Designation: E2698 – 10

Standard Practice for Radiological Examination Using Digital Detector Arrays[1]

This standard is issued under the fixed designation E2698; 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 radiological examination for metallic and nonmetallic material using a digital detector array (DDA) system.

1.2 The requirements in this practice are intended to control the quality of radiologic images and are not intended to establish acceptance criteria for parts or materials.

1.3 This practice covers the radiologic examination with DDAs including DDAs described in Practice E2597 such as a device that contains a photoconductor attached to a Thin Film Transistor (TFT) read out structure, a device that has a phosphor coupled directly to an amorphous silicon read-out structure, and devices where a phosphor is coupled to a CMOS (Complementary metal–oxide–semiconductor) array, a Linear Detector Array (LDA) or a CCD (charge coupled device) crystalline silicon read-out structure.

1.4 The DDA shall be selected for an NDT application based on knowledge of the technology described in Guide E2736, and of the selected DDA properties provided by the manufacturer in accordance with Practice E2597.

1.5 The requirements of this practice and Practice E2737 shall be used together and both be approved by the CEO Level 3 in Radiography before inspection of production hardware. The requirements of Practice E2737 will provide the baseline evaluation and long term stability test procedures for the DDA system.

1.6 The requirements in this practice shall be used when placing a DDA into NDT service and, before being placed into service, an established baseline of system qualification shall be performed in accordance with Practice E2737.

1.7 Techniques and applications employed with DDAs are diverse. This practice is not intended to be limiting or restrictive. Refer to Guides E94, E1000, E2736, Terminology E1316, Practice E747 and E1025, Fed. Std. Nos. 21CFR 1020.40 and 29 CFR 1910.96 for a list of documents that provide additional information and guidance.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E94 Guide for Radiographic Examination

E543 Specification for Agencies Performing Nondestructive Testing

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

E1000 Guide for Radioscopy

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

E1316 Terminology for Nondestructive Examinations

E1647 Practice for Determining Contrast Sensitivity in Radiology

E1742 Practice for Radiographic Examination

E2002 Practice for Determining Total Image Unsharpness in Radiology

E2597 Practice for Manufacturing Characterization of Digital Detector Arrays

E2736 Guide for Digital Detector Arrays

E2737 Practice for Digital Detector Array Performance Evaluation and Long-Term Stability

2.2 *AWS Documents:*[3]

AWS A2.4 Symbols for Welding and Nondestructive Testing

2.3 *Aerospace Industries Association Document:*[4]

NAS 410 Certification & Qualification of Nondestructive Test Personnel

2.4 *Government Standards:*

NIST Handbook 114 General Safety Standard for Installations Using Non-medical X-ray and Sealed Gamma Ray Sources, Energies up to 10 MeV[5]

DoD Contracts any specifications called out on the DoDISS (Department of Defense Index of Specifications and

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

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

[3] Available from American Welding Society (AWS), 550 NW LeJeune Rd., Miami, FL 33126, http://www.aws.org.

[4] Available from Aerospace Industries Association of America, Inc. (AIA), 1000 Wilson Blvd., Suite 1700, Arlington, VA 22209-3928, http://www.aia-aerospace.org.

[5] Available from National Institute of Standards and Technology (NIST), 100 Bureau Dr., Stop 1070, Gaithersburg, MD 20899-1070, http://www.nist.gov.

Standards) cited in the solicitation.
21-CFR-1020.40 Safety Requirements of Cabinet X-ray Systems
29-CFR-1910.96 Ionizing Radiation
NCRP 144 Radiation Protection for Particle Accelerator Facilities
SMPTE RP 133 Specifications for Medical Diagnostic Imaging Test Pattern for Television Monitors and Hard-Copy Recording Cameras

3. Terminology

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

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *component*—the part(s) or element of a system assembled or processed to the extent specified by the drawing, purchase order, or contract.

3.2.2 *energy*—a property of radiation that determines the penetrating ability. In x-ray radiography, energy machine rating is determined by kilo electron volts (keV), million electron volts (MeV). In gamma ray radiography, energy is a characteristic of the source used.

3.2.3 *like section*—a separate section of material that is similar in shape and cross section to the component or part being radiologically inspected, and is made of the same or radiologically similar material.

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

3.2.5 *NDT facility*—the facility or entity performing the radiologic examination.

3.2.6 *digital detector array (DDA)*—an electronic device that converts ionizing or penetrating radiation into a discrete array of analog signals which are subsequently digitized and transferred to a computer for display as a digital image corresponding to the radiologic intensity pattern imparted upon the input region of the device. The conversion of the ionizing or penetrating radiation into an electronic signal may transpire by first converting the ionizing or penetrating radiation into visible light through the use of a scintillating material. These devices can range in speed from many minutes per image to many images per second, up to and in excess of real-time radioscopy rates.

3.2.7 *digital driving level (DDL)*—for computer graphics display boards, the digital value that corresponds to a particular monochrome grayscale level. A particular DDL "drives out" a particular visible shade of gray. For example, in an 8-bit display, a DDL assumes 256 values from 0 to 255.

3.2.8 *grayscale*—2^N signal levels for an N-bit system

3.2.9 *gray level*—one of 2^N signal levels for an N-bit digital system

3.2.10 *mean gray level*—the average of all the pixel gray levels in a given region of interest.

3.2.11 *window width and level*—contrast (window width) and brightness (window level) adjustment of a digital image by changing how the Gray levels translate into displayed brightness levels.

3.2.12 *signal-to-noise ratio (SNR)*—quotient of mean value of the intensity (signal) and standard deviation of the intensity (noise). The SNR depends on the radiation dose and the DDA system properties.

3.2.13 *contrast-to-noise ratio (CNR)*—quotient of the difference in the mean values of the intensity (signal) in an area in the object subtracted from the mean value of the intensity of the background, and standard deviation of the intensity (noise). The CNR depends on the radiation dose and quality, thickness/attenuation of the object and the DDA system properties.

3.2.14 *basic spatial resolution (SRb)*—indicates the smallest geometrical detail, which can be resolved using the DDA. It is similar to the effective pixel size/pitch and corresponds to ½ of the measured unsharpness.

3.2.15 *ghosting*—residual signal or image from a prior exposure in a current image. Signal or image can be negative or positive and may affect interpretation of the image.

3.2.16 *bad pixel*—a pixel identified with a performance outside of the specification range for a pixel of a DDA as defined in Practice E2597.

3.2.17 *relevant cluster*—a cluster with a cluster kernel pixel (CKP), where there are fewer than five good neighboring pixels surrounding this pixel as defined in Practice E2597. A CKP is a pixel that does not have sufficient good neighboring pixels to perform interpolation, and is therefore not correctable.

4. Significance and Use

4.1 This practice establishes the basic parameters for the application and control of the digital radiologic method. This practice is written so it can be specified on the engineering drawing, specification, or contract. It will require a detailed procedure delineating the technique or procedure requirements and shall be approved by the CEO.

5. Basis of Application

5.1 The following items are subject to contractual agreement between the parties using or referencing this standard.

5.1.1 *Personnel Qualification*—If specified in the contractual agreement, personnel performing examinations to this standard shall be qualified in accordance with a nationally or internationally recognized NDT personnel qualification practice or standard and certified by the employer or certifying agency, as applicable. The practice or standard to be used and its applicable revision shall be identified in the contractual agreement between the using parties.

5.1.2 If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in E543. The applicable edition of E543 shall be specified in the contract.

6. Environment and Safety

6.1 The premises and equipment shall present no hazards to the safety of personnel or property. NCRP 144, and/or NIST Handbook 114 may be used as guides to ensure that radiologic

procedures are performed so that personnel shall not receive a radiation dosage exceeding the maximum permitted by the city, state, or national codes.

6.2 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.

6.3 Dust and dirt need to be kept to a minimum and the image display face needs to be cleaned often to prevent interference with interpretation.

7. Equipment

7.1 Different examination system configurations are possible. It is important that the user understands the advantages and limitations of each (see Practice E2597 and Guide E2736). The provider and the user of the examination system should be fully aware of the capabilities and limitations of each system proposed.

7.2 The DDA cannot be operated without computing hardware and software for image acquisition, image display and image storage/retrieval.

7.2.1 The software shall be capable of acquiring images frame by frame from the DDA and integrating, or averaging the frames, or both.

7.2.2 The software shall perform an image calibration to correct the inhomogenities of the detector and to determine and correct bad pixels (that is, bad pixel map) as defined in Practice E2597.

7.3 The software to display resulting imagery from a DDA shall be capable to scale images in size (geometrical magnification—zoom) and gray levels (window and level adjustment—brightness and contrast, for example from 16 bit to 8 bit). Additional functions shall be required such as a line profile measurement, histogram, and statistics window for measuring an region of interest (ROI) (mean and standard deviation).

7.4 *The Digital Detector Array (DDA):*

7.4.1 Only DDAs shall be used in practice as established in Guide E2736.

7.4.2 Users shall comply with the manufacturers' requirements of temperatures and humidity conditions for both operation and shipping.

7.4.3 The DDA shall be calibrated using the manufacturers' recommendation both for frequency of calibration and the method used. Other calibration methods are allowed as long as approved by the CEO.

7.4.4 The user shall ensure that all exposures are within the linear operating range of the DDA, using either information obtained from the manufacturer or data obtained by the user/CEO.

7.5 The image display shall meet the following requirements as a minimum. Alternate image displays or requirements may be used with CEO approval.

7.5.1 The minimum brightness as measured off the image display screen at maximum Digital Driving Level (DDL) shall be 250 cd/m^2.

7.5.2 The minimum contrast as determined by the ratio of the screen brightness at the maximum DDL compared to the screen brightness at the minimum DDL shall be 250:1.

7.5.3 The image display shall be capable of displaying linear patterns of alternating pixels at full contrast in both the horizontal and vertical directions without aliasing.

7.5.4 The display shall be free of discernable geometric distortion.

7.5.5 The display shall be free of screen flicker, characterized by high frequency fluctuation of high contrast image details.

7.5.6 The image display shall be capable of displaying a 5 % DDL block against a 0 % DDL background and simultaneously displaying a 95 % DDL block against a 100 % background in a manner clearly perceptible to the user. An image display test pattern, in accordance with the requirements of SMPTE RP 133, shall be configured for the system display resolution and aspect ratio. Alternate test patterns may be used provided they include the features described in SMPTE RP 133 required to perform the quality tests specified in this practice.

7.5.7 The monitor shall be capable of discriminating the horizontal and vertical low contrast (1 %) modulation patterns at the display center and each of the four corner locations.

7.6 *Image Quality Indicators (IQI):*

7.6.1 IQIs shall be in accordance with a recognized standard or approved by the Cognizant Engineering Organization. Hole plate type indicators shall comply with Practice E1025 or Practice E1742, Annex 1. Wire type indicators shall be in accordance with Practice E747 and correlated to the hole type penetrameters in accordance with Practice E747.

7.6.2 The IQI shall be constructed from material in the same material group (see Practice E1025) as the material to be radiologically inspected. If an IQI material of the same material group is not available, a material that is radiologically less dense shall be used.

7.6.3 The use of alternative IQIs that are approved by the CEO shall be documented in a written procedure with the design, materials designation, and thickness identification or documented on a drawing and that drawing referenced in the procedure.

7.6.4 The IQIs shall be procured or fabricated to the requirements of Practice E1025 or Practice E747 with a manufacturer's certification of compliance with respect to alloy and dimensions. Users shall visually inspect IQIs for damage and cleanliness in accordance with Appendix X1.

7.7 *Radiation Sources:*

7.7.1 *X-Radiation Sources*—Selection of appropriate X-ray voltage and current levels is dependent upon variables regarding the specimen being examined (material type and thickness) and exposure time. The suitability of these exposure parameters shall be demonstrated by attainment of the required radiographic quality level and compliance with all other requirements stipulated herein.

7.7.2 *Gamma Radiation Sources*—Isotope sources that are used shall be capable of demonstrating the required radiographic quality level.

8. Equipment Monitoring Requirements

8.1 The image display monitor shall be checked in accordance with Appendix X1.

8.2 Radiographic images shall be free of relevant bad pixels or other artifacts which may interfere with image interpretation (See Practices E2597 and E2737).

8.3 Detailed schedule and tests for monitoring the DDA performance over time shall be performed in accordance with Practice E2737.

8.4 The user shall adopt the manufacturer's recommendations for DDA gain, offset and bad pixel calibration, methodology and the frequency thereof, and alterations as needed defined by the CEO based on the object under test.

8.4.1 In the event that any non-uniformities or artifacts (other than bad pixels) appear in an image between recommended intervals of gain and offset calibration, the detector is to be immediately recalibrated for gain and offset correction so that these discontinuities are removed.

8.4.2 In the event that any non-uniformities or artifacts remain in the area of interpretation in an flat x-ray field image (no object) after recalibration, then the detector shall be tested in accordance with Practice E2737 for requalification and long term stability testing, where a determination will be made if the detector needs to be removed from service. If the detector is removed from service, than the part under question will be re-inspected with a fully qualified detector, and this new detector will be used for all future inspections. If the detector is returned to service following testing with recommended changes to methodology, these changes shall be implemented prior to re-inspection and approved by the CEO.

8.5 In the event that any new bad pixels appear in an image between recommended intervals of bad pixel mapping and are in the area of interest and interfere with interpretation and disposition of the object, a new bad pixel map is to be generated so that these bad pixels may be corrected. The object is to then be re-imaged with the fresh bad pixel map.

8.5.1 In the event that these new bad pixels still appear in the image following the bad pixel recalibration for example cluster kernel pixels (uncorrectable pixels), then the detector shall be tested in accordance with Practice E2737 for requalification and for long term stability testing where a determination will be made by the CEO if the detector needs to be removed from service. If the detector is removed from service, than the part under question will be re-inspected with a fully qualified detector, and this detector will be used for all future inspections. If the detector is returned to service following testing with recommended changes to methodology, these changes shall be implemented prior to re-inspection and approved by the CEO.

9. Procedural Requirements

9.1 Digital systems shall be qualified by the CEO for a particular material type, thickness range, application, and product acceptance. The radiologic parameters specified during qualification shall be used to develop the inspection techniques and procedure for production inspection. It shall be the responsibility of the user NDT facility to develop a workable examination technique recorded as a written procedure that is capable of consistently producing the desired results and radiologic quality level. When required by contract or purchase order, the procedure shall be submitted to the CEO for approval.

9.2 The following items shall be addressed in the written procedure:

9.2.1 Name and address of the NDT facility, the date, and revision of the procedure.

9.2.2 Radiological Image Identification scheme used to correlate the exposure to part. If the examination procedures are similar for many components, a master written procedure shall be used that covers the details common to a variety of components. All written procedures shall be approved by an individual qualified and certified as a Level 3 in Radiographic Testing in accordance with 4.1.

9.2.3 The thickness and type of material.

9.2.4 A drawing, sketch, or photograph of a component showing the location of the part and IQI with respect to the radiation source for each exposure. The angle of the radiation beam in relation to the component, the source to DDA distance, part to DDA distance, and any blocking or masking, if used shall be documented. For robotic or similar systems with hard fixturing and controlled scan plans, a drawing, sketch or photograph is not required.

9.2.5 The nominal exposure for the x-ray machine: voltage, milliamps, filter, exposure time, frame averages, beam- or detector- collimation, and effective focal spot size. For radioisotope sources: the isotope type, source strength, exposure time, frame averages, beam- or detector- collimation, and source size.

9.2.6 The make, model and manufacturer of the DDA used in the inspection.

9.2.7 The geometrical magnification factor used including source to object and object to detector distances.

9.2.8 The IQI size and type, the required radiologic quality level and a minimum quality level to achieve in the region of interest. If alternate IQIs are used, include details of the design or reference to documents where such information is found.

9.2.9 Thickness and type of material for shims or blocks, or both if used.

9.2.10 The window width and level used to visualize the image as well as any digital image zoom.

9.2.11 Any image processing parameters used to obtain the required image quality or improve fine detail detection. This would include noise reduction methods, contrast enhancement, or other filtering procedures.

9.2.12 The acceptance limits shall be documented and if applicable, the zones or sections of the part or assembly to which they apply. If permitted, the acceptance criteria may be separate from the procedure but documented and available to the image interpreters.

9.2.13 A system of measurement verification shall be documented. If a physical standard is used to verify the accuracy of a measurement, the standard shall be certified annually using standards traceable to NIST (or other recognized standardizing body). The user and the CEO shall agree to the tolerance of this standard.

10. Examination Details

10.1 Components shall be examined without surface preparation or conditioning except as required to remove surface conditions that may interfere with proper interpretation of the image.

10.1.1 Castings, forgings, and weldments shall be exposed in the as-cast, as forged or as welded condition provided the surface condition does not interfere with interpretation.

10.2 Each exposure shall carry the identification or serial number of the component and view number, when multiple views are taken. Each radiological exposure shall also carry the identification of the NDT facility inspecting the component and date of the examination. Digital labeling shall never permanently alter the nature of the image or hinder interpretation of an area within the image. Images of a repair/rework area shall be identified such that it can be uniquely related to the repair/rework that was attempted. For explosives and propellants, the conditioning temperature shall be identified on the exposure if the ordnance has been conditioned to a temperature other than facility ambient for purposes of examination. Other methods of identifying repairs may be used with prior approval of the CEO.

10.3 The radiological exposure coverage of each part and sampling if used shall be as specified by drawing, exposure techniques, radiologic manuals, handbooks for aircraft technical orders, or other specifications as applicable. Examination areas shall be identified on the drawing by using the symbols in accordance with ANSI/AWS A2.4 or other systems of designations that are easily identified on the drawing. If the number of parts to be examined and coverage is not specified, all parts shall be examined and 100 % coverage will be necessary.

10.4 The sequence for radiological examination in the production operation shall be specified in the manufacturing or assembly process, specification, and contract or purchase order. If not specified, radiological examination shall be performed at a stage in the process of manufacturing or assembly at which discontinuities can be detected. Radiological examination may be performed prior to heat treatment providing liquid penetrant or magnetic particle examinations are performed after heat treatment.

10.5 The five quality levels listed in Table 1 shall be assigned on the basis of IQI thickness and the perceptibility of one, two, or three holes in the Hole-Type IQI image on the image. If the quality level is not specified on the drawing or other applicable documents, it shall be 2-2T. Unless otherwise specified by the CEO, Hole-Type IQIs used for examination of material 6.35-mm (0.25 in.) or less in thickness shall be 0.13 mm (0.005 in.) minimum thick.

10.6 IQI selection shall be based on a thickness not greater than the nominal thickness to be radiographed. For double-wall exposure and double-wall viewing techniques, the IQI shall be based on the double-wall thickness of the component. For double-wall exposures and single-wall viewing techniques, the IQI shall be based on the single-wall thickness of the component. In no case shall the IQI thickness be based on a thickness greater than the thickness to be radiographed.

10.7 The IQI shall be placed on each part radiographed for the duration of the exposure, unless a number of identical parts are simultaneously exposed in a single image. In such a case, a single IQI shall be placed upon the source side of a part at the outer edge of the cone of radiation or farthest extremity from the central beam of radiation. For examination of irregular objects, the IQI shall be placed on the area of the part farthest from the detector. The IQI shall be placed adjacent to the area of interest since accept/ reject decisions cannot be made in the area directly beneath the IQI. Where it is not practical to place the IQI on the part, the separate block technique or detector side technique may be used as applicable as described in 10.8.

10.8 Where it is impractical to place the IQI upon the part radiologically inspected, the IQI shall be placed on the source side of a separate shim, block, or like section, from the same material group. The shim, block, or like section and IQI shall be placed onto the outer edge of the cone of radiation. The shim, block, or like section shall exceed the IQI dimensions so that at least three sides of the IQI shall be visible in the image. If required, the shim shall be placed on a low absorptive material (such as polystyrene plastic or its equivalent) to ensure that the IQI shall not be any closer to the detector than the source side of the part, or area of interest being evaluated.

10.9 When examining double-walled parts such as tubing or hollow castings, where it is not practical to place an IQI on the source side of the part, IQIs may be placed on the detector side of the part and a lead letter F shall be placed adjacent to the IQI. Alternatively, the resulting image may be labeled accordingly, in an overlaying manner delineating that the IQI is placed on the front surface of the part. As an overlay, the label can be removed so that region of the part may be interpreted.

TABLE 1 Quality Levels of Examination

IQI Designation	Radiologic Quality Level	Maximum IQI Thickness, %[A]	Minimum Hole Diameter[B]	Equivalent IQI Sensitivity, %[C]
00	1-1T	1	1T	0.7
0	1-2T	1	2T	1.0
1	2-1T	2	1T	1.4
2	2-2T	2	2T	2.0
3	2-4T	2	4T	2.8

[A] Expressed as a percentage of material thickness.
[B] Expressed as multiple thickness of IQI.
[C] Equivalent IQI sensitivity is that thickness of the IQI expressed as a percentage of the specimen thickness in which a 2T hole would be clearly visible under the same radiologic conditions.

Digital labeling shall never permanently alter the nature of the image or hinder interpretation of an area within the image.

10.10 When performing double-walled radiography in which both walls or a single wall is viewed for acceptance, the detector side radiologic technique shall be demonstrated on an exposure of a like section in which the required IQI shall be placed on the source side, and sets of wire IQIs (or a series of hole-type IQIs) ranging in thickness from that of the required IQI to one fourth that thickness shall be placed on the detector side. If the required IQI on the source side indicates the specified radiologic quality level, then the image of either the smallest IQI hole in the thinnest IQI, or the image of the smallest wire, visible on the detector side shall be used to determine the proper detector-side IQI to be used for production images.

10.11 When included in the written procedure and approved by the CEO Radiographic Level 3, a single exposure with the applicable IQI may be made to qualify the examination process. When it is impractical to continually place IQIs on a part requiring more than one exposure, or a series of similar parts, using the same radiologic technique are to be made, a single exposure of an IQI may be made to qualify the examination process. As long as the radiologic technique is not changed, subsequent exposures may be performed without an IQI. A new qualification exposure with an IQI shall be made daily, or whenever any of the following parameters are changed:

10.11.1 X-ray Tube Potential (Kilovolts, Megavolts)

10.11.2 Tube current (milliampere)

10.11.3 Integration time (s)

10.11.4 Source to detector distance

10.11.5 Object to detector distance

10.11.6 Collimation, masking or filters

10.11.7 Digital Detector Settings

10.11.8 X-ray source or detector change or repositioning/relocation

10.11.9 Software settings like brightness, contrast, filters, etc.

10.12 Subsequent exposures shall be positively tied to the qualification exposure by serialization or another method. A copy of the qualification shall be provided to all parties with review authority.

10.13 Scatter radiation reduces the contrast in the image. Five different physical effects can be used to reduce the influence of scatter radiation in the image:

10.13.1 The energy should be as low as possible.

10.13.2 A diaphragm in front of the tube should be used to mask out all radiation which would not penetrate the region of interest in the object.

10.13.3 A distance between object and detector reduces scatter significantly. For example, at 160 keV, scattered radiation for a given material and thickness may be half of the detector signal, when the object is directly on the DDA. With a distance of 500 mm (20 in.) the signal from scattered radiation is down to 3 %.

10.13.4 Shot, masking solutions, sheet lead and foils, polytetrafluoroethylene (PTFE), plastic, or other low density, non-metallic absorbers shall be used as masking to minimize the effects of scattered radiation or undercutting. Light materials may also contribute to scatter, if not properly applied. The shot may be filtered by a mixture of many thicknesses to provide a uniform density. Heavy chemical solutions used for masking may be toxic. Follow the proper health and safety requirements.

10.13.5 Filters shall be used whenever the contrast reductions caused by low energy scattered radiation occurring on production radiographs are of significant magnitude to cause difficulty in meeting the radiologic quality level or radiologic coverage requirements as specified in the contract, purchase order, or drawing.

10.14 When placed directly on the component, one IQI shall represent an area with a pixel Gray Level equal to or less than the least radiologically dense area of the represented area of the image.

10.14.1 Additional IQIs may be used, as necessary to cover the entire thickness range of the object. For components such as castings and forgings, where there are changes in wall thickness and wall alignment and the use of multiple IQIs is not possible, the use of one IQI is acceptable. The IQI thickness shall be based on the thinnest wall being radiographed and shall be placed on the thickest wall section.

10.15 The IQIs are not required under the following conditions.

10.15.1 Examining assemblies for debris.

10.15.2 Conducting radiography for defect removal provided final examination of the area includes an IQI.

10.15.3 Examining to show material details or contrast between two or more dissimilar materials in component parts or assemblies including honeycomb areas for the detection of fabrication irregularities or the presence or absence of material.

10.16 When surfaces are inaccessible, an alternative method of qualification shall be used subject to the approval of the CEO.

10.17 Fabrication welds shall be processed in accordance with Practice E1742, Annex A2.

10.18 Explosives / propellants, rocket motors, and their components shall be processed in accordance with Practice E1742, Annex A3.

10.19 *Geometrical Considerations*—(See Fig. 1)

10.19.1 *Establish Image Quality and Geometric Magnification:*

10.19.1.1 The image quality requirement (such as 2-1T) and IQI type shall be defined by the CEO and be based on the requirements for the inspection application. This may be done using hole or wire type IQIs.

10.19.1.2 The magnification requirement shall be set by one of two methods as determined by the CEO.

10.19.1.3 The first method is based on ensuring that an IQI hole is larger than the largest allowed bad pixel cluster. This is defined by stating how many pixels (for example, 4 by 4) are required to be in the IQI hole of interest as defined in 10.19.1.1. This method requires the use of hole-type IQIs. The second method is based on setting the magnification as a function of

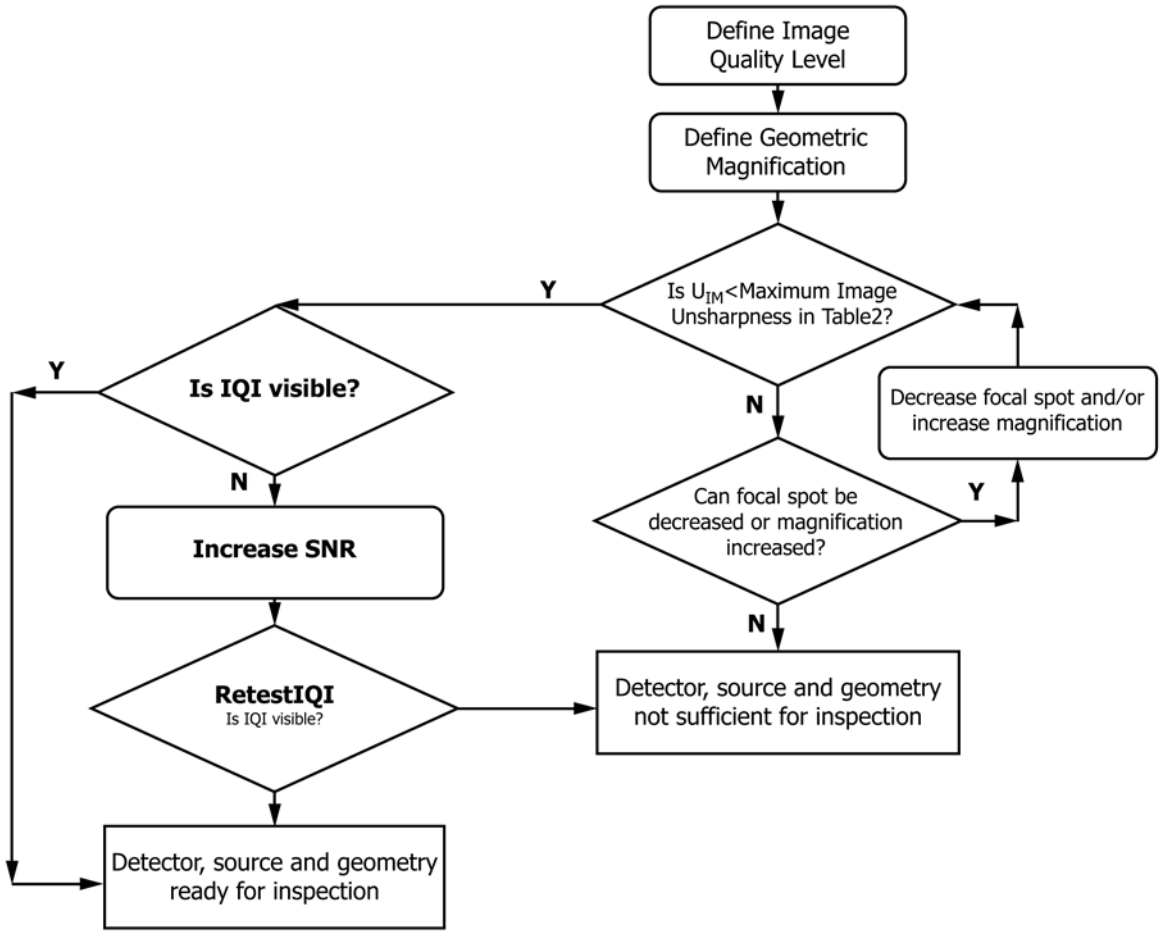

FIG. 1 Flowchart for Setting Geometry, Image Unsharpness and Image Quality (see 10.19)

the basic spatial resolution of the DDA and the required normalized image unsharpness as defined for small focal spot sizes ($\Phi << U_{Im}$) by the following equation if $1.6 * SR_b > U_{Im}$:

$$\upsilon_{min} = 1.6 * SR_b / U_{Im} \quad (1)$$

The required value of U_{Im} is given in Table 2.

10.19.2 *Determine and Test for Maximum Normalized Image Unsharpness (U_{Im}):*

10.19.2.1 First, determine the maximum image unsharpness, U_{Im}, that shall be met for the inspection as shown in Table 2.

10.19.2.2 Second, compute the expected image unsharpness for the geometry and DDA in use as defined in Guide E1000, Eq. 9 (shown here in a modified form for DDAs):

$$U_{Im} = \frac{1}{\upsilon} \cdot \sqrt[3]{U_g^3 + (1.6 \cdot SR_b)^3} \quad (2)$$

TABLE 2 Maximum normalized image unsharpness (U_{Im})

Under 1 in. through 1 in.	0.010 in.
(≤ 25.4 mm)	(0.254 mm)
Over 1 through 2 in.	0.020 in.
(>25.4 through 50.8 mm)	(0.508 mm)
Over 2 through 4 in.	0.030 in.
(>50.8 through 101.6 mm)	(0.762 mm)
Over 4 in.	0.040 in.
(>101.6 mm)	(1.016 mm)

$$U_g = (\upsilon - 1) * \Phi \quad (3)$$

where U_g is the geometrical unsharpness (see Eq 3, where Φ is the focal spot size.

10.19.2.3 Third, if the maximum unsharpness is less than required in Table 2, the inspection shall proceed with the defined geometry and continue in 10.19. Otherwise, a change shall be made to decrease the x-ray focal spot size until the recomputed image unsharpness meets Table 2. If at the smallest focal spot size, the required total image unsharpness is not met, it means that the DDA being tested is not suitable for the inspection.

10.19.3 *Evaluate IQI Visibility Using Contrast to Noise Ratio (CNR):*

10.19.3.1 Once the image unsharpness requirement is met, the image quality (IQI visibility) must be assessed. If the required hole is not clearly visible it shall be evaluated by measuring CNR on a hole-type IQI or other method approved and documented by the CEO.

10.19.3.2 For hole-type IQIs, the appropriate IQI shall be placed on the object and the mean of the pixels inside of the hole of interest and a neighbouring region on the IQI (but outside of the hole) shall be measured. The difference in the two means shall be divided by the standard deviation of the same region outside of the hole and the resulting quantity (contrast to noise ratio) shall be at least 2.5 unless otherwise

specified by the CEO. If the CNR is sufficient, the DDA and geometry are ready for inspection. If the contrast to noise ratio is less than the required amount proceed to 10.19.4.

10.19.3.3 For wire type IQIs, the required wire shall be clearly visible along at least two third of its length without interruption. The CNR measurement requires a profile measurement perpendicular to the wire direction which is averaged over 11 lines. A minimum CNR of 2 in. the averaged line profile shall be exceeded, unless otherwise specified by the CEO.

10.19.3.4 If the CNR of the IQI is not accessible, alternatively the Signal to Noise ratio (SNR) shall be measured in an area of homogeneous grey level in the unprocessed image. The SNR shall exceed 130 for 2 % contrast sensitivity and 250 for 1 % contrast sensitivity (see Practice E2597).

10.19.4 Increasing contrast to noise (and signal-to-noise) ratio by increasing X-ray exposure and/or changing X-ray tube potential.

10.19.4.1 For the following three methods used to increase the X-ray exposure for the image, there are two limits. First, the DDA will approach a limiting contrast to noise ratio value related to the quality of the calibration of the DDA. Increasing the frame averaging further will not increase the image quality, but just take a longer time to complete the image. Second, there is a practical economic time limit on the total exposure time that should be considered.

10.19.4.2 Increase X-ray source output and/or energy to bring the gray level of the brightest area in the image (largest gray level value) to no more than 90 % of the maximum gray level of the DDA.

10.19.4.3 Increase the exposure or frame time of the DDA.

10.19.4.4 Average multiple frames of data into one image using the manufacturer provided acquisition software.

10.19.5 After increasing the exposure, if the IQI is still not visible, the DDA system is not suitable for inspection. If the IQI is visible or meets the CNR criteria, the DDA and geometry are acceptable and ready to proceed with the inspection.

10.20 *Window Width and Window Level:*

10.20.1 The inspections shall be conducted using a defined window width. The window width value shall be based on the feature of interest and approved by the CEO.

10.20.2 Window level shall be adjusted during inspection with a fixed window width. Window level adjustment maybe necessary to view the entire part thickness range.

10.21 *Image Zoom:*

10.21.1 The inspections shall be conducted with a fixed image zoom. The image zoom shall be based on the feature of interest and approved by the CEO.

11. Quality Assurance Provisions

11.1 The NDT facility is responsible for furnishing all supplies in conformance to contract or purchase order requirements and, unless otherwise specified in the contract or purchase order, the performance of all examination requirements contained herein. The examination provisions contained herein shall become a part of the NDT facility overall examination system or quality program.

11.2 The results of all radiologic examinations shall be recorded and kept on file in accordance with the contract or purchase order. Additionally, refer to 7.1.7 of Practice E2002.

11.3 The viewing room or enclosure shall be an area with variable control lighting as each operator will have different background lighting needs. Subdued lighting in the viewing room is preferred rather than total darkness and shall preclude objectionable reflective glare on the surface of the image that could interfere with the interpretation.

11.4 The interpreter shall wait sufficient time, after entering the viewing area, before interpreting the radiological image that the features of the IQI are visible (hole and IQI outline).

11.5 Retention and delivery of images and other records shall be in accordance with the provisions specified in the contract. For DOD contracts they shall be in accordance with the contract data requirements list. If no specific requirements are specified for retention or delivery of images, they shall become the property of the purchaser of the component.

11.6 When the exposures are to be printed on film, paper, or other medium, there shall be a procedure controlling the printing and this procedure is subject to approval by the CEO.

12. Marking and Identification

12.1 Parts that conform satisfactorily to applicable radiological examination requirements shall be marked in accordance with the applicable drawing, purchase order, contract or as specified herein. Markings shall be applied in such a manner and location to be harmless to the part. Identification shall not be smeared or obliterated by subsequent handling. When subsequent processing would remove identification, the applicable marking shall be affixed to the records accompanying the parts or assemblies.

12.2 Impression stamping, laser marking, or vibro engraving shall be used only where permitted by the applicable specifications or drawings. Unless otherwise specified, marking shall be located in areas adjacent to the part number.

12.3 When impression stamping, laser marking, or vibro engraving is prohibited, parts may be marked by etching. Suitable echants and application methods shall be employed. Etching methods other than fluid etching may be used.

12.4 Where etching, impression stamping, laser marking, or vibro-engraving are not appropriate, identification may be accomplished by dyeing or ink stamping.

12.5 Each part that has successfully passed radiologic examination shall be marked as follows:

12.5.1 When impression stamping, laser marking, vibro-engraving, etching, or ink stamping is applicable, symbols shall be used. The symbol shall contain an identification symbol of the facility.

12.5.2 Except for specialized applications, use the symbol "X" enclosed in a circle to denote 100 % radiologic examination.

12.5.3 When using the sampling method, parts that are actually radiographed shall be marked as specified in 12.5.1. All items in the lot accepted on a sampling basis (part of the lot

but not actually radiographed) shall be marked using the symbol "X": enclosed in an ellipse.

12.6 When dyeing is applicable, blue dye shall be used to indicate 100 % radiologic examination. When sampling is used, orange dye shall be used to indicate parts accepted on a sampling basis (part of the lot not actually examined), while the parts of the lot actually examined shall receive blue dye.

13. Notes

13.1 *Government Contracts:*

13.1.1 The current issue of DOD 5010.12-L, Acquisition Management Systems and Data Requirements Control List (AMSDL), must be researched to ensure that only current, cleared DIDs are cited on the DD Form 1423. Reference DID number DI-MISC-80653, Test Reports.

14. Keywords

14.1 amorphous selenium; amorphous silicon; digital detector array; image processing; image quality indicator; nondestructive testing; penetrating radiation; radiography; radiologic examination; X-ray

APPENDIX

X1. MINIMUM PERIODIC PERFORMANCE EVALUATIONS

Reference qualification std	Paragraph Reference	Frequency (minimum)
Light Meter	Must be calibrated	Every 6 months
Image Display Evaluation		
Image Brightness	7.5.1	Once per month
Monitor	7.5.2-7.5.7	Daily
bad pixel, gain and offset maps	8.4-8.5	In accordance with manufacturers' recommendations or CEO
IQI Evaluation for Application	10.5	Each examination