1. **SCOPE**

This document provides requirements for using filmless digital computed radiography (CR) as an alternative to film radiography when conducting inspections used in determining the presence of surface and internal discontinuities in metals. Use of CR for production inspections requires specific written approval of NAVSEA prior to implementation. Requests for implementations of CR shall specifically state the application, equipment to be used and techniques to be employed.

Computed radiography (CR) may be performed on metals including weldments when the modified provisions of T9074-AS-GIB-010/271, as indicated within this document, and all other base requirements of T9074-AS-GIB-010/271 applicable to performing general radiography are satisfied. For purposes of this document, CR is considered part of the existing radiographic method, i.e. a “radiograph” can consist of a film or digital image.

2. **Non-Government Publications**

American Society for Testing Materials (ASTM)

E 1316 Standard Terminology for Nondestructive Testing
E 2445 Standard Practice for Qualification and Long Term Stability of Computed Radiology System
E 2446 Standard Practice for Classification of Computed Radiology Systems

3. **Definitions**

Definitions of terms used in this document may be found in NAVSEA T9074-AS-GIB-010/271 or other standards listed in section 1.4. In the event of conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

3.1 **Pixel Pitch (Sampling Pitch).** The brightness of a given spot on the phosphor when it is scanned in a CR system is proportional to the dose of radiation received at that spot. Linear pixel mapping shall be used for image analysis. Other pixel mapping schemes, such as logarithmic may be used for information but not final image analysis. Many CR scanners will read the plate using a raster scan of the plate, line by line, from the top to the bottom of the plate. Data samples are taken many times per inch or per mm along each line. The spacing between lines is often the same as the spacing between the samples along a line, creating an array of data samples with equal X and Y spacing. This is called sampling pitch or pixel pitch.

3.2 **Pixel Value (PV).** The numerical value assigned to a data sample (pixel) depends on the
number of bits used by the analog to digital converter in the scanner. An 8 bit converter can only create 256 steps or values from lowest value to highest value. A 12 bit A to D converter produces 4096 steps from darkest to brightest phosphor sample value. Each sample of the phosphor brightness is called a pixel value (PV).

3.3 Saturation. At times the brightness of a phosphor sample spot can exceed the A to D converter’s input range of sensitivity. When this occurs, the value of a scanned sample (pixel) is saturated because the A to D cannot convert a sample beyond its designed maximum.

4. Activity Approval

NAVSEA approval is required for an activity to perform CR for production inspections and specific written approval shall be obtained prior to implementation. Approval is contingent upon having a certified RT Text Examiner who meets the minimum CR training and work time experience (WTE) specified herein. The Test Examiner shall also demonstrate to the satisfaction of NAVSEA, process proficiency with approved procedures on NAVSEA-selected test props or production hardware, as required by Appendix A. Requests for use of CR shall be submitted to NAVSEA and shall include a copy of the CR written procedure(s), shooting sketches (if applicable), documentation validating CR system qualification, and a copy of the activity’s written practice for NDT personnel certification.

5. Computed Radiography Personnel Certification

All CR personnel shall be certified in accordance with a written practice that meets the requirements of NAVSEA T9074-AS-GIB-010/271 and the additional requirements contained herein. Personnel performing CR inspections or reviewing and evaluating CR images shall be examined and certified as a Level I Operator, Level II Inspector, or Level III Test Examiner in accordance with their employer’s written practice and shall meet the specific training and WTE stated herein. All of the required training hours and experience hours in TC-1A apply, with the exception that in lieu of the 24 hours of additional CR experience required for RT film certified Level II Inspectors and Level III Examiners in TC-1A, 160 hours of additional CR experience is required.

6. Computed Radiography Equipment Qualification

6.1 CR System. Each CR system to be used for final acceptance inspections shall be fully qualified in accordance with Appendix A, “Qualification Requirements for Computed Radiography Systems”. Records of system qualification shall be made available to NAVSEA or its authorized representative prior to performing any inspections. Periodic re-qualification of a previously qualified CR system is not required; however, repairs or replacements performed on CR systems that may affect the image quality shall necessitate re-qualification of the CR system to the requirements of Appendix A. Upgrades of CR system components, (e.g. scanner/readers with different resolutions, change of gray scale bit depth or use of different manufacturer’s equipment) shall necessitate a complete re-qualification to all requirements of Appendix A. Each CR system used for production inspections shall display a suitable calibration label validated by the responsible CR Test Examiner or an individual designated by the responsible CR Test Examiner.
6.2 Imaging Plates. Imaging plates shall be qualified with the CR system in accordance with Appendix A. As a minimum, imaging plates shall be ASTM E 2446 Class I. Use of less sensitive imaging plates (Class II, III, etc.) requires NAVSEA approval.

6.2.1 Image Plate Storage/Shelf Life

CR image plates are generally more sensitive (compared with film) to background sources of ionizing electromagnetic radiation, including intense natural sunlight, cosmic or other background sources of natural or artificial radiation. Image plates exhibiting visual evidence of degradation shall be erased and evaluated to the requirements of section 6. of Appendix A for unacceptable performance. Image plates exhibiting unacceptable performance shall not be used for production inspections. Scanning an exposed production IP if the latent image has been left on it for more than 24 hours is not recommended.

6.2.2 Image Plate Storage

Unexposed image plates shall be stored in a dark and dry environment and in a manner such that they are protected from sources of ionizing background exposure. Exposed image plates should be promptly processed in a facility where image plates are protected from these type conditions. It is recommended that all image plates be “erase cycled” prior to production use if the image plate has not been used (at least one exposure/erase cycle) for two weeks.

6.2.3 Shelf Life

Image plates used for computed radiography may contain hydrogenous (moisture absorbent) phosphors. Commercial image plates have protective coatings. Through wear and tear the phosphor material will become exposed to the humidity. Since the amount of wear is dependent upon the extent and type of use, no specific shelf life can be specified. It is recommended that image plates be inspected on a routine basis for surface wear and any signs of discoloration that could affect image quality.

6.2.4 Handling Image Plates

Since image plates can be used many times, their handling is an important issue to minimize artifacts and extend their useful life. Protective plastic on lead screens should not be removed to help prevent IP contamination from the lead. Image plates are especially prone to contamination from sources like lead oxide residues commonly associated with filter screens. Oily residues from unprotected fingers and hands can produce images of fingerprints on the CR image. Image plates should be handled with soft lint free gloves and kept free from any source of contamination that could result in artifacts (see 2.3.3) or reduce the image plate life.

6.2.5 Worn or Degraded Image Plates

The useful life of a CR Image Plate (IP) depends on a number of factors like physical damage mentioned above and the total dose the phosphor as seen to date. The exact re-usable life of a computed radiography image plate is dependent upon numerous issues, including the physical composition and quality of the commercial phosphor. All commercial phosphor based image plates used for industrial computed radiography have a finite re-
usable exposure life that requires periodic quality assurance monitoring. This assurance process shall be provided by the responsible activity's qualified CR level III Examiner or his/her duly authorized representative as detailed within the activity's qualified CR examination procedures. The assurance process shall consist of the following minimum attributes:

(a) Each image plate used for production examinations shall have a unique serialization mark, number, or equivalent record
(b) Each production inspection image shall be evaluated by a qualified CR Inspector for image quality compliance with this standard
(c) Any inspection image exhibiting signs of degradation that could mask or be confused with any defect shall be cause for re-evaluation of that image plate to the requirements of section 6. of Appendix A. Any image plate exhibiting unacceptable base sensitivity or objectionable conditions as prescribed under section 2.3 of this standard shall not be used for production inspections.

7. Computed Radiography Supplemental Requirements

7.1 General Requirements

The computed radiographic method of testing is used for determining the presence of discontinuities in all ferrous and nonferrous metals. The computed radiographic inspection methods specified herein are intended to apply to all items requiring radiographic inspection, in compliance with applicable specifications, drawings, contracts or purchase orders. One of the following shall be used in computed radiographic inspection:

(a) Low energy X-ray (up to and including 320 KV)
(b) Selenium-75
(b) Iridium-192
(c) The use of other radiation sources requires specific NAVSEA approval

7.1.1 Computed Radiographic Written Procedure

Prior to the performance of computed radiographic inspections to the requirements of this document, CR equipment (including hardware, software and image plate types) shall meet the requirements of Appendix A, “Qualification Requirements for Computed Radiography Systems”. Written computed radiographic inspection procedures shall contain, as a minimum, the following elements.

7.1.1.1 Minimum Radiographic Procedure Requirements

(a) X-ray machine information.
   (1) Model and type
   (2) Manufacturer
   (3) Focal spot size
   (4) Voltage rating
   (5) Maximum tube current (milliamps)
(b) Isotope source information.
   (1) Type of isotope(s) to be used
   (2) Isotope source dimensions (maximum)

(c) CR and CR system information.
   (1) CR system manufacturer and model
   (2) Scanner model identification and maximum resolution (pixels/mm)
   (3) Processing station software identification and version
   (4) Inspection monitor type, maximum display resolution and diagonal view dimensions
   (5) Calibration methods and frequency intervals for display monitor(s) and the scanner
   (6) Background illumination requirements for electronic viewing area
   (7) Image plate (IP) types used: manufacturer, series number
   (8) Digital image file format used and capability to save and read DICONDE-compliant image files
   (9) Method used for preservation of original digital images (meta files, digital layers, watermarks, etc)
   (10) Digital image archiving media (magnetic, optical or flash), storage and retrieval methods
   (11) Filter screen types, thicknesses and relative locations within the IP cassette
   (12) Pixel intensity value (PV) requirements (minimum and maximum numeric values, PV tolerances for pixel values in areas of interest and image quality indicators)
   (13) Image identification as specified in NAVSEA T9074-AS-GIB-010/271 paragraph 3.4.8
   (14) Recommended isotope and voltage ranges for inspected material thicknesses
   (15) Length measuring calibration process, including details of reference to be used and location of reference (source side, film side).
   (16) Image processing methods and techniques employed, including ability to save and archive each original inspection image (e.g. digital watermarks, meta files or other tracking method).

7.2 Computed Radiography Process Requirements

7.2.1 Filter Screens

Computed radiographic image quality usually benefits from the use of front and back filter screens. Optimization of screen material types, thicknesses and exposure positioning
arrangements for CR is dependent upon specific techniques and multiple variables including: exposing radiation energy level, radiation intensity, part thickness, material type, environmental conditions, IP type or combinations of all these conditions.

Pre-collimation (between the source & object) can reduce scatter. Post-collimation and/or masking around the item being radiographed may reduce scatter and lengthen the useful life of the IP.

Filter screens should be in intimate contact with the IP during exposure with the exception of a thin layer or coating (on the IP, filter or both) used to prevent damage to the IP. Additionally, all computed radiographs shall employ a back filter screen for protection from backscattered radiation. Recommended lead filter screens for general applications are shown in Table 1.

<table>
<thead>
<tr>
<th>Energy range</th>
<th>Source-side (Front maximum)</th>
<th>Back (minimum)</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥ 30 to 90 kV</td>
<td>.002”</td>
<td>.005”</td>
</tr>
<tr>
<td>&gt; 90 to 220 kV</td>
<td>.004”</td>
<td>.010”</td>
</tr>
<tr>
<td>&gt; 220 to 280 kV</td>
<td>.005”</td>
<td>.010”</td>
</tr>
<tr>
<td>&gt; 280 to 420 kV</td>
<td>.010”</td>
<td>.010”</td>
</tr>
<tr>
<td>Se 75</td>
<td>.005”</td>
<td>.010”</td>
</tr>
<tr>
<td>Ir 192</td>
<td>.010”</td>
<td>.010”</td>
</tr>
</tbody>
</table>

Table 1: Recommended screen thicknesses for computed radiography

Notes:
1. Recommended screen material is lead oxide or lead foil (Pb). Other filter materials such as aluminum, copper, tungsten, or tantalum may be more effective.
2. Recommended thicknesses in Table 1 are nominal dimensions with no specified tolerances. Other screen material types and thicknesses may be used if image quality requirements are met.
3. All screens should be clean with no visible signs of dents or contaminants that could affect image quality.
4. Some higher energy (i.e. > 250 KV) X-ray applications may benefit from the use of tubehead diaphragms that improve primary beam directionality and reduce external radiation scattering. Similarly, when employing isotopes as the exposing radiation source, collimators are highly recommended.
5. The majority of computed radiography techniques will benefit from use of a sufficient thickness of external (behind the cassette) back scatter reducing materials such as lead or tungsten.

7.2.1.1 Backscatter Control

Lead or other suitable filter materials shall be used behind the image plate holder to prevent scattered radiation from the floor, walls, air or other surrounding objects from fogging the computed radiographic image. Each exposure shall employ the use of a lead letter “B” not less than ½ inch high and not less than 1/16 inch thick positioned behind the image plate holder within the area of the image to be read. If the image of the lead letter “B” shows a light image on a darker background, the radiograph shall be rejected. A darker image of the lead letter “B” on a lighter background is not cause for rejection provided the darker image does not interfere with evaluation of the area-of-interest.

When performing panoramic exposures, one lead letter “B” may be placed in each quadrant. The lead letter “B” is not required for radiography of circumferential welds with an inside diameter less than ¾ inch performed with a single wall exposure technique.
7.2.2 Image Quality

Digital images produced by computed radiography shall be free from artifacts which might mask or be confused with defects in the material being examined. If doubt exists concerning the true nature of an indication within the digital image, the radiograph shall be rejected and reshot. Typical digital artifact types and potential causes are as follows:

(a) Excessive blooming or flare (may be a masking or selected energy issue).
(b) Visible aliasing or other forms of electronic distortion which may be a low resolution (or large pixel sample spacing) issue
(c) Light "specs" or other light “patchy” areas where the image plate may have become contaminated with dust and/or dirt
(d) Gray scale streaking or combination patterns of light and dark areas resulting from scanner/laser slippage or other mechanical scanner maintenance issues.
(e) Loss of image detail or poor sensitivity caused by worn or degraded IPs, including IP overexposure
(f) Residual images (sometimes called ghosting) from residual images resulting from incomplete erasures or damage of the IP (see 2.3.2.1)
(g) Image “fogging” due to inadvertent or prolonged exposure to light
(h) Excessive digital noise may result from low radiation dose to the IP or scanner/image processing issues
(i) Gray scale banding or iso-intensity bands which can result from failure to utilize a wide part of the IP latitude in a given area of interest. Increasing the exposure can often correct banding.
(j) Pressure marks

7.2.2.1 Residual Images. Residual gray scale images left over from a prior exposure (positive or negative gray scale image) are usually the result of an incomplete erasure of an IP, exposure of an IP subsequent to erasure or non-reversible IP damage. Residual gray scale conditions may be exhibited on production digital inspection images provided image quality requirements are met and the residual condition cannot mask or be confused with any defect. Image plates exhibiting substantial residual images shall be evaluated to the requirements of Appendix A for unacceptable sensitivity. Image plates exhibiting unacceptable sensitivity shall not be used for production inspections.

7.2.2.2 Artifact Images. The surface of a CR image plate may hold dust and other debris which will create unwanted image artifacts. Often these materials can be physically removed as recommended by the manufacturer. Some artifacts may be due to scratches or pressure marks that occur over time due to use of the IPs. Depending on the severity and location of the artifacts relative to the areas of interest, some image plates may continue to be used provided these artifacts do not hide, mask or be confused with any defects in the item being radiographed. It is not permissible to digitally remove or alter any artifact condition on an inspection image via software or other digital correction/restorative process.
7.2.2.3 Image Plate Fading

All phosphor imaging plates undergo some degree of fading of the latent image subsequent to radiation exposure. Fading characteristics may vary from one image plate to another. Generally, some small amount of fading will occur immediately and particularly within approximately ½ hour following image plate exposure, then taper off to smaller amounts over the next 10 to 12 hours subsequent to exposure. Image quality and pixel value requirements of these requirements shall be achieved.

7.2.2.4 Pixel Value Requirements. PV values in the area of interest and penetrameter shall range between 10 percent and 95 percent of the bit depth of the system.

7.2.3 Penetrameters

Penetrameters shall be employed for all radiographs, except as specified in 3.5.5.4 (in base document) and Table IV (in base document). The penetrameter image will be employed to determine the radiographic quality level. Either MIL-type penetrameters (as defined in the following paragraphs), or ASTM-type penetrameters (as defined in ASTM E 1025) may be used. None of the requirements of this document which apply to physical size, marking, etc. of penetrameters shall be interpreted as applying to ASTM-type penetrameters. The pixel value of the penetrameter image shall be not greater than 15 percent more than the pixel value of the area of interest using linear pixel mapping. It may be less dense than the pixel value of the area of interest. The pixel value of the penetrameter shall be measured directly over the penetrameter hole used to obtain the required sensitivity.

7.2.4 Other Metals

For radiography of materials not covered herein, penetrameters of the same material shall be used, or penetrameters of any other material may be used if the following requirements are met:

(a) Two blocks of equal thickness, one of the material to be radiographed and one of the material of which the penetrameters are made, shall be radiographed on the same IP by one exposure at the lowest energy level to be used for the production radiographs.

(b) Pixel value readings for both materials shall be within range of the lowest and highest pixel values to be used on the production radiograph (see 2.3.3.4).

(c) If the pixel value for the material to be radiographed is within plus 15 percent or less than the pixel value for the penetrameter material using linear pixel mapping, the penetrameter material may be used for radiography of the production material.

7.2.5 Requirements for Castings and Forgings

One penetrameter shall represent an area within which radiographic pixel values do not vary more than ±15% from the pixel value measured as specified in section 2.4 using linear pixel mapping. One or more penetrameters per radiograph shall be used except as specified in 3.5.5.4 (in Tech Pub 271). If a shim is used, it shall be of the
same or lower group number as the item being radiographed. When the pixel value varies more than ±15% using linear pixel mapping, the radiograph shall be qualified using two penetrameters: one penetrameter must show an acceptable sensitivity at the lowest pixel value in the area of interest of the radiograph, and the second penetrameter must show an acceptable sensitivity at the greatest pixel value. For components where there are changes in wall thickness and wall alignment and the use of two penetrameters is not practical, the use of one penetrameter is approved. The above required pixel value tolerance need not be met; however, the pixel value of the area of interest shall be within the pixel value range qualified under section 2.4. Where only one penetrameter is used, the penetrameter size shall be based on the thinnest wall being radiographed and shall be placed on the thickest wall section.

7.2.6 Tapered and fillet welds

Tapered and fillet-type welds shall have a minimum of two penetrameters representing the minimum and maximum weld thickness (see figures 14 and 15 in Tech pub 271). However, one penetrameter may be used for small differences in thickness, provided that:

(a) The penetrameter size is based on the thinner section but is placed on the thicker weld section, and

(b) The pixel value of the penetrameter image is not greater than 15 percent more than the lowest pixel value in the area of interest.

7.2.7 Multiple Image Plate Techniques. Simultaneous exposure of two image plates within the same cassette holder (e.g., to clear artifacts) is permitted as long as the system and procedure was qualified with the simultaneous exposure of the two plates.

7.2.8 Digital Imaging Techniques Other than Computed Radiography. The use of other modes of digital imaging (e.g. flat panel direct detectors, image intensifiers, etc.) shall be limited to in-process inspection and shall not be permitted for final acceptance inspection unless specifically approved by NAVSEA.

7.2.8.1 Printed Computed Radiography Images. Printed reproductions of computed radiographic digital images shall be limited to in-process evaluations or to facilitate repairs and shall not be permitted for final acceptance inspection or archival image storage unless approved by NAVSEA.

7.2.9 Radiation Sources for Computed Radiography

Cobalt 60 and high energy X-ray sources of radiation shall not be used with computed radiography without approval of NAVSEA or its authorized representative.

7.2.10 Lighting Conditions Affecting Imaging Plates

CR image plates are generally not overly sensitive to low intensity room lighting sources for short periods (e.g., generally less than a minute or 2500 lux-seconds as a guideline). Exposed production CR image plates shall be handled in conditions of
7.2.11 Image Viewing Facilities

CR images on a monitor shall be viewed in a facility with subdued ambient lighting. This area should be free from sources of glare or secondary light reflections.

7.2.11.1 Image Viewing Equipment

Viewing equipment used to evaluate CR digital images shall conform to the requirements specified in Appendix A “Qualification of Computed Radiography Systems”. The following requirements apply:

(a) Prior to performing inspections at the beginning of each shift, each qualified CR Inspector shall display the Society of Motion Picture and Television Engineers (SMPTE) test pattern image RP-133 on the electronic display to be used for evaluation of production inspections. Screen brightness and contrast may need to be adjusted in conjunction with ambient lighting to suit the needs for each CR Inspector. All SMPTE test pattern targets shall be clearly discernible as defined in Appendix A. Re-evaluation of the electronic display used for inspections shall minimally be performed at the beginning and end of each shift, following all repairs and/or major adjustments of display system, and anytime an inspector may have reason to question the performance of the electronic display system. An electronic display system that does not meet any of these requirements shall not be used for production inspections.

(b) Measuring scales: Electronic measuring scales used for determining dimensions of computed radiographic images shall be capable of providing accurate dimensions of the image. The measurement scale tool or method shall be based upon a reference feature with known dimensions that is part of the permanent digital inspection image. Electronic measurement accuracy shall be evaluated as part of the Appendix A system qualification.

(c) Digital enlargement of images: Digital enlargement (electronic magnification) of computed radiographic images is permissible up to a maximum of 3X (300%) provided all image quality requirements are met at the enlarged size. Any digital image processing, including enlargements, shall comply with the image quality requirements of 2.3.2.

(d) CR software shall be capable of saving all annotations, measurements, records, notes, etc. associated with the original production digital image file in electronic format.

8. Computed Radiographic Records

Computed radiographic records shall contain the following as a minimum:
(a) The information specified in T9074-AS-GIB-010/271

(b) The original unmodified, un-enhanced inspection image for each inspection view. This original inspection image shall always be saved and shall be clearly identified as such with digital watermarks, Meta files (digital annotations are acceptable) or equivalent. In the event it is necessary to save a modified version of the original inspection image (as when processed with filters and overwritten), the modified inspection image shall clearly reflect that it is no longer an original inspection image. When a modified inspection image is to be saved, it shall use a different file name and ensure it is linked to the original inspection view.

(c) Each inspection image file shall contain identification of the original software manufacturer and version used to perform original production inspections. Each CR storage media (e.g. optical, magnetic or flash) shall contain a text file identification of the software manufacturer and version used to perform original production inspections. It is permissible to group inspection images within a single storage media with single text file identification.

8.1 Computed Radiographic Records Archiving and Safeguarding

All records, digital or hardcopy, associated with CR inspections shall be maintained in a manner that will comply with contractual requirements. Storage media for digital images and viewing software shall comply with the requirements of ASTM E-1453 “Standard Guide for Storage of Media that Contains Analog or Digital Radioscopic Data”. CR image storage media shall be capable of securely storing digital inspection images for a minimum of 50 years and shall be write-protected.

All CR inspection images made to the requirements of this standard shall maintain a minimum of at least one “backup” copy in addition to the primary copy of original inspection images. Backup image files shall meet all requirements as specified in this document. It is recommended that backup inspection images be stored in a secure facility remote from the facility where primary images are located.

CR inspection image files must be safeguarded from any environmental factors that could damage storage media, including excessive heat, moisture, magnetism, sources of ultra violet light or sources of mechanical abrasions. Production inspection images entered into long term storage should be checked from time to time to assure integrity of storage facilities and inspection images.

8.1.1 Short Term Archiving

Qualified CR systems shall employ the capability to archive inspection images for a minimum period of three years from date of initial inspection such that subsequent reviews may be performed with the same image viewing and evaluation software (or equivalent version) used during original inspections.

8.1.2 Long term archiving
Qualified CR systems shall employ the capability to archive inspection images longer than 3 years such that subsequent reviews may be performed with any type DICOM viewing and evaluation software that supports, as a minimum, the contrast, brightness, magnification and linear measurements of the original inspection image. Long-term viewing software may be embedded with the image storage media or with stand-alone viewing software. Archived images shall be capable of subsequent review with hardware that has DICOM equivalent or better capability than used during original inspections.

8.2 Computed Radiographic Image Ownership

Unless otherwise specified, digital radiographic images and all associated inspection records of an item shall become the property of the purchaser of the item. Maintenance of digital radiographic images shall be as specified in section 2.3.10.
Appendix A
Qualification Requirements
for Computed Radiography Systems

1. Scope

This document is a mandatory appendix to NAVSEA Requirements for Computed Radiography and specifies minimum technical requirements for qualification of computed radiography (CR) systems.

3. Reference Documents

3.1 American Society for Testing and Materials (ASTM):
3.1.1 E-746 Standard Practice for Determining Relative Image Quality Response of Industrial Radiographic Imaging Systems
3.1.2 E-1316 Standard Terminology for Nondestructive Testing
3.1.3 E-1453 Standard Guide for Storage of Media that Contains Analog or Digital Radioscopic Data
3.1.4 E-2002 Standard Practice for Determining Total Unsharpness in Radiology
3.1.5 E-2007 Standard Guide for Computed Radiography
3.1.6 E-2445 Standard Practice for Qualification and Long-Term Stability of Computed Radiology Systems
3.1.7 E-2339 Standard Practice for Digital Imaging and Communications in Nondestructive Evaluations (DICONDE)

3.2 Society of Motion Picture and Television Engineers (SMPTE):
3.2.1 Recommended Practice #RP-133 “Specifications for Medical Diagnostic Imaging Test Pattern for Television Monitors and hard-Copy Recording Cameras”

5. General Computed Radiography System Requirements

Prior to commencement of any computed radiography qualifications to this standard, the candidate CR system shall meet minimum hardware and software requirements as defined in sections 5.2 and 5.3. These minimal requirements employ high resolution digital imaging systems with 50 microns (.05 mm) acquired image pixel size.

5.2 Hardware Requirements – The following requirements are applicable for all system classes:

5.2.1 Scanner/Reader Unit (SRU)
5.2.1.1 Image Acquisition System – CR data acquisition systems (scanner/reader) shall be capable of a minimum gray scale range of 12 bits (4096 levels of gray) and shall have a minimum scan resolution of 50 microns or 0.05 mm (20 pixels per mm of image plate scanned) in both horizontal and vertical scan dimensions.
5.2.1.2 Image Plates and Erasures – Image plate erasures may be performed as either an
integrated component of the scanner operation or as an adjunct to image plate scans and shall leave no residual images that can interfere with inspections.

5.2.1.3 PMT Calibration – CR system photomultiplier tube (PMT) components shall be calibrated as required by the system manufacturer. If recommended by the system manufacturer, calibration type and frequency shall become part of the activity’s procedures.

5.2.1.4 Gray Level Compensation – Algorithms used in conjunction with scanner/reader firmware and/or software for compensation of gray level variation across the width of the scanned image shall not induce visible gray scale banding on the displayed image that interferes with inspection.

5.2.1.5 Original Digital Image – CR system scanner/reader equipment shall be capable of producing a digital gray scale image data file whose pixel data is linearly proportional to radiation dose received prior to any image processing. The image data file will be created by application of original binary pixel data to a linear digital look-up table.

5.2.2 Central Processing Unit (CPU) – Any CPU capable of acquiring, processing, displaying, archiving and retrieving high quality computed radiographic images that comply with requirements of this standard may be used.

5.2.3 Electronic Display – Display of inspection images shall be performed on an electronic monochrome monitor with the following minimum capabilities:

5.2.3.1 Monitors – Monitors shall have a minimum display capability of 8 bits (256 shades) of gray scale. Minimum brightness, as measured at the monitor screen at maximum digital driving level, shall be 500 cd/m². Minimum contrast, as determined by the ratio of the monitor screen brightness at the maximum digital driving level compared to the monitor screen brightness at the minimum digital driving level, shall be 800:1. The above display parameters may be provided by the CR system supplier or equivalent qualified organization.

5.2.3.2 Monitor Resolution – Images shall be displayed with a maximum pixel pitch of 0.165 mm in both horizontal and vertical dimensions. The viewing area shall be such that the examined part (or designated part view) is visually present on the display without digital magnification. A maximum of 3X digital enlargement of the original image size is permitted for CR system qualifications, except for the laser beam function evaluation of section 6.2.1.2 where 4 X digital magnifications is required.

5.2.3.3 Display Verification – Display systems shall be capable of rendering faithful reconstruction of an electronic SMPTE test pattern image (Figure 1 illustrates a SMPTE test pattern) over the full inspection area of the monitor with no image processing. A qualified CR Inspector (see 2.2) shall certify that all contrast and resolution test targets can be successfully resolved as described within SMPTE RP-133. The following is a list of all required display performance parameters:

- Is the primary display system capable of rendering faithful reconstruction of all SMPTE RP-133 image targets over the range of digital driving levels?
- Are all vertical and horizontal resolution bars resolved in all 4 corners of the SMPTE pattern?
- Are 0% to 100% contrast squares (11 different targets) of the SMPTE pattern visually resolved over the range of system digital driving levels?
- Are all vertical and horizontal resolution bars resolved in the central area of the SMPTE pattern?
- Are top and bottom shading bars (long horizontal bars) of the SMPTE pattern discernible
over the entire gray scale range?

5.2.4 Image Archiving – CR systems shall have adequate capability to reliably store and retrieve acquired digital inspection images as described herein.

5.2.4.1 Storage and Retrieval – CR systems shall be capable of reliably storing and retrieving acquired full physical size, full pixel density and full bit depth digital images with any image annotations and dimensional measurements.

5.2.4.2 Storage Media – CR systems shall be capable of storing digital inspection images described in 5.2.4.1 on magnetic, optical or flash memory in compliance with ASTM E-1453 “Standard Guide for Storage of Media that Contains Analog or Digital Radioscopic Data”.

5.2.4.3 Hardware – CR system hardware shall support short and long term image storage requirements described under 5.3.5.

5.2.4.4 Image Compression – CR system hardware used for storage of compressed digital images shall support loss-less compression methods.

5.2.4.5 Printed Images – Printed digital images are not permitted for inspections or short or long term archival storage requirements; however, printed images may be used to facilitate repairs or in-process inspections.
5.3 Software Requirements – Computed radiography system software is grouped into categories:
   a) Acquiring a digital image;
   b) Display and evaluation of a digital image and c) Storage of the digital image.

   The following requirements are applicable for all system classes.

5.3.1 Acquiring a Digital Image – CR system acquisition software shall support hardware functions defined in 5.2 with the following specific capabilities:

   5.3.1.1 Original Digital Image – See 5.2.1.5 The original image data file is not required to be a viewable image; however, this data file shall be accessible for determination of pixel value requirements as specified in 5.3.1.3 of this standard. When an original image data file is not viewable on a qualified CR system, an original examination image (see 5.3.1.2) shall be used in conjunction with an original image data file for system qualification as specified within this standard.

   5.3.1.2 Original Examination Image – CR system viewing software shall be capable of producing a permanent digital image used to examine a part or area-of-interest. This original examination image may be derived from an original digital image data file as defined in 5.3.1.1 or a processed original digital image as defined in 5.3.2.4 provided the image file structure used to perform the examination is a permanently saved digital image file.

   5.3.1.3 Original Image Data File Linearity – The acquired original image data file in 5.3.1.1 shall be linear within ±10% of the mean measured pixel intensity value (PV) over the range of PV 500 through PV 3000 for 12 bit systems or over the range of PV 8000 through PV 48000 for 16 bit systems. Figure 5 illustrates PV/exposure linearity for 12 bit systems.

   5.3.1.4 Image File Format – The original image data file shall be acquired and saved in any file format that can be opened and displayed as required by this standard. The original image data file format shall be capable of conversion to an original DICONDE compliant image format as may be required.

5.3.2 Image Viewing and Evaluation – The following are minimum software capabilities for viewing and evaluation of CR inspection images. Viewing and evaluation software shall be capable of:

   5.3.2.1 Opening and displaying an original image data file or original examination image acquired in accordance with 5.3.1.1 and 5.3.1.2 with a non-distorted and true dimensional display representation.

   5.3.2.2 Opening and displaying saved digital images, as defined in 5.3.1.3 and 5.3.2.6, with embedded text annotations and dimensional measurements associated with image evaluations.

   5.3.2.3 Determining pixel value (PV) of an original digital image within a minimum area of one scanned pixel and within a minimum determined pixel area of 625 square pixels (25 x 25 pixels).

   5.3.2.4 Performing basic image processing functions: 1) adjust brightness (digital driving level change); 2) contrast adjustment (window level); 3) digital magnification of the original inspection image up to and including 300% (3X); 4) either incremental rank type pixel sharpening filter or incremental high-pass sharpening filter (removes low frequency
information).

5.3.2.5 Measuring, displaying and saving linear distance measurements between two selected points (that do not exceed 2 linear inches at 1 X magnification) with an accuracy of ± 1/64 inch using measurement software calibrated against a standard of known dimensions.

5.3.2.6 Tracking any processing changes that permanently alter the structure of the saved original digital image file, i.e. with accompanying digital water marks, Meta files, text files or combinations of these methods that include date of the change and qualified inspector who made the change.

5.3.2.7 Performing pixel line profile scans with a minimum sensitivity of one scanned original image pixel and displaying all original scanned pixel intensity values as a function of linear scanned distance.

5.3.2.8 Determining average and standard deviation pixel intensity values of selected pixel groups within a minimum 625 square pixel area for the original digital image.

5.3.2.9 Rotating image display 360 degrees in 90 degree increments (minimum) and horizontally flip image display 180 degrees.

5.3.2.10 Simultaneous display of at least two separate digital images on the same monitor screen or alternatively, two separate display monitors that can be independently evaluated.

5.3.2.11 Import and display of digital image file formats defined in 5.3.1.3.

5.3.3 Viewing and Evaluation with a Reference Digital Image – The following minimum software capabilities are applicable for viewing and evaluation of CR inspection images when a reference digital image is required.

5.3.3.1 Gray Scale Mapping – The capability to apply same gray scale mapping functions (i.e. digital driving levels for brightness and contrast adjustment) to both inspection and reference digital image (i.e. linear, exponential or custom gray scale maps).

5.3.3.2 Magnification – The capability to apply the same level of digital magnification for both inspection and reference digital image.

5.3.3.3 Image Processing – The capability to apply equivalent image processing, as defined in 5.3.2.4, to both inspection and reference digital image.

5.3.4 Optional Image Viewing and Evaluation – Following are optional permissible software capabilities that may extend the capabilities of some computed radiography systems for more complex inspection applications. Any of these optional provisions may be employed provided all image quality requirements of 2.1 are met.

5.3.4.1 Histograms – Each pixel within an image is mapped to a measured level of pixel intensity value and usually displayed as a graph where pixel intensity value is plotted as a function of the number of pixels with the same value. Either manual or automatic techniques may be employed whereby unused or degrading pixels may be eliminated or reduced from further image processing; thus, potentially improving overall image quality, dynamic range or both.

5.3.4.2 Electronic Image Transmissions – PACS (Picture Archiving and Digital Communications Software) or equivalent capability supports electronic transmission of compliant digital image file formats over large area networks and other compliant digital networks. Some applications may benefit from electronic transmission of acquired images to inspection workstations or the sharing of completed inspection images with reviewing activities.

5.3.5 Image Saving and Archiving
5.3.5.1 **Original Examination Image** – The original image used for examination of an area-of-interest, as defined in section 5.3.1.2, shall always be saved and shall be clearly identified as such with digital watermarks, Meta files (digital annotations are acceptable) or equivalent. In the event it is necessary to save a modified original examination image file (as when processed with filters and overwritten), the modified digital image shall clearly reflect that it is no longer an original examination image. When an original examination image is modified for the same inspected item, such images shall use different file names that are linked to the same inspected item.

5.3.5.2 **Image File Format** – The digital image file format (see 5.3.1.4) shall contain compatible “headers” and “tags” that support saving an original examination image, as per 5.3.1.2, such that subsequent electronic reviews of the original examination image file structure, including image annotations and measurements can be made. Image files shall contain text file identification of the original software manufacturer and version used to perform original production inspections. File compression techniques are permissible provided the method used is “lossless”.

5.3.5.3 **Short Term Archiving** – Qualified CR systems shall employ the capability to archive inspection images for a minimum period of three years from date of initial inspection such that subsequent reviews may be performed with the same image viewing and evaluation software (or equivalent version) used during original inspections.

5.3.5.4 **Long Term Archiving** – Qualified CR systems shall employ the capability to archive inspection images longer than 3 years such that subsequent reviews with any type viewing and evaluation software that supports, as a minimum: contrast, brightness, magnification and linear measurements of the original inspection image. Long term viewing software capability may be embedded with the image storage media or stand-alone viewing software. Archived images shall be capable of subsequent review with hardware that has equivalent or better capability than used during original inspections (see 5.2).

6. **Basic System Qualification**

This section employs the ASTM E 2445 CR test phantom (Figure 2) to assess the fundamental performance level of hardware/software capabilities associated with scanner, electronic display and software subsystems for using low energy X-ray radiation. Some provisions of ASTM E 2445 have been modified for use with this standard; therefore, where any conflicts may exist between E 2445 and this standard, the requirements of this standard shall prevail. Exposure requirements are provided in 6.1; evaluation requirements are provided in 6.2.

6.1 **ASTM Test Phantom** – Activities desiring to qualify CR systems shall obtain an ASTM E-2445 CR test phantom as illustrated in Figure 2. The reference location for each target type is painted on the plastic phantom material directly above the actual imbedded target, except for the converging line pair gauges which are visually apparent. A description of each target type is provided in the notes section of Figure 2. Each specific CR system to be qualified, as described in section 5, shall have all image targets exposed as specified in 6.1.1. Note: this test phantom may only be used with low KV X-ray radiation (see 6.1.2). Activities desiring to qualify only isotopes in accordance with this standard shall produce X-ray exposures of the ASTM test phantom as described herein. These exposures may be provided by the original CR equipment supplier or other outside activity, given such exposures are made with the specific qualifying CR system equipment and documented in qualification records of Appendix A. Use of this test phantom is intended to provide a basic
functional level of adequate mechanical and optical system performance and may not assure all CR operating components, including image plates, are functioning as required; therefore, specific CR technical image quality requirements shall be routinely monitored as required in section 7 and applicable inspection requirements.

6.1.1 Phantom Image Targets (A, B, D, EC, ER, EL, G and H) – Align an X-radiation source directly over the BAM snail target. A source-to-detector (SDD) distance of 36 to 45 inches shall be used. The IP detector shall be contained within a low absorption cassette. Lead filter screens may be used as appropriate within the image plate cassette; however, they are not required for this evaluation. Care should be taken during exposure to prevent backscattered radiation from degrading image quality. The phantom shall be exposed with low KV/high intensity X-radiation within the approximate range of 60 to 90 KV and 3 to 10 milli-amperes tube current for a minimum pixel value (PV) of 15% of saturated gray scale. For example: a 12 bit system (4096 gray scale divisions) would require a minimum PV of 614 and a 16 bit system (65,536 gray scale divisions) would require a minimum PV of 9830. Maximum PV shall not exceed 1000 (12 bit system) or 16000 (16 bit system) for this exposure area. Pixel value shall be determined in the approximate area beneath the “T” target and to the right of the BAM snail image.

6.1.2 Phantom Contrast Targets (J) – No evaluations are required.

Figure 2: ASTM CR Phantom for qualification of computed radiography systems

Target Keys:
A: T-target for Laser Jitter Test (Brass, 4.48 in. x 0.2 in.) B: Duplex Wire Sharpness (E-2002) C: Central Beam Alignment Verification (BAM Snail) D: Converging Line Pair Resolution E: EL, EC, ER: Measuring Points for Shading Correction F: Cassette positioning locator (does
not appear on image) G: Homogeneous strip
(Aluminum, 0.02 inch thick)
H: Lucite Host Plate
I:  Ruler Linearity Check
J:  Contrast Sensitivity (0.50 in. Al, 0.25 in. CU, 0.25 in. SS, E-1647).
1 = source side; 2 = IP side; 3 = gauge side.

6.2 Basic System Qualification Criteria – Evaluations are required for image distortion, aliasing, blooming, gray scale banding, improper erasures or other objectionable hardware/software performance conditions. If objectionable conditions are observed during basic evaluations, they should be corrected prior to advancement to technical imaging qualifications in sections 7, 8 and 9.

6.2.1 Phantom Image Targets
6.2.1.1 Geometric Distortions – The spatial linearity of the CR system shall be evaluated with the horizontal and vertical scales (targets H and I). The IP transport system should not allow the IP to tilt or twist during the scan resulting in geometrical image distortion. The measured spatial non-linearity shall be less than 5% as measured between any two points that do not exceed 2 linear inches at 1 X magnification (on target I) or any two points that do not exceed 5 centimeters (on target H) at 1 X magnification.

6.2.1.2 Laser Beam Function – Laser beam scan line integrity, beam jitter, signal dropout and focus are evaluated with the “T” (target A). Laser beam jitter is evaluated by examining the edges of the “T” on the image. The “T” edges should be straight and continuous. Under or over-shoot of the scan lines in the light to dark transitions along the “T” edge indicate a timing error or laser beam modulation problem. View the image scan lines with 4X magnification on the monitor in various areas across the image to check for uniform spacing. “Stair step” visual characteristics of the straight edge are normal due to digitization effects. Scan line drop out is detectable as a lucent straight line in the open field and likely represents dust/dirt particles on the light pickup guide, a fairly common image artifact. Image artifacts indicate sub-optimal performance and should be corrected by qualified personnel.

6.2.1.3 Shading (Bandaging) Evaluation (Targets ER, EC And EL) – This evaluation is used to ensure that the scanning laser intensity is uniform across the scanning width of the imaging plate as well as checking for proper alignment of the light guide/photo-multiplier tube assembly. Determine an average pixel intensity value for each of the three circles ER, EC and EL. The average pixel intensity value of the outer circles, EL and ER, shall both be within ±15% of the center circle EC.

6.2.1.4 Scanner Slipping Evaluation (Target G) – This evaluation is used to assess slipping of image plates in the scanner or any resultant distortion in the homogeneity of the scanning and reading system. The scanner-slipping target shall be visually evaluated for deviations in intensity of the scanned lines. Deviation between scanned line intensities shall be equal to or less than any visual impression of noise within the slipping target G, such that there is no evidence of slippage.

6.2.1.5 Blooming (Flare) and Aliasing (Targets A and D) – Examine the “T” target (A) for any visual evidence of intensity overshoot or streaking in areas with high density contrast. These conditions (blooming or flare) can be caused by saturation of the light detector or intensity transfer from regions with high light intensities into dark regions with a low intensity. Examine the converging line pair gauges (D) for any visual signs of distortions such as moiré
fringe patterns or non-uniformities in display of converging lines. Correct any abnormalities of hardware and/or software that cause these conditions.

Note: moiré fringe patterns within converging line pair gauges are common for higher resolution CR systems without digital magnification (1X). These patterns are not cause for rejection provided small increments (up to 3X) of digital magnification cause the patterns to greatly diminish. Care should be taken not to confuse moiré fringe patterns with other causes of rejectable image distortion.

6.2.1.6 Measured Unsharpness (Duplex Wire Gauge B) – Determine the measured unsharpness with a pixel line profile scan within the center 2/3 of the ASTM E 2002 duplex wire gauge as illustrated in Figure 3. Several scans may be acquired within the center 2/3 area of the gauge with the most representative scan selected for unsharpness measurement. A wire pair is considered resolved when the scan dip is greater than 20%. (ASTM E 2445 illustrates the basic method for determining scan dip on a duplex wire gauge). A successful qualification will achieve a profile scan dip of greater than 20% on the 10th duplex element pair (reference E 2002 for element pair identification numbers) as a minimum.

Note: total measured unsharpness will depend upon exposure geometry, unsharpness of the imaging system and other parameters such as system noise. Measurements of unsharpness for this assessment may not be determined visually. No measurements of spatial resolution are required for the converging line pair gauge; however, this gauge shall be used to assess system aliasing as required in 6.2.1.5.

6.2.1.7 Signal-To-Noise Ratio (SNR) – Determine the CR system signal-to-noise ratio (SNR) for the system by evaluation of pixel statistics within an approximate 625 square pixel area directly beneath the “T” target and to the right of the “BAM” snail. SNR is determined to the nearest tenth by \( I_{avg} \div S_d \), where \( I_{avg} \) is the average pixel intensity value (to the nearest tenth) and “\( S_d \)" is the standard deviation of pixel intensity value (to the nearest tenth). The minimum system signal-to-noise ratio shall be 100 within a PV range of 614 to 1000 (12 bit system).
Note: higher base pixel values (within the range specified) may render higher system signal-to-noise performance levels. SNR may be determined with software or manually using software derived values for I_{avg} and S_d.

6.2.2 **Image Artifacts** – Image artifacts are undesirable conditions consisting of any form of streaking, banding, inconsistent image shading, light or dark speckle, mottling, light or dark linear or scratch-like lines that would/could interfere with interpretation of production images. These type image artifacts may be associated with scanner optics, scanner hardware or software or IP handling issues and shall not interfere with basic system qualification results as determined by a CR Test Examiner qualified to the requirements of 2.1 and 2.2 herein. All IP’s shall be uniquely identified to aid with the identification of possible artifacts.

6.2.3 **Residual Images** – Residual images are undesirable images that may be left over from a prior exposure (positive or negative gray scale image) of the same image plate and are usually the result of an incomplete erasure, exposure of an image plate subsequent to erasure or non-reversible image plate damage. Residual images that may be encountered during basic system qualification shall not interfere with qualification results as determined by a CR Test Examiner. Upon completion of all basic system evaluations, the image plate shall be re-processed through the CR scanner erasure system without any further radiation exposure. If a residual image exists, the erasure time may not be long enough or sufficiently intense, or the erasure unit may be malfunctioning. Any residual images on the re-processed image plate that have a measurable pixel intensity value of .5 % or greater of the maximum saturated pixel intensity value shall be unacceptable for basic qualification.

Example: a 12 bit CR system has a maximum pixel intensity value of 4095 at saturation; 
.5 % of 4095 = 20 pixel value. Any area of the re-processed image with a pixel value of 20 or greater shall be unacceptable for basic qualification.

6.2.4 **Basic System Qualification Records** – All image qualification tests and test results from this section shall be documented and accompanied by a certificate of compliance attesting to successful validation of each test parameter described in this standard. This certification may be performed by the activity’s qualified CR Test Examiner, the applicable CR system supplier or an outside agency. Results shall be submitted to NAVSEA or its authorized representative prior to commencement of any production CR inspections. The certification documentation shall be available for review by NAVSEA or its authorized representative at all times.

6.3 **Requalification** – In event of routine CR system maintenance or repairs (not upgrades) of previously qualified components, it will not be necessary to requalify the entire CR system as prescribed in this standard. Upon repair/maintenance of a specific component, i.e. laser realignment, adjustments of gain settings, replacement of photomultiplier tube components, etc., attributes associated with only that component need be re-assessed. The type of re-assessment required may be determined as validated by the activity’s CR Radiographic Test Examiner and entered within maintenance records. All maintenance records shall be available for review by NAVSEA or its authorized representative.

7. **Relative Image Qualification/Classification for X-Ray**

These evaluations are adapted from ASTM E-746 – Relative Image Quality Response Method and EN 10 – Wire IQI’s Exposed With a Standard Absorber to qualify: 1) exposure/PV linearity; 2)
EPS (contrast sensitivity/system noise) performance; and 3) spatial resolution.

Note: Some provisions of the above ASTM standards have been modified for use with this standard; therefore, where any conflicts may exist between ASTM standards and this standard, the requirements of this standard shall prevail. Figure 4 illustrates a typical layout for a ¾ inch thick steel plate approximately 8 inches wide by 10 inches long containing a series of E 746-07 EPS plaques of varying thicknesses and hole sizes, EN #10 FE wire IQI's oriented perpendicular and parallel to plate axis, and two group I naval plaque penetrameters (for reference). The surface finish of the absorber plate shall be no worse than RMS 250. Successful qualifications performed to requirements of this section with low energy X-ray on group 1 material (steel) shall qualify all material groups with low energy X-ray.

7.1 Exposure/PV Linearity – Using the layout illustrated in Figure 4, produce an exposure graph similar to the one illustrated in Figure 5. Align an X-radiation source in the approximate center of the plate between the #8 and #10 EPS plaques (plates may be slightly separated for this purpose). Source-to-detector-distance (SDD) shall be a minimum of 36 inches for X-ray source. General radiographic technique parameters shall comply with Requirements for Computed Radiography. Any conventional (excludes micro-focus) X-ray machine focal spot size used in production radiography is permitted. Approximately ¼ inch backing lead (located behind the cassette) is recommended for all exposures. Radiograph the plate series with a minimum of 10 exposures using similar technique parameters for pixel intensity values between PV 500 and PV 3000 (for 12 bit CR systems). Additional exposure data points may be used to construct the exposure graph; however, exposures should be approximately distributed within the PV range. No exposure shall exceed a pixel value of 3891 (for a 12 bit system) or 95% of gray scale saturation for other systems.

Note: for CR systems with user selectable input gray scale levels (sometimes called exposure indices or variable photomultiplier tube gain settings), a “fixed” exposure index (for the original digital image) or fixed scanner photomultiplier tube gain setting shall be used and becomes the basis for each exposure. Determine (measure) pixel intensity value (PV) in the approximate center of the computed radiograph on the base plate between the #8 and #10 EPS plaques in an area free of any holes or, alternatively, within a central area of the base plate left of the EPS plaques. Multiple pixel intensity value readings can be taken provided they are averaged for the final measured pixel value for each exposure. Plot the exposure graph with a minimum of 10 data points uniformly distributed along the length of the line (Figure 5 illustrates). All CR system processing parameters, energy level and exposure data for each exposure shall be recorded on a suitable radiographic data sheet. The exposure/PV relationship is considered linear provided each data point is within ±10% of a straight line best fit of the data.
7.2 E-746 EPS – For each exposure (data point) of Figure 5, determine the lowest (best) EPS performance of each exposure by determining the duplex row (ASTM E-746 illustrates step layout and corresponding EPS %) where a minimum of 20 holes (out of 30 holes in each duplex row) are clearly visible. Table 1 provides EPS values for each duplex row on the specified standard ¾ inch absorber plate. Record the best (lowest numerical number)
EPS% on the computed radiography record that corresponds with the qualifying hole size row of Table 1, its corresponding exposure identification, and pixel intensity value. Maximum EPS% shall be no greater (larger number) than 1.41% (top row on .008" step).

Table 1: EPS values for low energy X-ray and Ir-192 on standard ¾ inch absorber plate

<table>
<thead>
<tr>
<th>Step Size</th>
<th>Hole Size</th>
<th>EPS %</th>
</tr>
</thead>
<tbody>
<tr>
<td>.38 mm (.015&quot;)</td>
<td>.71 mm (.028&quot;)</td>
<td>1.92</td>
</tr>
<tr>
<td></td>
<td>.64 mm (.025&quot;)</td>
<td>1.82</td>
</tr>
<tr>
<td></td>
<td>.58 mm (.023&quot;)</td>
<td>1.71</td>
</tr>
<tr>
<td>.25 mm (.010&quot;)</td>
<td>.79 mm (.031&quot;)</td>
<td>1.66</td>
</tr>
<tr>
<td></td>
<td>.71 mm (.028&quot;)</td>
<td>1.57</td>
</tr>
<tr>
<td></td>
<td>.64 mm (.025&quot;)</td>
<td>1.49</td>
</tr>
<tr>
<td>.20 mm (.008&quot;)</td>
<td>.71 mm (.028&quot;)</td>
<td>1.41</td>
</tr>
<tr>
<td></td>
<td>.64 mm (.025&quot;)</td>
<td>1.33</td>
</tr>
<tr>
<td></td>
<td>.58 mm (.023&quot;)</td>
<td>1.25</td>
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<tr>
<td>.13 mm (.005&quot;)</td>
<td>.81 mm (.032&quot;)</td>
<td>1.19</td>
</tr>
<tr>
<td></td>
<td>.71 mm (.028&quot;)</td>
<td>1.12</td>
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<tr>
<td></td>
<td>.64 mm (.025&quot;)</td>
<td>1.05</td>
</tr>
<tr>
<td></td>
<td>.58 mm (.023&quot;)</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>.50 mm (.020&quot;)</td>
<td>0.94</td>
</tr>
</tbody>
</table>

7.3 Wire Resolution Performance – Using the “best EPS” CR image determined in 7.2, determine the smallest diameter wire that can be visually resolved from the EN 10 wire group in both horizontal and vertical dimensions. A wire is considered visually resolved when the full length of wire is clearly discernible from the background. EN 10 wire sizes and corresponding EPS values for the ¾ inch base plate are shown in Table 2. Record the smallest discernible wire number and corresponding EPS value on the qualification data sheet. The minimum discernible wire size shall be at least EN # W-13 or smaller in both horizontal and vertical.

Table 2: EN 10 wire EPS equivalents for low energy X-ray on ¾ “absorber plate

<table>
<thead>
<tr>
<th>EN 10 Wire number</th>
<th>Wire diameter</th>
<th>EPS %</th>
</tr>
</thead>
<tbody>
<tr>
<td>W-10</td>
<td>.41 mm (.016&quot;)</td>
<td>2.83 %</td>
</tr>
<tr>
<td>W-11</td>
<td>.33 mm (.013&quot;)</td>
<td>2.36 %</td>
</tr>
<tr>
<td>W-12</td>
<td>.25 mm (.010&quot;)</td>
<td>2.00 %</td>
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<tr>
<td>W-13</td>
<td>.20 mm (.008&quot;)</td>
<td>1.60 %</td>
</tr>
<tr>
<td>W-14</td>
<td>.16 mm (.0063&quot;)</td>
<td>1.41 %</td>
</tr>
<tr>
<td>W-15</td>
<td>.13 mm (.0050&quot;)</td>
<td>1.07 %</td>
</tr>
<tr>
<td>W-16</td>
<td>.10 mm (.0040&quot;)</td>
<td>0.80 %</td>
</tr>
</tbody>
</table>

8. Relative Image Qualification/Classifications for Isotopes

Pixel value/exposure linearity qualification (see section 7.1) is not required for isotope sources if the CR system was qualified using X-ray radiation source. In the event that only isotope radiation source will be qualified, then the pixel value/exposure linearity qualification...
procedure of 7.1 shall be performed for the qualified isotope source.

8.1 Selenium 75 – Radiograph the setup arrangement shown in Figure 4 with a ½ inch steel absorber plate with Selenium 75 isotope source using the requirements of Supplement A of T.P. 271 Requirements for Computed Radiography. Use # .50 plaque penetrators in lieu of those shown in Figure 4. Source-to-detector distance (SDD) shall be between 15 and 24 inches inclusive. Any collimation/filtration employed on isotope radiation sources shall be recorded on qualification data sheets. Use Selenium 75 radiation source to produce a single exposure with a pixel intensity value (PV) between 614 and 1000 (for 12 bit systems) as measured within the approximate center of the absorber plate and clear of any holes or plaques, or alternatively within a central plate area left of the EPS plaques. Follow the same procedures provided in 7.2, 7.3 and 7.4 for determining best EPS, minimum discernible wire sizes and duplex unsharpness for Selenium 75. Table 4 provides EPS values for each duplex row of 30 holes for Selenium 75 source on ½ inch absorber plate. EN wire sizes (resolution) and corresponding EPS values for the ½ inch base plate are shown in Table 5. Maximum EPS shall be no greater than 2.37% (middle duplex row on .010” plaque). The minimum discernible wire sizes shall be at least EN # W-13 or smaller in both horizontal and vertical. Successful qualifications performed to requirements of this section with Selenium 75 on group 1 material (steel) shall qualify all material groups.

Table 3: EPS for Se 75 Source on 1/2 inch Absorber Plate

<table>
<thead>
<tr>
<th>Step Size</th>
<th>Hole Size</th>
<th>EPS %</th>
</tr>
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<tbody>
<tr>
<td>.38 mm (0.015”)</td>
<td>.71 mm (.028&quot;)</td>
<td>2.90</td>
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<tr>
<td></td>
<td>.64 mm (.025&quot;)</td>
<td>2.74</td>
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<tr>
<td></td>
<td>.58 mm (.023&quot;)</td>
<td>2.63</td>
</tr>
<tr>
<td>.25 mm (.010”)</td>
<td>.79 mm (.031&quot;)</td>
<td>2.49</td>
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<tr>
<td></td>
<td>.71 mm (.028&quot;)</td>
<td>2.37</td>
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<tr>
<td></td>
<td>.64 mm (.025&quot;)</td>
<td>2.24</td>
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<tr>
<td>.20 mm (.008”)</td>
<td>.71 mm (.028&quot;)</td>
<td>2.12</td>
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<td>.64 mm (.025&quot;)</td>
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<td>1.52</td>
</tr>
<tr>
<td></td>
<td>.50 mm (.020&quot;)</td>
<td>1.41</td>
</tr>
</tbody>
</table>

Table 4: EN 10 Wire EPS Equivalents for Se 75 Source on 1/2” Absorber Plate

<table>
<thead>
<tr>
<th>EN 10 Wire number</th>
<th>Wire diameter</th>
<th>EPS %</th>
</tr>
</thead>
<tbody>
<tr>
<td>W-10</td>
<td>.41 mm (.016”)</td>
<td>4.24%</td>
</tr>
<tr>
<td>W-11</td>
<td>.33 mm (.013&quot;)</td>
<td>3.54%</td>
</tr>
<tr>
<td>W-12</td>
<td>.25 mm (.010&quot;)</td>
<td>3.00%</td>
</tr>
<tr>
<td>W-13</td>
<td>.20 mm (0.008&quot;)</td>
<td>2.40%</td>
</tr>
<tr>
<td>W-14</td>
<td>.16 mm (0.0063&quot;)</td>
<td>2.00%</td>
</tr>
<tr>
<td>W-15</td>
<td>.13 mm (0.0050&quot;)</td>
<td>1.60%</td>
</tr>
<tr>
<td>W-16</td>
<td>.10 mm (0.0040&quot;)</td>
<td>1.20%</td>
</tr>
</tbody>
</table>
8.2 Relative Image Quality/Classifications for Iridium 192 – Radiograph the setup arrangement shown in Figure 4 with a 3/4 inch steel absorber plate with Iridium 192 radiation source using the requirements of Supplement A of T.P. 271 Requirements for Computed Radiography. Use #.75 plaque penetrimeters as illustrated in Figure 4. Source-to-detector distance (SDD) shall be between 15 and 24 inches inclusive. Any collimation/filtration employed on isotope radiation sources shall be recorded on qualification data sheets. Use Iridium 192 radiation source to produce a single exposure with a minimum pixel intensity value (PV) between 614 and 1000 (for 12 bit systems) as measured within the approximate center of the absorber plate, or alternatively within a central plate area left of the EPS plaques. Follow the same procedures provided in 7.2, 7.3 and 7.4 for determining best EPS, minimum discernible wire sizes and duplex unsharpness for Iridium 192. Maximum EPS shall be no greater than 1.71 % (bottom duplex row on .015” plaque with ¾ inch absorber thickness). The minimum discernible wire size shall be at least EN # W-12 or smaller in both horizontal and vertical.

Table 1 provides EPS values for each duplex row of 30 holes for 3/4 inch absorber plate. EN wire sizes (resolution) and corresponding EPS values for the 3/4 inch base plate are shown in Table 2. Successful qualifications performed to requirements of this section with Iridium 192 on group 1 material (steel) shall qualify material groups 1 or greater.

9. CR System Practical Qualification Requirements

This section requires that sample specimens be radiographed to the requirements to demonstrate compliant techniques and reliable detection of discontinuities. There are two qualification categories: category I for structural welds, and category II for piping welds for each energy type qualified. Each category will contain up to six samples of varying sizes and thicknesses of typical weld samples containing known discontinuities. An activity desiring to perform computed radiography inspections on one category shall only be required to qualify on that category. Samples shall be obtained from NAVSEA or its authorized representative.

9.1 Procedure – Upon receipt of the samples for the qualification category, the qualifying activity will develop CR techniques for the provided samples that demonstrate technique compliance for the inspection coverage specified. The qualifying activity shall use an approved computed radiographic inspection procedure and technique to radiograph each of the provided samples. All technique and other support information required by the procedure shall be recorded on the applicable data sheet accompanying each sample. Following exposures, digital images for each sample shall be transmitted to a qualified CR Inspector for identification and recording of all discontinuities to the satisfaction of the NAVSEA.

9.2 Qualification Criteria – The qualifying activity shall perform computed radiography of all samples (for each category to be qualified) to the requirements and shall correctly detect and disposition all discontinuities to the satisfaction of the NAVSEA.

9.2.1 Technique Attributes

9.2.1.1 Minimum image quality requirements achieved

9.2.1.2 Exposures within required pixel intensity value range
9.2.1.3 Pixel intensity value tolerance between IQI and area-of-inspection
9.2.1.4 Within geometrical unsharpness limits and recommended energy ranges
9.2.1.5 Required inspection coverage completed
9.2.1.6 Artifacts that interfere with inspection noted

9.2.2 Evaluation/Disposition Attributes
9.2.2.1 Detection/identification of all key discontinuities
9.2.2.2 Characterization of identified discontinuities
9.2.2.3 Disposition of identified discontinuities
9.2.2.4 Recording/annotation of inspection results