2.2 *Duplex Wire Image Quality Indicator*—The description of the duplex wire image quality indicator corresponds to Practice E2002. The gauge shall be oriented at approximately 2°–5° angle to the laser scan direction and at approximately 2°–5° angle to the IP transport direction. This test target may be evaluated visually or with software tools to measure basic spatial resolution and is implemented in one orientation in the Type I CR Phantom (Fig. X1.1).

7.2.3 *Converging Line Pair Image Quality Indicator*—This test target is contained in the Type I CR Phantom (Fig. X1.1), but is not used in this standard.

7.2.4 *Parallel Line Pair Image Quality Indicators*—The test target consists of multiple pairs of parallel slits cut into lead foil (0.05 mm [0.002 in.] thickness), which is used to measure basic spatial resolution. It shall cover a range from 1.5 to 10 line pairs per mm (lp/mm) as a minimum. The gauge shall be oriented at approximately 2°–5° angle to the laser scan direction and at approximately 2°–5° angle to the IP transport direction. Two of these test targets are arranged in each scan direction and implemented in the Type II CR Phantom (Fig. X2.1).

7.2.5 *Linearity Image Quality Indicators*—Rulers of high-absorbing materials are located on the perimeter of the scanned range and may be used to measure spatial linearity, geometric distortion, and scanner slippage. Two image quality indicators shall be used, one parallel with the scanned lines and the other one oriented in the perpendicular direction. The scaling should be at least in mm or tenths of inches. These test targets are implemented in the Type I CR Phantom (Fig. X1.1).

7.2.6 *Point Measurement Test Targets*—Small spherical test targets made of high density material (for example, 1.5 mm [0.06 in.] diameter steel or lead balls), placed at known locations at the four corners of the scanned image. These test targets may be used for evaluation of overall image geometric distortion or scanner slippage, or both, and are implemented in the Type II CR Phantom (Fig. X2.1).

7.2.7 *T-target*—This CR image quality indicator consists of a thin plate of brass or copper ≥2 mm [≥0.08 in.] thick with sharp edges. This plate is manufactured in a T-shape. The T should have a size of at least 114 by 5 mm [4.5 by 0.2 in.] for each leg. It shall be aligned perpendicular and parallel to the IP transport direction and is used to check for laser jitter and may be used to measure a Modulation Transfer Function (MTF) of the complete system. This test target is implemented in the Type I CR Phantom (Fig. X1.1).

7.2.8 *Strip Targets*—These CR image quality indicators consists of two thin plates of brass or copper (≥0.5 mm [≥0.02 in.] thick) with sharp edges. Each plate is 5 mm [0.2 in.] wide, one plate being at least 50 mm [2 in.], and one being nearly the full length of the image to be scanned [16 in.]. The short plate shall be aligned perpendicular to the transport direction and is used to check for PMT non-linearity, while the long plate is aligned parallel to the transport direction and is used to check laser jitter. These test targets are implemented in the Type II CR Phantom (Fig. X2.1).

7.2.9 *Homogeneous Strip Target*—The image quality indicator consists of a homogeneous strip of aluminum 0.5 mm [0.02 in.] in thickness. The image quality indicator has the shape of a rectangle and shall be aligned parallel to the transport direction and is implemented in the Type I CR Phantom (Fig. X1.1).

7.2.10 *Shading Image Quality Indicator*—A series of three holes, measuring 19 mm [0.75 in.] in diameter and 0.3 mm [0.01 in.] deep. These test targets are implemented (labeled EL, ER, and EC) in the Type I CR Phantom (Fig. X1.1).

7.2.11 *Equivalent Penetrameter Sensitivity (EPS) Test Standard*—The EPS test standard is built to the dimensional specifications of the Practice E746 Relative Image Quality Indicator (RIQI), but may be made of steel, aluminum, or other materials. See Appendix X3 for details of the EPS test standard.

7.2.12 *Central Beam Alignment Image Quality Indicator (BAM-snail)*—The alignment image quality indicator consists of a roll 1.5 to 2.0 mm high [0.06 to 0.08 in.] of thin lead foil separated by a spacer of 0.1 to 0.2 mm [0.004 to 0.008 in.] of low-absorbing material. This test target is implemented in the Type I CR Phantom (Figs. X1.1 and X1.2).

7.3 *Application Procedures for CR Image Quality Indicators*—The CR system image quality indicators provide an evaluation of the image quality of a CR system as well as for a periodic quality control. Selection and arrangement of the CR image quality indicators shall be in accordance with this practice, or as specified by the CEO.

8. Test Procedures

8.1 The tests listed in this section shall be performed with the listed phantom and corresponding IQIs at specified intervals as established in this practice.

8.1.1 *Core Image Quality Tests:*

8.1.1.1 Contrast Sensitivity (by contrast sensitivity gauges in either Type I or Type II CR Test Phantom).

8.1.1.2 Basic Spatial Resolution (by duplex wire gauge in Type I CR Test Phantom or parallel line pair gauges in Type II CR Test Phantom).

8.1.1.3 Geometric Distortion (by spatial linearity image quality indicators in Type I CR Test Phantom or point measurement targets in Type II CR Test Phantom).

8.1.1.4 Laser Jitter (by T-target in Type I CR Test Phantom or long strip target in Type II CR Test Phantom).

8.1.1.5 PMT Non-linearity (by T-target in Type I CR Test Phantom or short strip target in Type II CR Test Phantom).

8.1.1.6 Laser Beam Scan Line Integrity (no test object required).

8.1.1.7 Scan Column Dropout (no test object required).

8.1.1.8 Scanner Slippage (by homogeneous strip slippage target in Type I CR Test Phantom or point measurement targets and visual evaluation in Type II CR Test Phantom).

8.1.1.9 Shading (by three shading image quality targets in Type I CR Test Phantom or three measurements in background of Type II CR Test Phantom).

8.1.1.10 Banding (no test object required).

8.1.1.11 Erasure (high absorption object per 8.3.1).

8.1.1.12 *Sensitivity Tests Considering Image Noise:*

(1) EPS (EPS Test Standard per 7.2.11), or

(2) SNR (no test object required).

8.1.2 *Optional Tests:*

8.1.2.1 Burn-In (high absorption object per 8.3.1).

8.1.2.2 Spatial Linearity (by spatial linearity image quality indicators in Type I CR Test Phantom).

8.1.2.3 Central Beam Alignment (by BAM-snail target in Type I CR Test Phantom).

8.1.2.4 Imaging Plate Artifacts (no test object required).

8.1.2.5 Imaging Plate Response Variation (no test object required).

8.1.2.6 Imaging Plate Fading (no test object required).

8.2 *Procedure for Core Image Quality Tests (except EPS and SNR)*—For the tests involving the phantoms of this practice, either the Type I or Type II CR Test Phantom shall be placed on the cassette, which contains an imaging plate. The radiation source shall be set at a distance of at least 1 m [39 in.] or greater and the beam aligned with the center of the plate. Testing of the Type I CR phantom shall be performed at 220 kV for applications >160 kV, or 90 kV for applications ≤160 kV; Testing of Type II CR phantom shall be performed at 50 kV. Above radiation energy of 100 kV, use of a front screen is recommended (such as lead ≥0.1 mm [0.005 in.] or steel ≥0.5 mm [0.02 in.]) to reduce scattered radiation. Background pixel value shall not be saturated, to avoid "burning" edges of the test targets and producing erroneous data. The final image for evaluation shall have the PV of all targets of interest within the EPS or SQRT(1/SNR) plateau as defined in 9.4.2 and 9.5.2.2.

8.2.1 Note that for tracking performance of the CR system, the same technique, CR scanner settings, and CR system components shall be used during long term stability or process checking.

8.2.2 Before the capture of images for evaluation begins, the CR system shall have the scanner normalization performed in accordance with the manufacturer's recommendations.

8.3 *Procedure for Erasure and Burn-In Test:*

8.3.1 *Erasure:*

8.3.1.1 Using an IP that has been erased, an exposure shall be taken at 220 kV or a typical kV for the application range. This shall be accomplished using an absorber plate that covers approximately one half of the imaging plate and results in 5-10 % maximum achievable mean linear PV in the region covered by the absorber plate. In the free beam area, the exposure shall result in 80-90 % of the maximum achievable mean linear PV.

8.3.1.2 Erase the IP. Scan the IP after erasure.

8.3.1.3 Document the orientation of the IP during exposure and processing on the technique. Ensure the same orientation is maintained for subsequent tests.

8.3.2 *Burn-In (Optional):*

8.3.2.1 The burn-in test shall only be performed on an IP that has successfully met the acceptance criteria for the erasure test (9.2.10). Prior to exposure, wait approximately 20 min from completion of the erasure test (8.3.1). Expose the IP without an absorber plate in such a way as to achieve a PV within the plateau as defined in 9.4.2 or 9.5.2.2 with the same kV as used in the erasure test.

8.3.2.2 The burn-in test may be repeated after a longer wait time to determine if the burn-in fades.

8.4 *Procedure for Sensitivity Tests Considering Image Noise (Only One of the Following Methods is Required: EPS or SNR):*

8.4.1 *Procedure for EPS Test:*

8.4.1.1 For CR system baseline performance testing, place the EPS Test Standard (Appendix X3) on the IP and align an X-radiation source in the approximate center of the EPS Test Standard between the #8 and #10 EPS plaques (plaques may be slightly separated for this purpose). If the EPS Test Standard does not cover the entire IP, the IP should be masked with lead around the absorber plate. The Source-to-Detector Distance (SDD) shall be at least 1 m [39 in.]. The geometric unsharpness, Ug, shall not exceed 50 µm and Ug should not exceed 50 % of SR_b detector. A collimator should be used which provides a beam projection that approximately matches the area of the EPS Test Standard. The kilovoltage setting shall be 220 kV if using steel, or 65 kV if using aluminum. Backing materials of 1 mm [0.04 in] steel and a minimum of 4 mm [0.1 in.] lead should be placed beneath the IP with the steel being placed nearest the IP. Radiograph the EPS Test Standard with a minimum of eight exposures with similar technique parameters (that is, the only technique variable is exposure, mA × time) for a range of dose sufficient to produce approximately 10-90 % of the maximum pixel value (PV) of the system in approximately equal increments (that is, for a 16 bit system, 100 % max PV=65535; 10-90 % max PV 6554-58982, PV increments ~6500-8000). The %EPS shall be determined per 9.4.

8.4.1.2 For long-term stability tests, %EPS only needs to be verified at a selected dose in the "plateau" region (that is, only one exposure required).

8.4.2 *Procedure for SNR Tests:*

8.4.2.1 For CR system baseline performance testing, a system consisting of a cassette and IP shall be uniformly exposed. The IP shall be positioned with an SDD of 1 m [39 in.]. Leave free space of at least 1 m [39 in.] behind the cassettes or use a steel screen of about 0.5 mm [0.02 in.] and a lead plate of > 2 mm [0.08 in.] just behind the cassette (steel screen is positioned between cassette and lead) and in eight exposures using similar technique parameters (that is, the only technique variable is exposure, mA × time) for a range of dose sufficient to produce approximately 10-90 % of the maximum linear pixel value (PV) of the system in approximately equal increments (that is, for a 16 bit system, 100 % max PV=65535; 10-90 % max PV=6554-58982, PV increments ~6500-8000). The SNR shall be measured per 9.5.

8.4.2.2 For high-energy applications, the kilovoltage setting shall be 220 kV and the filter shall be of copper 8 mm [0.32 in.] in thickness. A front lead screen of 0.1 mm [0.005 in.] thickness may be used in the exposure cassette.

8.4.2.3 For low-energy applications, the kilovoltage setting shall be 90 kV and the filter shall be of aluminum 2 mm [0.08 in.] in thickness. No front and back screens of lead are required.

8.4.2.4 For long-term stability tests, SNR or SQRT(1/SNR) only needs to be verified at a selected dose in the plateau region (that is, only one exposure is required).

8.5 *Procedures for Supplemental (Optional) Tests:*

8.5.1 *Burn-In*—See 8.3.2.

8.5.2 *Spatial Linearity (Optional)*—Same as 8.2 using Type I CR Test Phantom.

8.5.3 *Central Beam Alignment (Optional)*—The radiation beam shall be aligned perpendicular to the center of the alignment image quality indicator (BAM-snail) within the Type I CR Test Phantom (Appendix X1).

8.5.4 *Imaging Plate Artifacts (Optional):*

8.5.4.1 All IPs in inventory should be serialized.

8.5.4.2 Prior to testing for artifacts, each IP should be cleaned in accordance with manufacturer instructions, recommended cleaner and lint-free cloth.

8.5.4.3 Expose each IP to the lowest kV used in examination. Use sufficient exposure conditions to achieve a PV within the plateau as defined in 9.4.2 or 9.5.2.2. Scan the IP and store the corresponding image file.

8.5.5 *Imaging Plate Response Variation (Optional)*—In some instances, performance of the same type imaging plate may vary by lot, resulting in differing image intensities when exposed to the same exposure parameters. The following evaluation may be performed as an initial acceptance test of imaging plate lots.

8.5.5.1 Expose each IP to the lowest kV used in examination. Use sufficient exposure conditions to achieve a PV within the plateau as defined in 9.4.2 or 9.5.2.2. Scan the IP and store the corresponding image file.

8.5.5.2 Set the linear pixel value of this measurement as reference for the specific imaging plate type.

8.5.5.3 Using the same X-ray parameters (kV, mAs, and distance), evaluate same imaging plate types from other lots.

8.5.6 *Imaging Plate Fading (Optional)*—The fading effect needs to be considered to ensure correct exposure conditions. To enable reproducible test results, it is important to consider fading effects, which influence the required exposure time. The time between IP exposure and IP scanning for all tests shall correspond to the application of the CR system. The measurement of fading characteristic shall be done by performing the following steps:

8.5.6.1 Expose an imaging plate homogeneously using typical exposure conditions. For documentation, the following parameters shall be recorded: kV, mAs, SDD, pre-filter material and thickness, and imaging plate type. The exposed image shall have a mean linear pixel value between 70 and 90 % of the maximum possible PV of the CR reader at lowest gain and under linearized conditions.

8.5.6.2 Scan the IP as soon as practical after exposure (that is, using a short wait time) and establish a baseline mean linear PV using an ROI that covers a majority of the IP image. Subsequent tests should use a similar short wait time to achieve consistent results.

8.5.6.3 Set the linearized read-out intensity of this measurement as reference (=100 %).

8.5.6.4 Subsequent exposures shall have increasing time intervals between IP exposure and IP scanning. Suggested steps are 5 min and 1 h, or as needed to match application requirement.

9. Calculation of the Results, Acceptance Criteria, and Report

9.1 All test results shall be documented. An example data sheet format is shown in Table 2.

9.2 The results using the Type I CR Test Phantom shall be calculated as follows:

9.2.1 *Determination of Contrast Sensitivity:*

9.2.1.1 A line profile (with line profile width to cover half of the width of the contrast step) shall be taken through the steps on at least one of the three Practice E1647 contrast sensitivity gauges (7.2.1) as selected by the user.

9.2.1.2 The average noise of the profile shall be less than the difference in the intensity between the full and reduced wall thickness at the 2 % step (see Fig. 7). The same gauge material(s) shall be used for subsequent periodic tests and shall be recorded with the result.

9.2.2 *Determination of Basic Spatial Resolution:*

9.2.2.1 The first unresolved wire pair element shall be taken for determination of the unsharpness value corresponding to Practice E2002. This is the first wire pair element, which is projected with a dip between the wires of less than 20 % (see Fig. 8), as measured with a line profile. The line profile width should be approximately 30-60 % of the length of the wires (see Fig. 9) in order to obtain a robust repeatable value, but shall use a minimum of 11 pixel width line profile (or average of 11 single pixel width line profiles).

9.2.2.2 The SR_b measurement shall be determined from the largest of the readings of both the laser scan and IP transport directions. (A second exposure must be acquired with the phantom rotated 90 degrees to obtain both measurements using this phantom.)

9.2.2.3 For long-term stability tests, SR_b readings shall be no more than ± one wire pair element of the baseline reading.

9.2.3 *Geometric Distortion:*

9.2.3.1 The overall geometric distortion of the CR image shall be checked by exposing a spatial linearity image quality indicator (mm-scale or finer, 7.2.5), in *x*- and *y*-directions.

9.2.3.2 Calibrate the resident software distance measurement tool on either the *x*- or *y*-scale, and then check the accuracy of the overall length of the scale not used for calibration. Measured geometric distortion shall be less than or equal to 2 %.

9.2.4 *Laser Jitter:*

9.2.4.1 Using a T-target (7.2.7), evaluate for laser beam jitter by examining the edges of the "T" on the image. View the "T" edges with 100 % (1:1 pixel mapping) up to a maximum of the monitor display megapixels (MP) × 50 % (that is, max magnification of 100 % (2MP), 150 % (3MP), 250 % (5MP), 400 % (8MP)) magnification on the image display monitor in

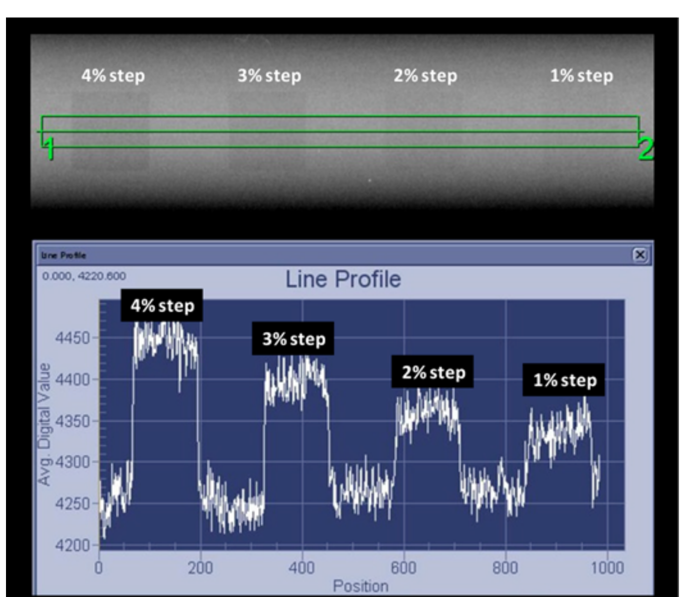

FIG. 7 Radiographic Image of Contrast Sensitivity Gauge With Line Profile Data Illustrating <1 % Contrast Sensitivity