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

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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.