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Designation: E2597 – 07$^{\varepsilon 1}$

StandardPractice for Manufacturing Characterization of Digital Detector Arrays[1]

This standard is issued under the fixed designation E2597; 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.

ε[1] NOTE—Editorial corrections were made throughout in April 2008.

1. Scope

1.1 This practice describes the evaluation of Digital Detector Arrays (DDAs), and assures that one common standard exists for quantitative comparison of DDAs so that an appropriate DDA is selected to meet NDT requirements.

1.2 This practice is intended for use by manufacturers or integrators of DDAs to provide quantitative results of DDA characteristics for NDT user or purchaser consumption. Some of these tests require specialized test phantoms to assure consistency among results among suppliers or manufacturers. These tests are not intended for users to complete, nor are they intended for long term stability tracking and lifetime measurements. However, they may be used for this purpose, if so desired.

1.3 The values stated in SI units are to be regarded as standard. The values given in parentheses are for information only.

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

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E1316 Terminology for Nondestructive Examinations

E1647 Practice for Determining Contrast Sensitivity in Radiology

E1742 Practice for Radiographic Examination

E1815 Test Method for Classification of Film Systems for Industrial Radiography

E2002 Practice for Determining Total Image Unsharpness in Radiology

E2445 Practice for Qualification and Long-Term Stability of Computed Radiology Systems

E2446 Practice for Classification of Computed Radiology Systems

2.2 *Other Standards:*

ISO 7004 Photography—Industrial Radiographic Films—Determination of ISO Speed, ISO Average Gradient and ISO Gradients G2 and G4 When Exposed to X- and Gamma-Radiation[3]

IEC 62220-1 Medical Electrical Equipment Characteristics of Digital X-ray Imaging Devices Part 1: Determination of the Detective Quantum Efficiency[4]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *digital detector array (DDA) system*—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 energy 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 seconds per image to many images per second, up to and in excess of real-time radioscopy rates (usually 30 frames per seconds).

3.1.2 *active DDA area*—the size and location of the DDA, which is recommended by the manufacturer as usable.

3.1.3 *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.

3.1.4 *contrast-to-noise ratio (CNR)*—quotient of the difference of the mean signal levels between two image areas and the standard deviation of the signal levels. As applied here, the two

[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.

Current edition approved Dec. 1, 2007. Published January 2008. DOI: 10.1520/E2597-07E01.

[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 National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

[4] Available from International Electrotechnical Commission (IEC), 3 rue de Varembé, Case postale 131, CH-1211, Geneva 20, Switzerland, http://www.iec.ch.

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image areas are the step-wedge groove and base material. The standard deviation of the intensity of the base material is a measure of the noise. The CNR depends on the radiation dose and the DDA system properties.

3.1.5 *basic spatial resolution (SRb)*—the basic spatial resolution indicates the smallest geometrical detail, which can be resolved using the DDA. It is similar to the effective pixel size.

3.1.6 *detector signal-to-noise ratio–normalized (dSNRn)*—the SNR is normalized for basic spatial resolution SRb as measured directly on the detector without any object other than beam filters in the beam path.

3.1.7 *internal scatter radiation (ISR)*—scattered radiation within the detector.

3.1.8 *efficiency—dSNRn* (see 3.1.6) divided by the square root of the dose (in mGy) and is used to measure the response of the detector at different beam energies and qualities.

3.1.9 *achievable contrast sensitivity (CSa)*—optimum contrast sensitivity (see Terminology E1316 for a definition of contrast sensitivity) obtainable using a standard phantom with an x-ray technique that has little contribution from scatter.

3.1.10 *specific material thickness range (SMTR)*—the material thickness range within which a given image quality is achieved. As applied here, the wall thickness range of a DDA, whereby the thinner wall thickness is limited by 80 % of the maximum gray value of the DDA and the thicker wall thickness by a SNR of 130:1 for 2 % contrast sensitivity and SNR of 250:1 for 1 % contrast sensitivity. Note that SNR values of 130:1 and 250:1 do not guarantee that 2 % and 1 % contrast sensitivity values will be achieved, but are being used to designate a moderate quality image, and a higher quality image respectively.

3.1.11 *frame rate*—number of frames acquired per second.

3.1.12 *lag*—residual signal in the DDA that occurs shortly after the exposure is completed.

3.1.13 *burn-in*—change in gain of the scintillator that persists well beyond the exposure.

3.1.14 *GlobalLag1f (global lag 1st frame)*—the ratio of mean signal value of the first frame of the DDA where the x-rays are completely off to the mean signal value of an image where the x-rays are fully on. This parameter is specifically for the integration time used during data acquisition.

3.1.15 *GlobalLag1s (global lag 1 s)*—the projected value of GlobalLag1f for an integration time of 1 second.

3.1.16 *GlobalLag60s (global lag 60 s)*—the ratio between mean gray value of an image acquired with the DDA after 60 s where the x-rays are completely off, to same of an image where the x-rays are fully on.

3.1.17 *bad pixel*—a pixel identified with a performance outside of the specification range for a pixel of a DDA as defined in 6.2.

3.1.18 *step-wedge*—a stepped block of a single metallic alloy with a thickness range that is to be manufactured in accordance with 5.2.

3.1.19 *phantom*—a part or item being used to quantify DDA characterization metrics.

3.1.20 *DDA offset image*—image of the DDA in the absence of x-rays providing the background signal of all pixels.

3.1.21 *DDA gain image*—image obtained with no structured object in the x-ray beam to calibrate pixel response in a DDA.

3.1.22 *calibration*—correction applied for the offset signal, and the non-uniformity of response of any or all of the x-ray beam, scintillator and the read out structure.

3.1.23 *gray value*—the numeric value of a pixel in a DDA image. This is typically interchangeable with the term *pixel value, detector response, Analog-to-Digital Unit, and detector signal*.

3.1.24 *pixel value*—the numeric value of a pixel in a DDA image. This is typically interchangeable with the term *gray value*.

3.1.25 *saturation gray value*—the maximum possible gray value of the DDA after offset correction.

4. Significance and Use

4.1 This practice provides a means to compare DDAs on a common set of technical measurements, realizing that in practice adjustments can be made to achieve similar results even with disparate DDAs given geometric magnification, or other industrial radiologic settings that may compensate for one shortcoming of a device.

4.2 A user must understand the definitions and corresponding performance parameters used in this practice in order to make an informed decision on how a given DDA can be used in the target application.

4.3 The factors that will be evaluated for each DDA are: basic spatial resolution (*SRb*), efficiency (Detector *SNR*-normalized (*dSNRn*) at 1 mGy, for different energies and beam qualities), achievable contrast sensitivity (*CSa*), specific material thickness range (*SMTR*), image lag, burn-in, bad pixels and internal scatter radiation (*ISR*).

5. Apparatus

5.1 *Duplex Wire Image Quality Indicator for SRb*—The duplex wire quality indicator corresponds to the design specified in Practice E2002 for the measurement of SRb and not unsharpness.

5.2 *Step-Wedge Image Quality Indicator*—The wedge has six steps in accordance with the drawing provided in Fig. 1. The wedge may be formed with built-in masking to avoid X-ray scatter and undercut. In lieu of built-in masking, the step-wedge may be inserted into a lead frame. The Pb frame can then extend another 25.4 mm (1 in.) about the perimeter of the step-wedge, beyond the support. The slight overlap of the Pb support with the edges of the step-wedge (no more than 6 mm (~0.25 in.) assures a significantly reduced number of X-rays to leak-through under the step-wedge that will contaminate the data acquired on each step. The step-wedges shall be formed of three different materials Aluminum–6061, Titanium–Ti-6Al-4V, and Inconel 718 with a center groove in

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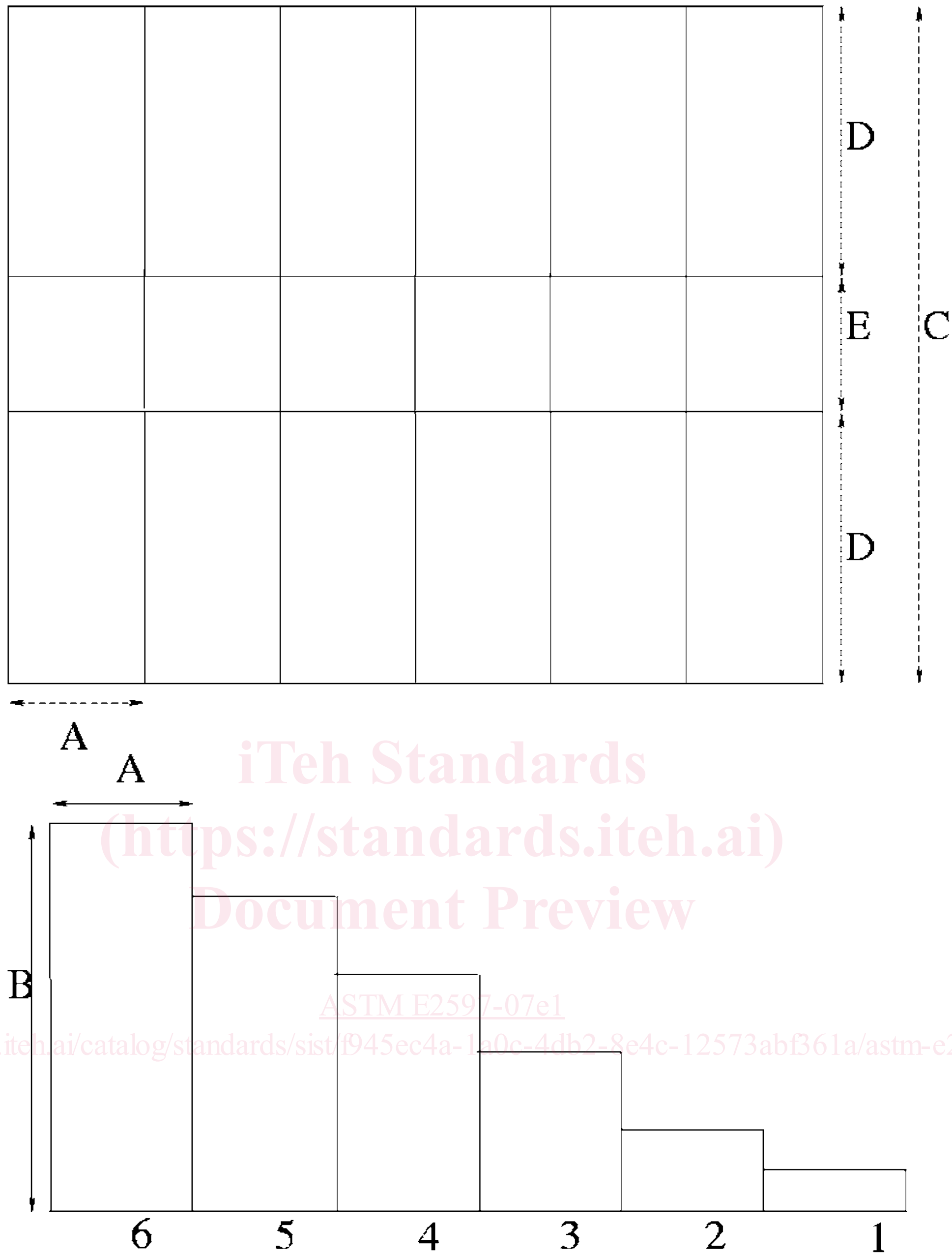

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FIG. 1 Step-Wedge Drawing (dimensions are listed in Table 1)

each step, as shown in Fig. 1. The dimensions of the wedges for the different materials are shown in Table 1.

5.3 *Filters for Measuring Efficiency of the DDA*—The following filter thicknesses (5.3.1-5.3.7) and alloys (5.3.8) shall be used to obtain different radiation beam qualities and are to be placed at the output of the beam. The tolerance for these thicknesses shall be ±0.1 mm (±0.004 in.).

5.3.1 No external filter (50 kV).

5.3.2 30 mm (1.2 in.) Al (90 kV).

5.3.3 40 mm (1.6 in.) Al (120 kV).

5.3.4 3 mm (0.12 in.) Cu (120 kV).

5.3.5 10 mm (0.4 in.) Fe (160 kV).

5.3.6 8 mm (0.3 in.) Cu (220 kV).

5.3.7 16 mm (0.6 in.) Cu (420 kV).

5.3.8 The filters shall be placed directly at the tube window. The aluminum filter shall be composed of Aluminum 6061. The Copper shall be composed of 99.9 % purity or better. The Iron filter shall be composed of Stainless steel 304.

NOTE 1—Radiation qualities in 5.3.2 and 5.3.3 are in accordance with DQE standard IEC62220-1, and radiation quality in 5.3.4 and 5.3.5 are in accordance with ISO 7004. Radiation quality in 5.3.6 is used also in Test Method E1815, Practice E2445, and Practice E2446.

5.4 *Filters for Measuring, Burn-In and Internal Scatter Radiation*—The filters for measuring burn-in and ISR shall consist of a minimum 16 mm (0.6 in.) thick Cu plate (5.3.7) 100 by 75 mm (4 by 3 in.) with a minimum of one sharp edge.

TABLE 1 Dimension of the Three Step-Wedges for Three Different Materials Used as Image Quality Indicators in this Practice

Material	Unit	A	B1	B2	B3	B4	B5	B6	C	D	E
Step-wedge (Inconel 718)	mm	35.0	1.25	2.5	5.0	7.5	10.0	12.5	175.0	70.0	35.0
Tolerance (±)	microns	200	25	25	38	38	38	38	200	200	200
5 % Groove	microns		63	125	250	375	500	625			
Tolerance (±)	microns		10	10	10	10	10	10			
Material	Unit	A	B1	B2	B3	B4	B5	B6	C	D	E
Step-wedge (Ti-6Al-4V)	mm	35.0	2.5	5.0	7.5	10.0	20.0	30.0	175.0	70.0	35.0
Tolerance (±)	microns	200	50	50	50	50	50	50	200	200	200
5 % Groove	microns		125	250	375	500	1000	1500			
Tolerance (±)	microns		10	10	10	10	10	10			
Material	Unit	A	B1	B2	B3	B4	B5	B6	C	D	E
Step-wedge (Al-6061)	mm	35.0	10.0	20.0	40.0	60.0	80.0	100.0	175.0	70.0	35.0
Tolerance (±)	microns	200	100	100	300	300	300	300	200	200	200
5 % Groove	microns		500	1000	2000	3000	4000	5000			
Tolerance (±)	microns		13	25	50	50	50	50			

Material	Unit	A	B1	B2	B3	B4	B5	B6	C	D	E
Step-wedge (Inconel 718)	inch	1.4	0.05	0.1	0.2	0.3	0.4	0.5	6.9	2.8	1.4
Tolerance (±)	mils	8.0	1.0	1.0	1.5	1.5	1.5	1.5	8.0	8.0	8.0
5 % Groove	mils		2.5	4.9	9.8	14.8	19.7	24.6			
Tolerance (±)	mils		0.5	0.5	0.5	0.5	0.5	0.5			
Material	Unit	A	B1	B2	B3	B4	B5	B6	C	D	E
Step-wedge (Ti-6Al-4V)	inch	1.4	0.1	0.2	0.3	0.4	0.8	1.2	6.9	2.8	1.4
Tolerance (±)	mils	8.0	2.0	2.0	2.0	2.0	2.0	2.0	8.0	8.0	8.0
5 % Groove	mils		4.9	9.8	14.8	19.7	39.4	59.1			
Tolerance (±)	mils		0.5	0.5	0.5	0.5	0.5	0.5			
Material	Unit	A	B1	B2	B3	B4	B5	B6	C	D	E
Step-wedge (Al-6061)	inch	1.4	0.4	0.8	1.6	2.4	3.1	3.9	6.9	2.8	1.4
Tolerance (±)	mils	8.0	4.0	4.0	12.0	12.0	12.0	12.0	8.0	8.0	8.0
5 % Groove	mils		19.7	39.4	78.7	118.1	157.5	196.9			
Tolerance (±)	mils		0.5	1.0	2.0	2.0	2.0	2.0			

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If the DDA is smaller than 15 by 15 cm (5.9 by 5.9 in.) use a plate that is dimensionally 25 % of the active DDA area.

6. Calibration and Bad Pixel Standardization

6.1 *DDA Calibration Method*—Prior to qualification testing the DDA shall be calibrated for offset and, or gain (see 3.1.20 and 3.1.21) to generate corrected images per manufacturer's recommendation. It is important that the calibration procedure be completed as would be done in practice during routine calibration procedures. This is to assure that data collected by manufacturers will closely match that collected when the system is entered into service.

6.2 *Bad Pixel Standardization for DDAs*—Manufacturers typically have different methods for correcting bad pixels. Images collected for qualification testing shall be corrected for bad pixels as per manufacturer's bad pixel correction procedure wherever required. In this section a standardized nomenclature is presented. The following definitions enable classification of pixels in a DDA as bad or good types. The manufacturers are to use these definitions on a statistical set of detectors in a given detector type to arrive at "typical" results for bad pixels for that model. The identification and correction of bad pixels in a delivered DDA remains in the purview of agreement between the purchaser and the supplier.

6.2.1 *Definition and Test of Bad Pixels:*

6.2.1.1 *Dead Pixel*—Pixels that have no response, or that give a constant response independent of radiation dose on the detector.

6.2.1.2 *Over Responding Pixel*—Pixels whose gray values are greater than 1.3 times the median gray value of an area of a minimum of 21×21 pixels. This test is done on an offset corrected image.

6.2.1.3 *Under Responding Pixel*—Pixels whose gray values are less than 0.6 times the median gray value of an area of in a minimum of 21×21 pixels. This test is done on an offset corrected image.

6.2.1.4 *Noisy Pixel*—Pixels whose standard deviation in a sequence of 30 to 100 images without radiation is more than 6 times the median pixel standard deviation for the complete DDA.

6.2.1.5 *Non-Uniform Pixel*—Pixel whose value exceeds a deviation of more than ±1 % of the median value of its 9×9 neighbor pixel. The test should be performed on an image where the average gray value is at or above 75 % of the DDA's linear range. This test is done on an offset and gain corrected image.

6.2.1.6 *Persistence/Lag Pixel*—Pixel whose value exceeds a deviation of more than a factor of 2 of the median value of its 9×9 neighbors in the first image after X-ray shut down (refer to 7.11.1).

6.2.1.7 *Bad Neighborhood Pixel*—Pixel, where all 8 neighboring pixels are bad pixels, is also considered a bad pixel.

6.2.2 *Types or Groups of Bad Pixels:*

6.2.2.1 *Single Bad Pixel*—A single bad pixel is a bad pixel with only good neighborhood pixels.

6.2.2.2 *Cluster of Bad Pixels*—Two or more connected bad pixels are called a cluster. Pixels are called connected if they are connected by a side or a corner (8-neighborhood possibilities). Pixels which do not have 5 or more good neighborhood pixels are called cluster kernel pixel (CKP) (Fig. 2).

6.2.2.3 A cluster without any CKP is well correctable and is labeled an irrelevant cluster. The name of the cluster is the size of a rectangle around the cluster and number of bad pixels in the irrelevant cluster, for example, "2×3 cluster4" (Fig. 2).

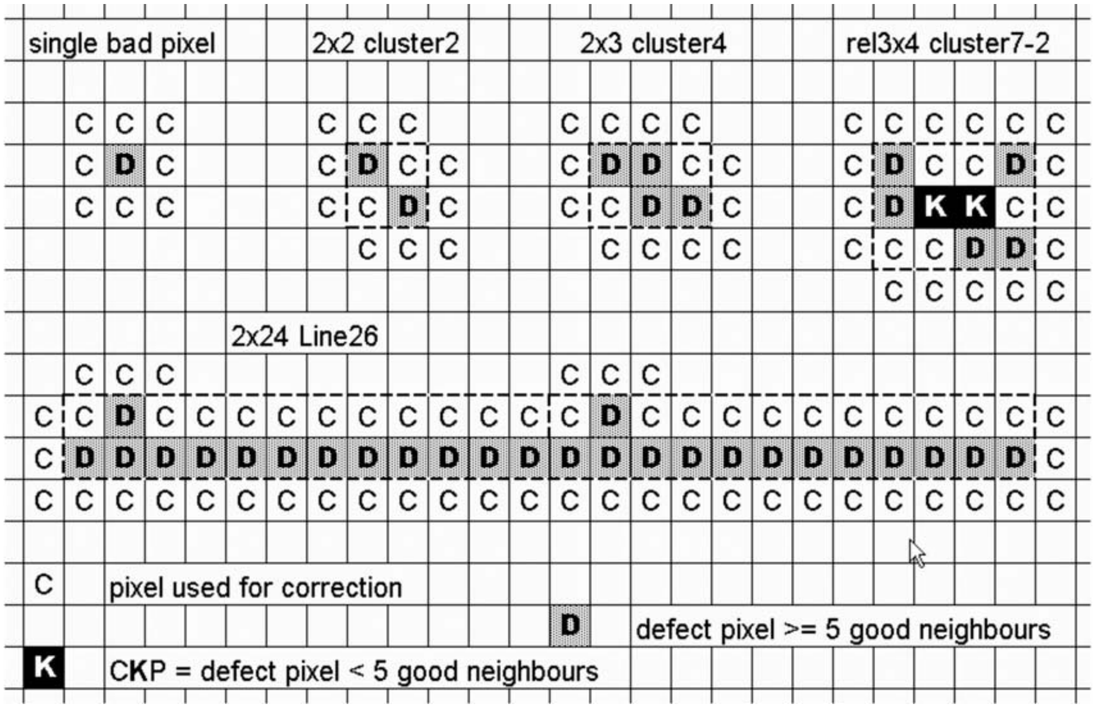

FIG. 2 Different Types of Bad Pixel Groups: Cluster, Relevant Cluster, and Bad Line

6.2.2.4 A cluster with CKP is labeled a relevant cluster. The name of the cluster is similar to the irrelevant cluster; with the exception that the prefix "rel" is added and the number of CKPs is provided as a suffix, for example, "rel3×4 cluster7-2", where 7 is the total number of bad pixels and 2 are those in this group that are CKPs (Fig. 2).

6.2.2.5 A bad line segment is a special irrelevant cluster with ten or more bad pixels connected in a line (row or column) where no more than 10 % of this line has adjacent bad pixels; no pixel in the bad line segment shall be a CKP (Fig. 2). The name of a bad line segment will have the word "line" substituted for the word "cluster", for example, "1×256 Line256" or "2×24 Line26" (Fig. 2).

7. Procedure

7.1 Beam filtration shall be defined by the test procedure for each individual test. It is to be noted that intrinsic beam filters may be installed in the X-ray tube head. Where possible, those values should be obtained, and listed.

7.2 For all measurements the x-ray source to detector distance (SDD) shall be >1000 mm (39.3 in.), unless specifically mentioned. The beam shall not interact with any other interfering object other than that intended, and shall not be considerably larger than the detector area through the use of collimation at the source. Note, the exposure times listed in this procedure can be obtained by any combination of extended exposures or multiple frames as available from the DDA. However, whichever is used, that information shall be recorded in the test report and the same DDA integration time (per frame) shall be used for all tests. In the following sections, where an image is required, this image shall be stored in a format that contains the full bit depth of the acquisition for later analysis.

7.3 The unsharpness in the images due to the finite size of X-ray focal spot and geometrical magnification should not exceed the value of standard radiographic practice as described in Practice E1742.

7.4 Measurement parameters for each test shall be recorded using the data-sheet template provided in Appendix X1, Data Sheet (Input).

7.5 All images shall be calibrated for offset and gain variations of the DDAs unless otherwise mentioned. Bad pixel correction using the manufacturer's correction algorithms also needs to be completed for all tests with the exclusion of the bad pixel identification testing (see 7.12 and 8.7).

7.6 All tests specified for a given DDA type need to be performed at the same internal detector settings such as gain and analog-digital conversion.

7.7 *Measurement Procedure for Basic Spatial Resolution (SRb):*

7.7.1 The test object to evaluate the *SRb* is the duplex wire gage (Practice E2002). It should be placed directly on the detector with an angle between 2° and 5° to the rows/columns of the detector. If a DDA has a non-isotropic pixel, two images shall be made, one with the duplex wire near parallel to the columns and one near parallel to the rows. No image processing shall be used other than gain/offset and bad pixel corrections.

7.7.2 The exposure shall be performed at a distance of >1 m (40 in.) using a focal spot size as specified in 7.3.

7.7.3 The measurement of basic spatial resolution may depend on the radiation quality. For DDAs that can operate above 160 kV, the test shall be performed with 220 kV (no pre-filtering). For all other DDAs, the test shall be completed at 90 kV (no pre-filtering). The mA of the x-ray tube shall be

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selected such that the gray value off the object (the duplex wire gage) is 80 % (±5 %) of full saturation for that DDA. If a successful image cannot be achieved with either of these energies without filtration, the test engineer shall decrease the beam current or increase the source to DDA distance to achieve said successful image. If this is still not practical, the radiation quality defined in 5.3.2 shall be used for the 90 kV measurement, while the radiation quality defined in 5.3.6 shall be used for the 220 kV measurement. In either case, the beam quality shall be recorded using the data-sheet template provided in Appendix X1, Data Sheet (Input).

NOTE 2—The intent of this test is to determine the achievable SRb, or the best SRb obtainable from the DDA under test. In this regard, it is important that the quantum noise of the measurement be significantly reduced. This may involve capturing multiple frames at the gray values listed above and falls within the procedure listed in 7.7.

7.8 *Measurement Procedure for Efficiency:*

7.8.1 The measurement shall be performed at a few points where the dose is above and below 1 mGy. The efficiency at 1 mGy can then be computed from the series of measured points. The series of points measured during the tests also provides additional information on the linear response of the detector. A few data points at the top of the response of the DDA is also recommended to obtain maximum levels of *dSNRn*.

7.8.2 An offset image (without radiation) shall be collected using the same integration time as the images described in 7.8.4.

7.8.3 The radiation qualities to be used for this measurement are defined in 5.3.

7.8.4 To achieve the efficiency measurement, the X-ray tube settings shall be as those listed in 5.3, with the filters located immediately adjacent to the port of the X-ray tube, such that no unfiltered radiation is reaching the DDA. The beam current and or time of exposure shall be adjusted such that a certain known dose rate is obtained at the location of the DDA as measured with an ionization gage. The measurement of dose rate shall be made without any interference from scatter, so it is best to complete this measurement prior to placing the detector. The dose is obtained by multiplying the dose rate by the exposure time in seconds (or fractions thereof). To arrive at the 1 mGy dose, it is recommended to measure all of the data points (few points below and above 1 mGy dose) and record the mAs values required to achieve these dose levels prior to placing the detector.

NOTE 3—The ionization gage used for measuring the dose rate should be calibrated as per the recommendation by its manufacturer.

7.8.5 Two images are collected under these conditions. These are used to acquire the noise without fixed patterns or other potential anomalies through a difference image.

7.9 *Measurement Procedure for Achievable Contrast Sensitivity:*

7.9.1 The step-wedge image quality indicators as defined in 5.2, of three different materials shall be used for this test. The full range of thickness of these shall be used as described in 5.2. The step-wedge shall be placed for all these tests at a minimum of 600 mm (24 in.) from the detector (while SDD is ≥1000 mm (40 in.)). The pre-filter should be placed directly in front of the tube. The beam shall be collimated to an area where only the step-wedge is exposed. The pre-filter used shall be recorded in the data sheet (input).

7.9.2 If the area of the detector is too small to capture the complete stepwedge within one image, two or more images with identical X-Ray and DDA settings may be captured to cover the complete step-wedge.

7.9.3 The energy for this measurement shall be set to 160 kV, with a 0.5 mm (0.02 in.) Cu filter. The x-ray tube current (mA) under this beam spectrum shall be determined such that the DDA is not saturated under the thinnest step for the integration time selected for all tests. Images shall be generated by averaging frames to obtain as minimum 1 s, 4 s, 16 s, and 64 s effective exposure times. The manufacturer can provide data at other exposure times if required.

7.10 *Measurement Procedure for Specific Material Thickness Range:*

7.10.1 No further measurements are needed for this test, if the procedure in 7.9 was already completed. If this test needs to be completed independent of the CS test, then the procedure in 7.9 shall be followed.

7.11 *Measurement Procedure of Lag and Burn In:*

7.11.1 *Procedure for Lag*—For this measurement no offset- and gain-correction shall be applied.

7.11.1.1 The lag of the detector shall be measured using a sequence of images. The DDA shall be powered ON and not exposed for more than 30 minutes. Before starting, an offset frame (image0) shall be captured (without radiation).

7.11.1.2 The DDA shall be exposed with a constant dose rate at 120 kV using a 120–kV beam with a 0.5-mm (0.020-in) Cu filter and 80 % of saturation gray value for a minimum of 30 minutes. Immediately following this, imagery shall be captured leading to a single image for a total exposure time of 4 s.

7.11.1.3 A sequence of images shall then be captured for about 70 s while shutting down the x-rays after approximately 5 seconds.

7.11.2 *Procedure for Burn-In:*

7.11.2.1 Burn-in shall be measured at 120 kV with a 16 mm Cu plate directly on the surface of the DDA and covering one half of the DDA. The DDA shall be exposed for 30 min with 80 % of saturation gray value of the DDA in the area not covered by the Cu plate. The X-rays shall be switched off and the Cu plate shall be removed from the beam. The DDA shall be exposed at the same kV but at a tenth of the original exposure dose. An image with 30 s effective exposure time shall be captured. A shadow in the area where the Cu plate was previously located may be slightly visible.

7.11.2.2 The time between the 30 min dosing and the 30 s exposure should be no longer than required to remove the Cu plate from the beam. Any delay in this procedure will alter the results of the measurement. Repeat the measurement after 1 h, 4 h, and 24 h without further exposure between measurements.

7.12 *Measurement Procedure of Bad Pixel*—Data required to determine bad pixel identification are described below. All measurements shall use 100 kV with 0.5 mm (0.02 in.) Cu

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