Designation: ~~E2033 – 99 (Reapproved 2013)~~ E2033 – 17

Standard Practice for ~~Computed Radiology~~Radiographic Examination Using Computed Radiography (Photostimulable Luminescence Method)[1]

This standard is issued under the fixed designation E2033; 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 establishes the minimum requirements for computed radiographic (CR) examination for metallic and nonmetallic materials using X-ray or gamma radiation.

1.2 *Applicability*—The requirements in this practice are intended to control the quality of computed radiographic examinations and are not intended to establish acceptance criteria for parts or materials.

1.3 *Basis of Application*—~~This practice~~The requirements ~~covers application details for computed~~of this practice, Practice E2445 ~~radiology (CR)~~and E2446 ~~examination using a process in which photostimulable luminescence is~~shall be used together. The requirements of Practice E2445 ~~emitted by the penetrating radiation detector, a storage phosphor imaging plate (SPIP). Because the techniques involved and the~~will provide the baseline performance evaluation and long term stability test procedures for the CR system. Practice E2446 ~~applications for CR examination are diverse, this practice is not intended to be limiting or restrictive, but rather to address the general applications of the technology and thereby facilitate its use. Refer to Guides~~CR performance levels are recommended in Table 1. The user of the CR system shall establish a written procedure that addresses the specific requirements and tests to be used in their application and shall ~~E94 and~~be approved ~~E2007, Terminology~~by the ~~E1316, and Practices~~Cognizant Radiographic Level ~~E747 and~~3 before ~~E1025, and 21 CFR 1020.40 and 29 CFR 1910.96 for additional information and guidance.~~examination of production hardware. The items that shall be determined and addressed in the written procedure are:

(a) Personnel qualification and certification.

(b) Minimum effective pixel coverage appropriate to the acceptance criteria and to meet the radiographic image quality level requirements of Table 1.

(c) Additional tests per Practice E2445 deemed appropriate.

(d) Organizations using a gamma source or radiation energy above 320 kV may need to modify the E2445 tests, gauges, or both.

(e) Maximum allowed unsharpness when other than Table 1.

(f) The method used to provide image traceability to the part and the examination facility.

1.3.1 This practice also requires the user to perform a system qualification suitable for its intended purpose and to issue a system qualification report (see subsection 7.1). Additionally, the user shall develop part specific inspection procedures (see subsections 5.5 and 7.5).

1.4 *Units*—The ~~general principles discussed in this practice apply broadly to penetrating radiation CR systems. However, this document is written specifically for use with X-ray and gamma-ray systems. Other CR systems, such as those employing neutrons, will involve equipment and application details unique to such systems.~~values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard. Where applicable, SI units are shown in brackets [xx].

1.5 *Compliance*—Systems, equipment and materials that do not comply with this practice shall require a waiver from the Cognizant Engineering Organization (CEO).

[1] This test method 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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TABLE 1 Total Image Unsharpness, Maximum

Material Thickness	Maximum Allowed Image Unsharpness ($U_T^{20\%}$ or U_{im})	Recommended CR Performance Level per E2446
≤ 0.5 inch [≤ 12.7 mm]	0.010 inch [0.254 mm]	CR level I or Higher
> 0.5 through 1 inch [> 12.7 through 25.4 mm]	0.015 inch [0.381 mm]	CR level I or Higher
> 1 through 2 inches [> 25.4 through 50.8 mm]	0.020 inch [0.508 mm]	CR level II or Higher
> 2 through 4 inches [> 50.8 through 101.6 mm]	0.030 inch [0.762 mm]	CR level II or Higher
> 4 inches [> 101.6 mm]	0.040 inch [1.016 mm]	CR level II or Higher

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~~ safety, health, and ~~health~~environmental practices and determine the applicability of regulatory limitations prior to use.~~For specific safety statements, see Section 10 and 21 CFR 1020.40 and 29 CFR 1910.96.~~*

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]

~~E94~~E746 ~~Guide for Radiographic Examination Using Industrial Radiographic Film~~Practice for Determining Relative Image Quality Response of Industrial Radiographic Imaging Systems

E747 Practice for Design, Manufacture and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used for Radiology

E1025 Practice for Design, Manufacture, and Material Grouping Classification of Hole-Type Image Quality Indicators (IQI) Used for Radiology

E1030 Practice for Radiographic Examination of Metallic Castings

E1032 Test Method for Radiographic Examination of Weldments

E1114 Test Method for Determining the Size of Iridium-192 Industrial Radiographic Sources

E1161 Practice for Radiologic Examination of Semiconductors and Electronic Components

E1165 Test Method for Measurement of Focal Spots of Industrial X-Ray Tubes by Pinhole Imaging

E1316 Terminology for Nondestructive Examinations

~~E1453~~E1647 ~~Guide for Storage of Magnetic Tape Media that Contains Analog or Digital Radioscopic Data~~Practice for Determining Contrast Sensitivity in Radiology

~~E1475~~E1735 ~~Guide for Data Fields for Computerized Transfer of Digital Radiological Examination Data~~Test Method for Determining Relative Image Quality of Industrial Radiographic Film Exposed to X-Radiation from 4 to 25 MeV

E1742 Practice for Radiographic Examination

E1817 Practice for Controlling Quality of Radiological Examination by Using Representative Quality Indicators (RQIs)

E2002 Practice for Determining Total Image Unsharpness and Basic Spatial Resolution in Radiography and Radioscopy

E2339 Practice for Digital Imaging and Communication in Nondestructive Evaluation (DICONDE)

E2445 Practice for Performance Evaluation and Long-Term Stability of Computed Radiography Systems

E2446 Practice for Manufacturing Characterization of Computed Radiography Systems

E2736 Guide for Digital Detector Array Radiology

~~E2007~~E2738 ~~Guide for Computed Radiography~~Practice for Digital Imaging and Communication Nondestructive Evaluation (DICONDE) for Computed Radiography (CR) Test Methods

E2903 Test Method for Measurement of the Effective Focal Spot Size of Mini and Micro Focus X-ray Tubes

2.2 *ASNT Standards:*[3]

~~SNT-TC-1A~~ANSI/ASNT-CP-189 ~~Recommended Practice~~ Standard for ~~Personnel~~ Qualification and Certification ~~in~~of Nondestructive Testing Personnel

~~ANSI/ASNT-CP-189~~SNT-TC-1A ~~Standard~~ Recommended Practice for Personnel Qualification and Certification ~~of~~in Nondestructive Testing ~~Personnel~~

~~[2] For ASME Boiler and Pressure Code applications, see related Practice SE-2033 in Section II of that code.~~

[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] Available from American Society for Nondestructive Testing, 1711 Arlingate Plaza, P.O. Box 28518, Columbus, OH 43228-0518.

2.3 *Aerospace Industries Association of America Document:*[4]
NAS-410 Certification and Qualification of Nondestructive Testing Personnel
2.4 *Society of Motion Picture and Television Engineers (SMPTE):*[5]
RP133 Specifications for Medical Diagnostic Imaging Test Pattern for Television Monitors and Hard Copy Recording Cameras
2.5 ~~*Federal Standards:*~~*Government Documents:*[6]
~~Title 21, CFR 1020.40~~NCRP 116 ~~Safety Requirements of Cabinet X-Ray Systems~~Limitation to Exposure to Ionizing Radiation
~~Title 29, CFR 1910.96~~NCRP 147 ~~Ionizing Radiation~~Structural Shielding Design for Medical X-ray Imaging Facilities
2.6 ~~*AIA Standard:*~~*ISO Documents:*[7]
~~NAS-410~~ISO 9712 ~~Certification~~ Non-destructive Testing—Qualification and ~~Qualification~~Certification of ~~Nondestructive Testing~~ NDT Personnel
ISO 10012 Measurement Management Systems—Requirements for Measurement Processes and Measuring Equipment
ISO 17636-2 Non-destructive Testing of Welds—Radiographic Testing—Part 2: X- and Gamma-Ray Techniques with Digital Detectors
ISO 19232-1 Non-destructive Testing—Image Quality of Radiographs—Part 1: Determination of the Image Quality Value Using Wire-type Image Quality Indicators
ISO 19232-2 Non-destructive Testing—Image Quality of Radiographs—Part 2: Determination of the Image Quality Value Using Step/Hole-Type Image Quality Indicators
2.7 *EN Documents:*[8]
EN 4179 Aerospace Series—Qualification and Approval of Personnel for Non-destructive Testing
EN 12543-2 Non-destructive Testing—Characteristics of Focal Spots in Industrial X-ray Systems for Use in Non-destructive Testing—Part 2: Pinhole Camera Radiographic Method
EN 12543-5 Non-destructive Testing—Characteristics of Focal Spots in Industrial X-ray Systems for Use in Non-destructive Testing—Part 5: Measurement of the Effective Focal Spot Size of Mini and Micro Focus X-ray Tubes.
2.8 *ANSI Documents:*[9]
Z540–3 Requirements for the Calibration of Measuring and Test Equipment

3. Terminology

3.1 *Definitions:* Definitions relating to radiographic examination, which appear in Terminology E1316, shall apply to the terms used in this practice.

3.1.1 *1:1*—an image display scenario where a single pixel of the image is mapped to a single pixel on the image display monitor.

3.1.2 *Cognizant Radiographic Level 3*—the certified level 3 radiographer holding final technical responsibility for the radiographic facility and staff.

3.1.3 *Effective Pixel Size*—effective pixel size is equal to the basic spatial resolution of the detector ($SR_b^{detector}$).

3.1.4 *Fast Scan Direction*—the fast scan direction refers to the laser scan direction along an image line of the IP. This may also be referred to as "laser scan direction."

3.1.5 *Material Group*—materials that have the same predominant alloying elements and which can be examined using the same material group IQI. A listing of common material groups is given in Practices E747 and E1025.

3.1.6 *Pixel Coverage*—for the purpose of this practice, the term "pixel coverage" refers to the minimum number of effective pixels required to cover a feature such as a critical flaw size or the IQI designated hole or essential wire size, whichever is smallest. Geometric magnification may be required to achieve adequate pixel coverage. Additional information on pixel coverage and geometric magnification can be found in Guide E2736.

3.1.7 *Slow Scan Direction*—Slow scan direction refers to the mechanical transport direction of the IP through the scanner. This may also be referred to as "IP transport direction."

4. Summary of Practice

4.1 *Apparatus*—~~A CR examination system can be used for a wide variety of applications. A typical CR examination system~~ This practice covers application details for computed radiography using a system that consists of a radiation source, a storage phosphor imaging plate ~~detector, a plate reader, an electronic imaging system, a digital image processor, a monitor display, a~~ (IP) and cassette, an IP scanner/digitizer, scan parameter settings, a workstation with software, an image display monitor, and a digital

[4] Available from Aerospace Industries Association of America, Inc., 1250 Eye St. NW, Washington, D.C. 20005.
[5] Available from Society of Motion Picture and Television Engineers, 3 Barker Ave, White Plains, NY 10601.
[6] Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.
[7] Available from ~~Aerospace Industries Association of America, Inc., 1250 Eye St. NW, Washington, D.C. 20005.~~International Organization for Standardization (ISO), ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, http://www.iso.org.
[8] Available from British Standards Institution (BSI), 389 Chiswick High Rd., London W4 4AL, U.K., http://www.bsigroup.com.
[9] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

image archiving ~~system, and, if desired, equipment for producing hard copy analog images. This practice establishes the basic parameters for the application and control of the CR method.~~system.

4.2 *Safety*—The premises and equipment shall present no hazards to the safety of personnel or property. NCRP 116 and NCRP 147 may be used as guides to ensure that radiographic facilities and procedures are performed so that personnel shall not receive a radiation dose exceeding the maximum permitted by city, state, or national codes.

5. Significance and Use

5.1 ~~The X-, gamma-ray detector discussed in this practice is a storage phosphor imaging plate, hereafter referred to as SPIP. The SPIP, which is the key component in the CR process, differentiates CR from other radiologic methods.~~This practice establishes the basic parameters for the application and control of the CR examination method. This practice is written so ~~that~~ it can be specified on the engineering drawing, specification, or ~~contract and must be supplemented by a detailed procedure (see Section~~ contract.~~6 and Annex A1 and Annex A2~~).

5.2 *Weld Examination*—Additional information on weld examination may be found in Practice E1032, ISO 17636-2, or both.

5.3 *Casting Examination*—Additional information on casting examination may be found in Practice E1030.

5.4 *Electronic Components*—Radiographic examination of electronic components shall comply with Practice E1161.

5.5 *Part-Specific Examination Technique*—A detailed written procedure in the form of a part-specific examination technique (7.5) shall be documented for each part, or group of parts, and shall be approved by the Cognizant Radiographic Level 3.

5.6 *Personnel Qualification*—Personnel performing examinations to this practice shall be qualified in accordance with ISO 9712, NAS 410, EN 4179, ANSI/ASNT CP 189, or SNT-TC-1A and certified by the employer or certifying agency as applicable. Other equivalent qualification documents may be used when specified on the contract or purchase order. The applicable revision shall be the latest unless otherwise specified in the contractual agreement between parties.

5.7 *System Qualification*—All CR systems shall be qualified for their intended use. System qualification requirements are specified in subsection 7.1.

5.8 *Process Control*—All CR systems shall be monitored for long term stability (process control) as specified in subsection 7.1.4.

5.9 *Preventative Maintenance*—All CR systems and X-ray machines require periodic maintenance to ensure proper functionality. Preventative maintenance requirements are specified in subsection 6.2.

5.10 *Environmental Conditions*—CR systems should be operated within environmental conditions that are in compliance with manufacturer's stated acceptable environmental conditions, e.g., temperature and humidity. When CR systems are operated outside the specified manufacturer's environmental ranges, the system shall be qualified (7.1) for such conditions.

~~5. Equipment~~

~~5.1 *System Configuration*—Different examination systems configurations are possible, and it is important to understand the advantages and limitations of each. It is important that the optimum system be selected for each examination requirement through a careful analysis of the benefits and limitations of the available system components and the chosen system configuration. The provider as well as the user of the examination services should be fully aware of the capabilities and limitations of the examination system that is proposed for examination of the part. The provider and the user of examination services shall agree upon the system configuration to be used for each application under consideration and how its performance is to be evaluated.~~

~~5.1.1 The minimum system configuration will include an appropriate source of penetrating radiation, a phosphor plate detector, a plate reader, and an electronic imaging system with a CRT display.~~

~~5.1.2 A more complex system might include a microfocus X-ray system, a digital image processing evaluation system, and an image recording and printing system.~~

~~6. General Procedure Considerations~~

~~6.1 The purchaser and supplier shall mutually agree upon a written procedure using the applicable annex of supplemental requirements and also consider the following general requirements.~~

~~6.1.1 *Equipment Qualifications*—A listing of the system features that must be qualified to ensure that the system is capable of performing the desired examination.~~

~~6.1.2 *Source Parameter*—A listing of all the radiation source-related variables that can affect the examination results for the selected system configuration such as: source energy, intensity, focal spot size, range of source to object distances, range of object to image plane distances, and source to image plane distances.~~

~~6.1.3 *Image Processing Parameters*—A listing of the image processing variables, if any, necessary to enhance fine detail detectability in the part and to achieve the required image quality. These would include, but are not limited to, techniques such as noise reduction, contrast enhancement, and spatial filtering. Great care should be exercised in the selection of directional image~~

processing parameters such as spatial filtering, which may emphasize features in certain orientations and suppress them in others. The listing should indicate the means for qualifying image processing parameters.

6.1.4 *Image Display Parameters*—A listing of the techniques and the intervals at which they are to be applied for standardizing the video image display as to brightness, contrast, focus, and linearity.

6.1.5 *Accept-Reject Criteria*—A listing of the expected kinds of part imperfections and the rejection level for each.

6.1.6 *Performance Evaluation*—A listing of the qualification tests and the intervals at which they are to be applied to ensure the system is suitable for its intended purpose.

6.1.7 *Image Archiving Requirements*—A listing of the requirements, if any, for preserving a historical record of the examination results. The listing may include examination images along with written or electronically recorded alphanumeric or audio narrative information, or both, sufficient to allow subsequent reevaluation or repetition of the examination.

6.1.8 *Qualifications*—Nondestructive testing (NDT) personnel shall be qualified in accordance with a nationally recognized NDT personnel qualification practice or a standard such as ANSI/ASNT-CP-189, SNT-TC-1A, NAS-410, or a similar document.

6. CR Examination System Performance Considerations and Measurement Equipment and Facilities

7.1 *Factors Affecting System Performance*—Total examination system performance is determined by the combined performance of the system components that includes the radiation source, storage phosphor plate detector, plate reader, electronic image processing system, image display, and examination record archiving system.

7.1.1 *Radiation Sources*—Examination systems may utilize either radioisotope or X-ray sources. The energy spectrum of the X-radiation contains a blend of contrast enhancing longer wavelengths as well as the more penetrating, shorter wavelengths. X-radiation is adjustable in energy and intensity to meet the CR examination requirements and has the added safety feature of discontinued radiation production when switched off. A radioisotope source has the advantages of small physical size, portability, simplicity, and uniformity of output.

7.1.1.1 X-ray machines produce a more intense X-ray beam emanating from a smaller focal spot than do radioisotope sources. X-ray focal spot sizes range from a few millimeters down to a few micrometers. Reducing the source size reduces geometric unsharpness, thereby enhancing detail sensitivity. X-ray sources may offer multiple or variable focal spot sizes. Smaller focal spots produce higher resolution with reduced X-ray beam intensity, while larger focal spots can provide higher X-ray intensity with lower resolution. Microfocus X-ray tubes are available with focal spots that may be adjusted to as small as a few micrometers in diameter while still producing an X-ray beam of sufficient intensity so as to be useful for the CR examination of finely detailed parts.

7.1.1.2 Conventional focal spots of 1.0 mm and larger are useful at low geometric magnification values close to 1×. Fractional focal spots ranging from 0.4 mm up to 1.0 mm are useful at geometric magnifications up to approximately 2×. Minifocus spots in the range from 0.1 mm up to 0.4 mm are useful at geometric magnifications up to about 6×. Greater magnifications suggest the use of a microfocus spot size of less than 0.1 mm to minimize the effects of geometric unsharpness. Microfocus X-ray tubes are capable of focal spot sizes of less than 10 µm (10^{-8} m) and are useful for geometric magnifications of more than 100×.

7.1.2 *SPIP*—The storage phosphor imaging plate is a key element. It has the function of converting the radiation input signal containing part information into a corresponding optical signal while preserving the maximum amount of part information. The SPIP is a two-dimensional area detector providing an area field of view.

7.1.3 *SPIP Reader*—The SPIP reader has the function of optically scanning the imaging plate, collecting the emitted light, converting the light to an electronic signal, then converting this signal to a digital format.

7.1.4 *Electronic Imaging Processing System:*

7.1.4.1 The function of the electronic imaging processing system is to take the output of the SPIP reader and present a digital file for image display and operator interpretation.

7.1.4.2 The electronic imaging processing system includes all of the electronics and interfaces after the SPIP reader, including image enhancement and image display.

7.1.4.3 The digital image processing system warrants special attention because it is the means by which examination information will be interpreted. Great care must be exercised in determining which image processing techniques are most beneficial for the particular application. Directional spatial filtering operations, for example, must be given special attention as certain feature orientations are emphasized while others are suppressed.

7.1.5 *Image Display:*

7.1.5.1 The function of the image display is to convey information about the part to the system operator. The image display size, spatial resolution, magnification, and ambient lighting are important system considerations.

7.1.6 *Examination Record Archiving System*—Many applications require an archival quality examination record of the examination. The archiving system may take many forms, a few of which are listed in 7.1.6.1 through 7.1.6.5. Each archiving system has its own peculiarities as to image quality, archival storage properties, equipment, and media cost. The examination record archiving system should be chosen on the basis of these and other pertinent parameters, as agreed upon by the provider and user of services. The reproduction quality of the archival method should be sufficient to demonstrate the same image quality as was used to qualify the examination system.

7.1.6.1 Film or paper radiographs of the part made under the same conditions as the examination image.

~~7.1.6.2 Photograph of the actual image display.~~

~~7.1.6.3 CRT hard copy device used to create a paper copy image from the CRT signal.~~

~~7.1.6.4 Digital recording on magnetic disk or tape used to store the image of the part digitally.~~

~~7.1.6.5 Digital recording on optical disk used to store the image of the part digitally.~~

~~7.1.7 *Examination Record Data*—The examination record should contain sufficient information to allow the examination to be reevaluated or duplicated. Examination record data should be recorded contemporaneously with the CR examination image. Examination record data should be in accordance with Guide E1475 and may be in writing or a voice narrative, providing the following minimum data:~~

~~7.1.7.1 Examination system designation, examination date, operator identification, operating turn or shift, and other pertinent and customer data;~~

~~7.1.7.2 Specific examination data as to part number, batch, serial number, and so forth (as applicable);~~

~~7.1.7.3 Part orientation and examination site information by reference to unique part features within the field of view; and~~

~~7.1.7.4 System performance monitoring by recording the results of the prescribed examination system performance monitoring tests, as set forth in Section 5, at the beginning and end of a series of examinations.~~

~~6.1 *Performance Measurement—*~~*Equipment:* ~~System performance parameters must be determined initially and monitored regularly to ensure consistent results. The best measure of total CR examination system performance can be made with the system in operation, utilizing a representative quality indicator (RQI) similar to the part under actual operating conditions. This indicates the use of an actual or simulated part containing actual or simulated features that must be reliably detected. Such an RQI will provide a reliable indication of the system's capabilities. Conventional wire or plaque-type Image Quality Indicators (IQIs) may be used in place of, or in addition to, the RQI. Performance measurement methods are a matter of agreement between the provider and user.~~

6.1.1 *X-Radiation Sources*—Selection of appropriate X-ray machine parameters (e.g., voltage, current, focal spot) is dependent upon the examination requirements for the specimen being examined (e.g., material type, geometry, acceptance criteria). The suitability of any X-ray machine and the examination technique parameters shall be demonstrated by attainment of the required radiographic quality level and compliance with all other requirements specified herein.

6.1.2 *Gamma Radiation Sources*—Selection of an appropriate isotope source (e.g., energy, source size) is dependent upon the examination requirements for the specimen being examined (e.g., material type, geometry, acceptance criteria). The suitability of any gamma ray source and the examination technique parameters shall be demonstrated by attainment of the required radiographic quality level and compliance with all other requirements specified herein.

6.1.3 *Computed Radiography Scanner*—Selection of an appropriate CR scanner is dependent upon the examination requirements for the specimen being examined (e.g., material type, geometry, acceptance criteria). The suitability of the CR scanner and the examination technique parameters shall be demonstrated by attainment of the required radiographic quality level and compliance with all other requirements specified herein.

6.1.3.1 The minimum acquisition bit depth of the CR scanner shall be 12.

6.1.3.2 *Discussion:* Guidance for appropriate CR scanner capability may be found in subsection 7.6 and Table 3 for radiographic quality level requirements, Table 1 for recommended CR performance levels, and subsection 7.5 for the examination technique requirements.

6.1.4 *Storage Phosphor Imaging Plate (IP)*—IPs selected for application to this practice shall meet the requirements of the CR scanner manufacturer.

6.1.4.1 *IP Storage and Handling*—IPs should be stored flat (not bent or curled) and in a manner that will not induce pressure marks (e.g., vertical storage or storage in non-crushable containers if stacked) when not in use. The IP storage area shall be free of radiation. IPs should be handled with care in order to prevent crimp marks or other surface flaws that will render image artifacts.

6.1.4.2 *IP Cleaning Materials*—Only manufacturer-approved IP cleaning materials shall be used. Care shall be taken to not over-clean IPs in such a way as to damage or remove the clear protective coating.

6.1.4.3 *IP Artifacts*—When IPs are tested for artifacts, compliance with Practice E2445 shall be required. IPs with artifacts that interfere with interpretation in the Area of Interest (AOI) are not acceptable.

6.1.5 *IP Cassettes*—IP cassettes shall be clean, light tight, and constructed of materials that do not interfere with the quality of the radiographic image. Cassettes that exhibit light leaks shall be repaired or discarded.

6.1.6 *IP Cassette Screens*—Front or back metallic screens, or both, should be used with IPs whenever they improve radiographic image quality.

6.1.6.1 Screens shall be visibly free of any cracks, creases, scratches, or foreign materials that would create image artifacts.

6.1.6.2 *Discussion*—For the purpose of this practice, when a metallic screen is used inside the cassette in front of the IP, it shall be referred to as a screen, when used in front of the cassette it shall be referred to as a filter. Back screens, whether inside the cassette or outside the cassette are considered shielding for backscattered radiation.

6.1.7 *Filters*—Filters should be used at the radiation source whenever they improve radiographic image quality. Filters shall be free of any cracks, creases, scratches, or foreign materials that could create image artifacts.

6.1.8 ~~*Performance Measurement Intervals—*~~*Image Display Monitor*—~~System performance measurement techniques should be standardized so that performance measurement~~The image display monitor used for accept/reject evaluations shall be tested in

TABLE 2 Calibration and Process Control

Check	Method	Frequency	Subsection
Image Display Monitor:			
Brightness	Light Meter	Monthly	6.1.8.1
Contrast	Light Meter	Monthly	6.1.8.2
High Contrast Resolution	Visual	Daily[A]	6.1.8.3
Low Contrast Resolution	Visual	Daily[A]	6.1.8.4
Flicker	Visual	Daily[A]	6.1.8.5
Distortion	Visual	Daily[A]	6.1.8.5
Small Contrast Change	Visual	Daily[A]	6.1.8.6
Light Meter(s)	Calibration	6 months	6.1.10
Image Quality Indicators	Certified	When Procured	6.1.11
	Visual	Prior to Use[A]	6.1.11
Representative Quality Indicators	Visual	Prior to Use[A]	6.1.12
Relative Image Quality Indicators	Certified	When Procured	6.1.13
	Visual	Prior to Use[A]	6.1.13
RIQI Absorber Plate	Certified	When Procured	6.1.13.1
	Visual	Prior to Use[A]	6.1.14
Duplex Wire Gauge	Certified	When Procured	6.1.14
	Visual	Prior to Use[A]	6.1.14
CR Phantom	Certified	When Procured	6.1.15
	Visual	Prior to Use[A]	6.1.15
Reference Standard	Calibration	[B]	6.1.16
Measurement Tools	Calibration	[B]	6.1.17
Contrast Sensitivity Gauge	Certified	When Procured	6.1.18
	Visual	Prior to Use[A]	6.1.18
Miscellaneous Radiographic Tools	Visual	Prior to Use[A]	6.1.19
Background Ambient Light	Light Meter	6 months[C]	6.3.3.1

[A]Documentation of this check is not required.
[B]Calibrated and recorded in accordance with ANSI Z540-3 or ISO 10012, as applicable.
[C]Fixed viewing locations with acceptable and controlled ambient lighting conditions need not be re-verified as long as those conditions are maintained.

TABLE 3 Radiographic Quality Levels

Radiographic Quality Level	Maximum IQI Thickness, %[A]	Minimum Perceptible Hole Diameter[B,D]	Equivalent IQI Sensitivity, %[C,E]
1–1T	1	1T	0.7
1–2T	1	2T	1.0
2–1T	2	1T	1.4
2–2T	2	2T	2.0
2–4T	2	4T	2.8

[A]1/50th (2%) of specimen thickness, except the minimum thickness may be 0.005 in. [0.127 mm].
[B]The hole, expressed as a multiple thickness of the IQI that shall be clearly visible, except the minimum hole sizes may be 0.010 in. [0.254 mm], 0.020 in. [0.508 mm], and 0.040 in. [1.016 mm].
[C]Equivalent IQI (Penetrameter) Sensitivity (EPS) is the thickness of the IQI expressed as a percentage of specimen thickness at which a 2T hole would be clearly visible under the same radiographic conditions–see Practice E1025, Appendix X1.
[D]When using Wire Type IQIs, Table 4 of Practice E747 shall be used to determine equivalent wire size to corresponding 1T, 2T or 4T hole size.
[E]EPS values shown above are not applicable for material thicknesses below 0.500 inch [12.7 mm] when using standard Hole Type IQIs with minimum thickness and hole size (Note A & B).

accordance with Table 2 ~~tests may be readily duplicated at specified intervals. System performance should be evaluated at sufficiently frequent intervals, as agreed upon by the supplier and user, to minimize the possibility of time-dependent performance variations.~~and shall meet the following minimum requirements:

6.1.8.1 *Brightness:* The minimum brightness at maximum Digital Driving Level (DDL) shall be 250 cd/m^2,

6.1.8.2 *Contrast:* The minimum contrast as determined by the ratio of the brightness at maximum DDL compared to the brightness at the minimum DDL shall be at least 250:1,

6.1.8.3 *High Contrast Resolution:* The image display monitor shall be capable of displaying linear patterns of alternating pixels at full contrast (modulation depth of 100%) without aliasing in both the horizontal and vertical directions at the display center and at each of the four corners,

6.1.8.4 *Low Contrast Resolution:* The image display monitor shall be capable of discriminating linear patterns of alternating pixels at low contrast (1% modulation patterns where white equals 51% DDL and black equals 50% DDL) in both the horizontal and vertical directions at the display center and each of the four corners,

6.1.8.5 *Flicker and Distortion:* The image display monitor shall be free of screen flicker and discernible geometric distortions, and,

6.1.8.6 *Small Contrast Changes:* The image display monitor shall be capable of displaying a 5% DDL block against a 0% DDL background while simultaneously displaying a 95% DDL block against a 100% background in a manner that is clearly perceptible to the user.

6.1.9 ~~*Measurement with IQIs—*~~*Image Display Monitor Test Pattern—*~~System performance measurement using IQIs shall be in accordance with accepted industry standards~~The test pattern for measuring the image display monitor requirements of subsection 6.1.8 ~~describing the use of IQIs. The IQIs should be placed on the part as close as possible to the area of interest. The use of wire-type IQIs should also take into account that the system may exhibit asymmetrical sensitivity, in which case the wire diameter axis shall be oriented along the system's axis of least sensitivity. Selection of IQI thickness should be consistent with the thickness of the part along the radiation path length. IQIs are described in Practices~~shall comply with SMPTE RP 133 and shall be configured to the image display monitors resolution and aspect ratio. The test pattern shall be viewed at 1:1 digital zoom. Alternate test patterns may be used when approved by the Cognizant Radiographic Level 3 provided they include the features described in SMPTE ~~E747 and~~RP 133 ~~E1025.~~required to perform the image display tests specified herein.

6.1.10 *Light Meters:*

6.1.10.1 *Luminance*—A calibrated light meter shall be used to measure image display monitors for brightness and contrast and shall measure luminance in candelas per square meter (cd/m^2) or foot-lamberts.

6.1.10.2 *Illuminance*—A calibrated light meter shall be used to measure ambient background lighting and shall measure illuminance in lux [$lumens/m^2$] or in foot candles (fc).

6.1.10.3 Calibration frequency for light meters is listed in Table 2.

6.1.11 ~~*Measurement with RQIs—*~~*Image Quality Indicators (IQIs)—*~~The RQI may be an actual part with known features that are representative of the range of features to be detected or may be fabricated to simulate the part with a suitable range of representative features. Alternatively, the RQI may contain known imperfections that have been verified independently. RQIs containing known, natural defects are useful on a single-task basis. Where standardization among two or more CR systems is required, a duplicate RQI should be used. The RQIs should approximate the part as closely as is practical, being made of the same material with similar dimensions and features in the area of interest. Manufactured RQIs should include features at least as small as those that must be reliably detected in the actual parts in locations where they are expected to occur in the actual part. Where features are internal to the part, it is permissible to produce the RQI in sections. RQI details are a matter of agreement between the user and supplier. RQIs are described in Practice~~A Certificate of Compliance (COC) is required to verify material type and dimensional accuracy. A means to trace COCs to individual IQIs shall be provided. Users shall visually inspect IQIs for damage and cleanliness in accordance ~~E1817~~with Table 2.

6.1.11.1 *Hole-Type IQIs*—Hole-type IQIs shall comply with Practice E1025, Practice E1742 Annex A1, or ISO 19232-2, however, the minimum thickness may be 0.005 in. [0.127 mm] and the minimum hole sizes may be 0.010 in. [0.254 mm], 0.020 in. [0.508 mm] and 0.040 in. [1.016 mm].

6.1.11.2 *Wire-Type IQIs*—Wire-type IQIs shall comply with Practice E747 or ISO 19232-1 and shall be correlated to hole-type radiographic quality levels.

6.1.11.3 ~~*Use of an RQI—*~~*IQI and Shim Material—*~~The RQI should be placed into the system in the same position as the actual part.~~IQIs and shims shall be of the same material group as the specimen being examined. When IQIs and shims of the same material group are not available, radiographically similar IQIs and shims as defined in Practice E1025 may be used. IQIs and shims of radiographically less dense material than the subject shall be allowed.

6.1.11.4 ~~*Examination Techniques—*~~*IQI Shims—*~~Radiation beam energy, intensity, focal spot size, enlargement, digital image processing parameters, and other system variables utilized for examination of the RQI shall be identical to those used for the actual examination.~~Shims used with IQIs shall exceed the IQI dimensions such that the pertinent features of the IQI are visible in the image.

6.1.12 *Representative Quality Indicators (RQIs)*—When used, RQIs shall comply with the requirements of Practice E1817. Users shall visually inspect RQIs for damage and cleanliness in accordance with Table 2.

6.1.13 ~~*Use of Calibrated Line Pair Test Pattern and Step Wedge:*~~ *Relative Image Quality Indicators (RIQIs)—*

~~7.2.4.1 A calibrated line pair test pattern and step wedge may be used, if so desired, to determine and track performance in terms of spatial resolution and contrast sensitivity. The line pair test pattern is used without an additional absorber to evaluate system spatial resolution. The step wedge is used to evaluate system contrast sensitivity.~~All RIQIs shall comply with the requirements of Practices E746 or E1735 as applicable, except the material type may be of any material deemed appropriate by the Cognizant Radiographic Level 3. A COC is required to verify material type and dimensional accuracy. Users shall visually inspect RIQIs for damage and cleanliness in accordance with Table 2.

~~7.2.4.2 The step wedge must be made of the same material as the part with steps representing 100, 99, 98, and 97 % of both the thickest and the thinnest material sections to be examined. The thinner steps shall be contiguous to their respective 100 % section thicknesses to facilitate discerning the minimum visible thickness step. Other thickness steps are permissible upon agreement between the user and the supplier.~~

~~7.2.4.3 The line pair test pattern and the step wedge tests shall be conducted in a manner similar to the performance measurements for the IQI or RQI set forth in 7.2.2 and 7.2.3. It is permissible to adjust the X-ray energy and intensity to obtain a usable line pair test pattern image brightness. In the case of a radioisotope or X-ray generating system where the energy or intensity may not be adjusted, additional filtration may be added at the radiation source to reduce the contrast to a useful level. Contrast sensitivity shall be evaluated at the same energy and intensity levels as are used for the CR technique.~~

~~7.2.4.4 A system that exhibits a spatial resolution of 3 line pairs/mm, a thin-section contrast sensitivity of 3 %, and a thick-section contrast sensitivity of 2 % is considered to have an equivalent performance level of 3 - 2 % - 3 lp/mm.~~

6.1.13.1 *RIQI Absorber Plate*—The ~~line pair test pattern and the step wedge~~ absorber plate shall be of the same material group or radiographically similar material as the RIQIs. Dimensions and surface finish shall comply with Practice E746 or E1735 as applicable. Other thicknesses may be used ~~to make more frequent periodic system performance checks than required in accordance with~~when approved by the Cognizant Radiographic Level 3. A COC is required to verify material ~~7.2.1. Resolution and contrast sensitivity checks must be correlated with IQI or RQI performance measurements. This may be done by first evaluating system measurement~~ type and dimensional accuracy and surface finish. Users shall visually inspect the RIQI absorber plate for damage and cleanliness in accordance with ~~7.2.2~~Table 2 ~~or .7.2.3 and immediately thereafter determining the equivalent spatial resolution and contrast sensitivity values.~~

6.1.14 *Duplex Wire Gauge (DWG)*—Spatial resolution and unsharpness measurements shall be performed using a DWG that complies with Practice E2002. A COC is required to verify dimensional accuracy. Users shall visually inspect the DWG for damage and cleanliness in accordance with Table 2.

6.1.15 *CR Test Phantom*—The CR test phantom shall comply with Practice E2445. Either the Type I or the Type II CR test phantom is acceptable for compliance to this practice. A COC is required to verify dimensional accuracy and compliance to E2445. Users shall visually inspect the CR test phantom for damage and cleanliness in accordance with Table 2.

6.1.15.1 In the event an E2445 compliant CR test phantom is not available, other types of gauges or phantoms may be used when approved by the Cognizant Radiographic Level 3 and when applicable, COCs are available to verify dimensional accuracy.

6.1.16 *Reference Standard*—When image features are measured for accept/reject evaluations, a calibrated physical standard shall be used when calibrating the software measurement tool. Users shall visually inspect the reference standard to ensure the calibration is current and for damage and cleanliness in accordance with Table 2. A dimensional calibration of the measuring function based upon a verifiable scanned pixel size may also be used.

6.1.17 *Measurement Tools*—As an alternative to the reference standard, a feature or item included in the image, such as the IQI, may be measured with a calibrated measurement tool (e.g., calibrated dial caliper) to establish software calibration. Users shall ensure the calibration is current in accordance with Table 2. A dimensional calibration of the measuring function based upon a verifiable scanned pixel size may also be used.

6.1.18 *Contrast Sensitivity Gauge*—Contrast sensitivity gauges shall comply with Practice E1647. A COC is required to verify material type and dimensional accuracy. Users shall visually inspect contrast sensitivity gauges for damage and cleanliness in accordance with Table 2.

6.1.19 ~~*Importance of Proper Environmental Conditions*~~—*Miscellaneous Radiographic Tools*—~~Environmental conditions conducive to human comfort and concentration will promote examination efficiency and reliability. A proper examination environment will take into account temperature, humidity, dust, lighting, access, and noise level factors. Proper reduced lighting intensity is extremely important to provide for high-contrast glare-free viewing of images.~~Holding fixtures, tooling, and other miscellaneous radiographic aids may be used to aid the radiographic set-up, and shall not interfere with the radiographic image clarity in the AOI or the image of the IQI. Devices used as radiographic set-up aids shall be examined for damage and cleanliness prior to use.

6.2 *CR System Preventative Maintenance (PM)*—Preventative maintenance shall be performed to ensure the system generates uniform images free of artifacts that would interfere with image interpretation and evaluation in the AOI. Preventative maintenance requirements shall be as stated by the system manufacturer. After PM or repairs, retesting to Practice E2445 is required.

6.3 *Facilities*—Facilities shall be kept clean and equipped so that acceptable radiographic images are produced in accordance with this practice.

6.3.1 *Cleanliness*—Environmental conditions involving dust, dirt, or debris shall be controlled to prevent introduction of artifacts to the images and to minimize wear on the CR system hardware.

6.3.2 *CR IP Loading and Scanning Area:*

6.3.2.1 The surface of the IP loading and scanning area shall be kept visibly clean and free of dust and dirt particles so that contamination is not introduced into the IP cassette or CR scanner

6.3.2.2 Exposed IPs should be handled in conditions of subdued background lighting. It is recommended that exposed IPs be subjected to no more than 2500 *lux* × *seconds* of visible light prior to scanning.

6.3.2.2.1 *Discussion*—

The overall exposure to background lighting determines the signal loss and radiographic image quality degradation. Exposure is equal to the lighting intensity multiplied by time.

6.3.3 *Image Viewing Area*—The image viewing area shall be an area with subdued background lighting with the equipment arranged in such a manner to prevent reflective glare from the surface of the image display monitor. Subdued lighting, rather than total darkness, is required in the image viewing area.

6.3.3.1 *Background Ambient Light Level*—Background ambient light levels shall not exceed 30 lux (3 fc) at the image display monitor used for image analysis and final disposition. Background ambient light levels shall be measured at the surface of the image display monitor with the monitor off and recorded in accordance with Table 2.

6.3.4 *Environmental Conditions*—Humidity and temperature shall be maintained within the limits stated by the equipment and IP manufacturer.

6.4 *Software*—All software shall be revision controlled. The following software features and tools are required:

6.4.1 *Line Profile*—A line profile function capable of displaying the pixel values (PVs) along a user defined line as a graph. The line profile tool should also be capable of adjusting the line width where the values of the line profile are averaged across the line width.

6.4.2 *Region of Interest Tool*—A histogram type tool capable of displaying the PVs of a user-defined Region of Interest (ROI) as a graph. The ROI tool shall also display the size of the ROI (e.g., *x* pixels by *y* pixels), and as a minimum, the statistical mean and standard deviation of the ROI PVs.

6.4.3 *Negative/Positive Image Display*—Display images in either negative or positive gray scale (negative or inverse).

6.4.4 *Linearized Pixel Values*—The software shall be capable of performing calculations using linearized pixel values.

6.4.4.1 *Discussion*—Linearized pixel values, which are directly proportional to the exposure dose, are required for measuring values such as normalized signal to noise ratio (SNR_N). The linear pixel value is zero if the radiation dose is zero.

6.4.5 *Digital Image Magnification (Zoom)*—Adjust and display the digital magnification level, as well as display the image at 1:1 pixel mapping (i.e., each pixel of the image is mapped to an image display monitor pixel).

6.4.6 *Image Pan*—Capability to pan the image.

6.4.7 *Window Width and Window Level (Window/Level)*—Adjust window width (contrast) and window level (brightness).

6.4.8 *Size Measurement Tool*—Perform measurements for distance or sizing of discontinuities. The software shall be capable of calibrating the measuring tool to a reference standard.

6.4.8.1 *Software Calibration*—When the system software is capable of self-calibration, such as using pixel size and set up geometry, a reference standard (6.1.17) may not be required when the software has been validated during system qualification (7.1).

6.4.9 *DICONDE Compliance*—Compliance with Practice E2339 and E2738 is recommended.

6.4.10 *Image Format*—Lossy compression shall not be allowed for images that are used for final product disposition. For systems that are not DICONDE compliant, TIFF images are recommended.

6.4.11 *Image Processing Software*—Image processing used for final product disposition shall be verified by adequately displaying the pertinent IQI or RQI features. The software shall be capable of saving a copy of the radiographic image with image processing applied.

~~**8. Examination Interpretation and Acceptance Criteria**~~

~~8.1 *Interpretation*—Interpretation is performed by an operator in a typical CR environment.~~

~~8.2 *Personnel Qualification*—The supplier and user should reach an agreement as to operator qualifications, including duty and rest periods.~~

~~8.3 *Accept/Reject Criteria*—Accept/reject criteria is a matter of contractual agreement between the user and the supplier.~~

7. Procedure

7.1 *System Qualification*—Prior to the examination of production hardware, the CR system shall be tested to establish baseline performance as required in Practice E2445, as well as its suitability for its intended application. In addition to the E2445 tests, the following minimum tests shall be conducted:

(a) Determine if saturation occurs below the maximum theoretical PV.

(b) Applicable software tools described in Section 6 shall be tested and verified, e.g., "the line profile tool shall display the pixel values along a user defined line as a graph," an example of this requirement can be seen in Practice E2002 Figure 2(b) and Figure 3. A line profile tool that only shows the graph, but does not display the pixel values, would not meet the requirements of subsection 6.4.1.

(c) Image display monitor(s) shall be tested to ensure the requirements of subsection 6.1.8 and 6.1.9 are met.

(d) Background ambient light per 6.3.3.1.

(e) Image archiving and retrieval shall be tested and verified.

(f) When systems are intended to be used outside of specified environmental conditions, such as portable systems, system qualification tests shall be performed in the expected conditions for temperature and humidity.

7.1.1 *System Qualification Test Plan*—System qualification shall be documented as a qualification test plan and shall include a complete list of the system components and software (including revision level).