INTERNATIONAL

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Standard Practice for Manufacturing Characterization of Digital Detector Arrays[1]

This standard is issued under the fixed designation E2597/E2597M; 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 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.

NOTE 1—Further information on application of DDAs is contained in Guide E2736 and Practices E2698 and E2737.

1.3 The results reported based on this practice should be based on a group of at least three individual detectors for a particular model number.

1.4 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system are not necessarily exact equivalents; therefore, to ensure conformance with the standard, each system shall be used independently of the other, and values from the two systems shall not be combined.

1.5 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E1316 Terminology for Nondestructive Examinations

E1815 Test Method for Classification of Film Systems for Industrial Radiography

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

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

E2446 Practice for Manufacturing Characterization of Computed Radiography Systems

E2698 Practice for Radiographic Examination Using Digital Detector Arrays

E2736 Guide for Digital Detector Array Radiography

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

2.2 *ISO Standards:*[3]

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

ISO 17636-2 Non-destructive Testing of Welds — Radiographic Testing — Part 2: X- and Gamma-ray Techniques With Digital detectors

ISO 10893-7 Non-destructive Testing of Steel Tubes — Part 7: Digital Radiographic Testing of the Weld Seam of Welded Steel Tubes for the Detection of Imperfections

2.3 *Other Standards:*

EN 12681-2 Founding — Radiographic Testing — Part 2: Techniques With Digital Detectors[4]

IEC 62220-1 Medical Electrical Equipment Characteristics of Digital X-ray Imaging Devices Part 1: Determination of

[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 International Organization for Standardization (ISO), ISO Central Secretariat, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, https://www.iso.org.

[4] Available from https://www.en-standard.eu/.

the Detective Quantum Efficiency[5]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *achievable contrast sensitivity (CSa), n*—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.

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

3.1.3 *bad pixel, n*—a DDA pixel that does not conform to a specified performance as defined in 6.2.

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

3.1.5 *DDA correction, n*—the process of subtracting the response of each pixel in absence of ionizing radiation (DDA offset image) and normalization of the gain of each pixel in the presence of ionizing radiation and the absence of a specimen (DDA gain image) and finally the replacement of the bad pixels by corrected values (bad pixel correction). The result is a corrected digital radiograph.

3.1.6 *DDA gain image, n*—image obtained with no structured object in the X-ray beam to correct the pixel response in a DDA.

3.1.7 *DDA offset image, n*—image of the DDA in the absence of X-rays providing the background signal of all pixels.

3.1.8 *efficiency, n*—SNR_N (see 3.1.16) divided by the square root of the dose (in mGy), this is used to measure the response of the detector at different beam energies and qualities.

3.1.9 *frame rate, n*—number of frames acquired per second.

3.1.10 *GlobalLag1f (global lag 1st frame), n*—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.

3.1.11 *GlobalLag1s (global lag 1 s), n*—the projected value of GlobalLag1f for an integration time of 1 s.

3.1.12 *GlobalLag60s (global lag 60 s), n*—the ratio between mean pixel 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.

3.1.13 *internal scatter ratio (ISR), n*—ratio of external primary radiation to scattered radiation within the detector.

3.1.14 *ISO material thickness limit (ISO-MTL), n*—limit determined similar to SMTR, but using as thicker wall thickness limit the value where the normalized SNR (SNR_N) is above 70 (basic technique) or 100 (enhanced technique).

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

3.1.16 *normalized signal-to-noise ratio of the detector–(SNR_N), n*—the SNR is normalized by the interpolated basic spatial resolution $iSR_b^{detector}$ as measured directly on the detector without any object other than beam filters in the beam path.

3.1.17 *pixel value, n*—the numeric value of a pixel in the DDA image; this is typically interchangeable with the terms *gray value*, *detector response*, *Analog-to-Digital Unit*, or *detector signal*.

3.1.18 *phantom, n*—a part or item being used to quantify DDA characterization metrics.

3.1.19 *saturation pixel value, n*—the maximum possible pixel value of the DDA after offset correction.

3.1.20 *specific material thickness range (SMTR), n*—the penetrated material thickness range within a given minimum SNR in the image is achieved. The wall thickness range of a DDA is limited for the thinner wall thickness by 80 % of the saturation pixel value at this thickness and the thicker wall thickness by a SNR of 130 (basic contrast sensitivity) or 250 for (enhanced contrast sensitivity).

NOTE 2—This is not related to the image quality requirement of 1-2T or 2-2T, because the spatial resolution is not considered.

3.1.21 *total image acquisition time, n*—complete acquisition time of a DDA image, consisting of the effective exposure time of the integrated frames and the image transfer time between detector and computer including the detector read-out time, that is, from start of the exposure until storage of the final image on the computer.

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 should 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 parameters that will be evaluated for each DDA are: interpolated basic spatial resolution ($iSR_b^{detector}$), efficiency (normalized Detector *SNR* (SNR_N) at 1 mGy, for different energies and beam qualities), achievable contrast sensitivity (*CSa*), specific material thickness range (*SMTR*) and ISO-MTL , image lag, burn-in, bad pixels distribution and statistics and internal scatter ratio (*ISR*).

4.4 Given that each of these parameters are discussed together in many of the following sections, the following list will be helpful in selecting the key sections for a given test as follows. It should be noted that other sections of the document are needed to establish the appropriate technique for the parameter under test. Note that for each parameter (test), the first section listed is typically an apparatus or gauge (if required), the second section listed are the standardized measurements, and the third section listed involves the analysis or computations:

[5] Available from International Electrotechnical Commission (IEC), 3, rue de Varembé, 1st floor, P.O. Box 131, CH-1211, Geneva 20, Switzerland, https://www.iec.ch.

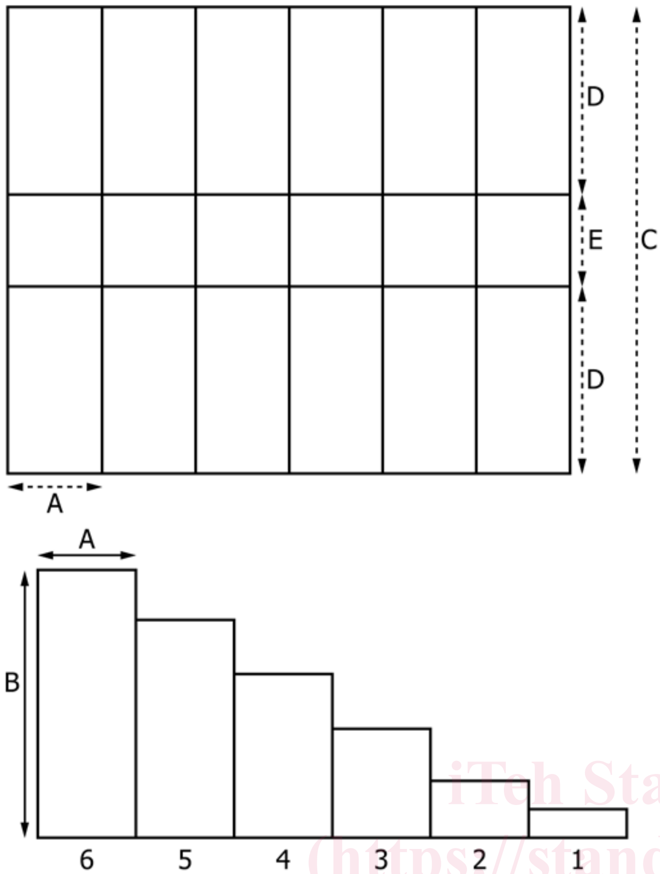

FIG. 1 Step-Wedge Drawing (Dimensions Are Listed in Table 1)

4.4.1 *For* $iSR_b^{detector}$, see 5.1, 7.7, 8.2.

4.4.2 *For Detector Efficiency,* see 5.3, 7.8, 8.3.

4.4.3 *For CSa,* see 5.2, 7.9, 8.4.

4.4.4 *For SMTR,* see 5.2 (or 7.9, if already completed), 7.10, 8.5.

4.4.5 *For ISO-MTL,* see 5.2 (or 7.9, if already completed), 7.10, 8.6.

4.4.6 *For Image Lag,* see 7.11.1, 8.7.1.

4.4.7 *For Burn-in,* see 5.4, 7.11.2, 8.7.2.

4.4.8 *For Bad Pixel Tests,* see 6.2, 7.12, 8.8.

4.4.9 *For ISR,* see 5.4, 7.13, 8.9.

5. Apparatus

5.1 *Duplex Wire Image Quality Indicator for* $iSR_b^{detector}$—The duplex wire quality indicator corresponds to the design specified in Practice E2002 for the measurement of $iSR_b^{detector}$.

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 lead frame should then extend approximately 25 mm [1 in.] around the perimeter of the step-wedge, beyond the support. A slight overlap of the lead support with the edges of the step-wedge (no more than approximately 6 mm [~0.25 in.]) assures a significantly reduced of X-ray dose will leak through under the step-wedge and will influence the data acquired on each step. The step-wedges shall be formed of two different materials: Aluminum 7022 or Stainless Steel 316L, with a center groove in 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.] aluminum (90 kV).

5.3.3 40 mm [1.6 in.] aluminum (120 kV).

5.3.4 3 mm [0.12 in.] copper (120 kV).

5.3.5 10 mm [0.4 in.] iron (160 kV).

5.3.6 8 mm [0.3 in.] copper (220 kV).

5.3.7 16 mm [0.6 in.] copper (420 kV).

5.3.8 The filters shall be placed directly at the tube window. The aluminum filter shall be composed of 97 % purity or better. The copper shall be composed of 99.9 % purity or better. The iron filter shall be composed of Stainless Steel 316L. At minimum 3 of the above radiation qualities shall be used for the detector characterization.

NOTE 3—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 qualities in 5.3.6 are used also in Test Method E1815, Practice E2445, and Practice E2446.

5.4 *Filters for Measuring, Burn-In and Internal Scatter Ratio*—The filters for measuring burn-in and ISR shall consist of a minimum 16 mm [0.6 in.] thick copper plate (5.3.7) 100 mm by 75 mm [4 in. by 3 in.] with a minimum of one sharp edge. If the DDA is smaller than 15 cm by 15 cm [5.9 in. by 5.9 in.] use a plate that is dimensionally 25 % of the active DDA area.

6. Detector Correction and Bad Pixel Classification

6.1 *DDA Correction Method*—Prior to qualification testing, the DDA shall be corrected for offset, gain, and bad pixels (see 3.1.7 and 3.1.8) to generate corrected images per manufacturer's recommendation. It is important that this correction procedure be completed as would be done in practice during routine correction 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 Classification 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:*

TABLE 1 Dimension of the Two Step-Wedges for Two Different Materials Used as Image Quality Indicators In This Practice

Material	Unit	A	B1	B2	B3	B4	B5	B6	C	D	E
Step-wedge (Steel SS 316L)	mm	35	1.5	3	6	9	12	15	175	70	35
Tolerance (±)	µm	200	50	50	50	50	50	50	200	200	200
5 % Groove	µm		75	150	300	450	600	750			
Tolerance (±)	µm		10	10	10	10	10	10			
Material	Unit	A	B1	B2	B3	B4	B5	B6	C	D	E
Step-wedge (Al-7022)	mm	35	10	20	40	60	80	100	175	70	35
Tolerance (±)	µm	200	100	100	300	300	300	300	200	200	200
5 % Groove	µm		500	1000	2000	3000	4000	5000			
Tolerance (±)	µm		13	25	50	50	50	50			
The values stated in SI units above and inch-pound units below are to be regarded separately as standard.											
Material	Unit	A	B1	B2	B3	B4	B5	B6	C	D	E
Step-wedge (Steel SS 316L)	inch	1.40	0.06	0.12	0.24	0.36	0.48	0.60	6.9	2.8	1.4
Tolerance (±)	mils	8	2	2	2	2	2	2	8	8	8
5 % Groove	mils		6	12	24	36	48	60			
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-7022)	inch	1.4	0.4	0.8	1.6	2.4	3.1	3.9	6.9	2.8	1.4
Tolerance (±)	mils	8	4	4	12	12	12	12	8	8	8
5 % Groove	mils		20	40	80	120	155	195			
Tolerance (±)	mils		0.5	1	2	2	2	2			

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 values are greater than 1.3 times the median pixel 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 values are less than 0.6 times the median pixel value of an area of 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 six 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 in the corrected digital radiograph. The test should be performed on an image where the average pixel value is at or above 80 % 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 two of the median value of its 9×9 neighbors in the first image after X-ray shut down or exceeds six times the median noise value in the dark image (refer to 7.11.1).

6.2.1.7 *Bad Neighborhood Pixel*—Pixel, where all eight 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 (eight-neighborhood possibilities). Pixels which do not have five or more good neighborhood pixels are called cluster kernel pixel (CKP) (Fig. 2). A pixel direct at the detector rim is not called CKP if it has three or more good neighbors, but a pixel in a detector corner with less than 2 good neighbors is called a CKP.

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).

6.2.2.4 A cluster (excluding a bad line segment defined in 6.2.2.5) with CKP is labeled a relevant cluster. A line cluster with CKP is classified differently (example given below and demonstrated in Fig. 2). 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" (Fig. 2), where 7 is the total number of bad pixels and two are those in this group that are CKPs.

6.2.2.5 A bad line segment is a special 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. If there are CKPs in the line segment, then the following rule is to be followed: As shown in Fig. 2, a relevant cluster is located at the end of a bad line segment. The bad line segment is then separated from the relevant cluster. In this example, the bad line segment is a 1×24 line24 and attached with a relevant cluster rel3x3 cluster7-7 directly at the detector rim (at bottom of Fig. 2). Crossing bad lines are reported like two single separated lines with a C at the end as, for example, 1x24 line24C. There may be configurations where a single CKP exists for two connected line segments, which is considered as non-relevant.

NOTE 4—The positions of finally detected bad pixels as described before are a snapshot, which represents the current state of the detector. Some pixels could behave only temporarily like bad pixels. Therefore, at a later bad pixel analysis, the positions of bad pixels may vary from the snapshot before. The agreed thresholds for bad pixels shall always relate only to the number and region and not to the specific position during a snapshot.

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.

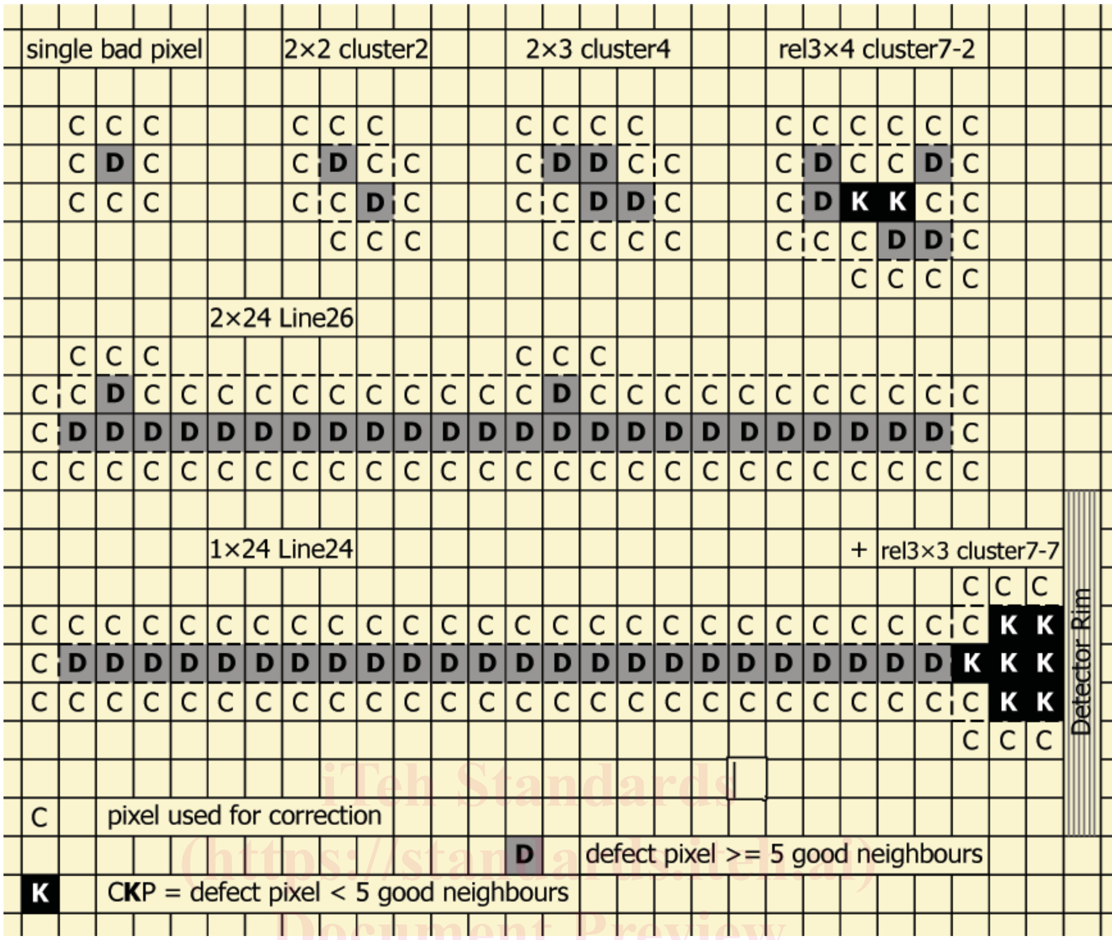

FIG. 2 Different Types of Bad Pixel Groups: Small Clusters, A Relevant Cluster And Bad Lines; At Bottom An Example of A Bad Line Segment Attached To A Relevant Cluster At The Detector Rim is Shown; The Line Segment Is A 1x24 line24 (Not Relevant), But Connected To A Relevant Cluster rel3x3 cluster7-7

7.2 For all measurements, the X-ray source to detector distance (SDD) shall be ≥1000 mm [~ 40 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.

7.3 The geometric unsharpness shall be less than or equal to 5 % of the total unsharpness for the $iSR_b^{detector}$ measurements. This avoids additional unsharpness due to the finite size of the X-ray focal spot on the measurement of $iSR_b^{detector}$. See example below.

e.g. 100 µm pixel size (equal to $iSR_b^{detector}$*) and focal spot size: 2 mm*
Duplex wire to active sensor area distance: 2.5 mm
Source-to-Object distance: 1000 mm
Maximum expected unsharpness: 2 mm / 1000 mm × 2.5 mm = 0.005 mm = 5 µm
Maximum unsharpness due to the limited focal spot size relative to $iSR_b^{detector}$*: 5 %*

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

NOTE 5—The effective exposure times listed in this procedure can be obtained by any combination of extended single 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, the total image acquisition time (including the read-out and image transfer time) should be noted too. 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.

7.5 All images shall be corrected 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 Interpolated Basic Spatial Resolution (*$iSR_b^{detector}$*):*

7.7.1 The test object to measure the $iSR_b^{detector}$ 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 geometric unsharpness levels as specified in 7.3.

7.7.3 The measurement of the interpolated basic spatial resolution of the detector may depend on the radiation quality. For DDAs that can operate above 160 kV, the test shall be performed with 220 kV. A filter of up to 0.5 mm Copper in front of the tube port shall be used. For all other DDAs, the test shall be completed at 90 kV (with no added pre-filter). The mA of the X-ray tube shall be selected such that the pixel value of the object (the duplex wire gage) is between 50 % and 80 % of full saturation for that DDA. If this cannot be achieved, a SNR of ≥ 100 shall be obtained. Frame integration is recommended to achieve the required SNR. If the pixel value of 80 % of full saturation is exceeded, the source to DDA distance shall be increased until the required pixel value is reached.

NOTE 6—The intent of this test is to determine the achievable $iSR_b^{detector}$ 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 pixel values listed above to provide robust measurements.

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 by changing the effective exposure time of the DDA. The series of points measured during the tests also provides additional information on the linear response (relative to the effective exposure time) of the detector. A few data points near the top of the response of the DDA is also recommended to obtain maximum levels of SNR_N.

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, or time of exposure, or both, shall be adjusted such that a certain known dose is obtained at the location of the DDA as measured with a calibrated ionization chamber. 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 effective 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 7—The ionization chamber used for measuring the dose rate should be calibrated as per the recommendation by its manufacturer.

7.8.5 For each dose, two images are collected. 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 of two different materials shall be used for this test, as defined in 5.2. 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 step-wedge 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.] copper filter. If the DDA is not specified to such high energy, the maximum allowed energy shall be used; in that case, the energy used shall be printed in the data sheet (output) "C" and "D" (see appendix X1.2 for details). 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 total image acquisition time including the read-out time should be given too. The manufacturer can provide data at other exposure times if required.

7.10 *Measurement Procedure for Specific Material Thickness Range and ISO-MTL:*

7.10.1 No further measurements are needed for these tests, if the procedure in 7.9 was already completed. If these tests need to be completed independent of the CS test, then the procedure in 7.9 shall be followed. If these tests shall be performed with the extended quality level (larger than 15), the procedure in 7.9 shall be followed with the additional plate specified in the Table 2 note; the X-ray and DDA settings shall be the same as specified in 7.9.3; the X-ray tube current (mA) under this beam spectrum shall be determined such that the DDA is not saturated under the thinnest step without the additional plate for the integration time selected for all tests.

7.11 *Measurement Procedure of Lag and Burn-In:*

7.11.1 *Procedure for Lag*—For this measurement, no additional gain or bad pixel correction shall be applied in the final computation.

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 a suitable time to warm up the detector and remove prior lag before the measurement is acquired. An offset frame (image0) shall be captured (without radiation).

7.11.1.2 The DDA shall be exposed with a constant dose rate using a 120 kV beam with a 0.5 mm [0.020 in.] copper filter to 80 % of saturation pixel value for a minimum of 5 min. Immediately following this, imagery shall be captured leading to a single image for a total image acquisition 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 s.

7.11.2 *Procedure for Burn-In:*

7.11.2.1 For this measurement offset, gain, and bad pixel corrections shall be applied to the final image that will be used for the burn-in computation. Burn-in shall be measured at 120 kV with a 16 mm copper plate directly on the surface of the DDA and covering one half of the DDA. The DDA shall be exposed for 5 min with 80 % of saturation pixel value of the DDA in the area not covered by the copper plate. The X-rays shall be switched off and the copper 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 total image acquisition time shall be captured. A shadow in the area where the copper plate was previously located may be slightly visible.

7.11.2.2 The time between the 5 min dosing and the 30 s image acquisition should be no longer than required to remove the copper 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.] copper pre-filtering. Bad pixel tests are to be reported based on a group of at least three individual detectors for a particular model of DDA.

7.12.1 A sequence of dark images with about 120 s of total integration time for the sequence in the absence of X-ray radiation is acquired. The image sequence is stored for noisy pixels identification. The image sequence is then averaged to obtain one single offset image. This is referred to as *offsetdata*.

7.12.2 A sequence of images with about 120 s of total integration time for the image sequence is acquired using an X-ray setting where the average pixel value is 50 % of the saturation pixel value of the DDA range after offset correction. The image sequence is then averaged and offset corrected to obtain one single image. This is referred to as *badpixdata1*.

7.12.3 A sequence of images with about 120 s of total integration time for the image sequence is acquired using an X-ray setting such that the average pixel value is 10 % of the saturation pixel value of the DDA range after offset correction. These images are then averaged and offset and gain corrected. This is then referred to as *badpixdata2*.

7.12.4 A sequence of images with about 120 s total integration time is acquired using an X-ray setting such that the average pixel value is 80 % of the saturation pixel value of the DDA range after offset correction. These images are then averaged and offset and gain corrected. This will be referred to as *badpixdata3*.

7.12.5 *Persistence/Lag Pixel*—No gain correction shall be applied. The detector shall be powered ON and not exposed for a suitable time to warm up the detector and get rid of old lag. Before starting the exposure an offset image shall be acquired. The detector is then exposed with a constant dose rate at 120 kV using a 0.5-mm copper filter (as in 5.4) and 80 % of saturation pixel value after offset correction for a minimum of 300 s. A sequence of images of about 70 s shall be captured. X-rays shall be shut off 5 s after start of the sequence.[6]

7.13 *Measurement Procedure for Internal Scatter Ratio*—A 16 mm copper plate in accordance with 7.11.2.1 shall be placed directly on the DDA in a manner that the sharp edge is exactly in the middle of the DDA and perpendicular to the beam to get a sharp edge in the image. The DDA shall be exposed with 220 kV filtered with an 8 mm [0.31 in.] copper pre-filter. For DDAs which are not recommended for energy in this range, the test shall be performed at the highest recommended X-ray energy range with a filter between 3 mm and 8 mm of copper. The beam current of the tube shall be adjusted so that 80 % of the saturation pixel value is attained after offset correction. An image shall be captured with 60 s effective exposure time using a focal spot size as specified in 7.3. The image shall be offset and gain corrected.

8. Calculation and Interpretation of Results

8.1 All test results are to be documented using the data sheet format as shown in Appendix X1, Data Sheet (Output).

8.2 *Calculation of Interpolated Basic Spatial Resolution of a DDA ($iSR_b^{detector}$):*

8.2.1 The measurement shall be done across the middle area of the IQI image integrating along the width of 60 % of the lines of the duplex wires to avoid variability along the length of the wires (see Practice E2002).

8.2.2 For improved accuracy in the measurement of the $iSR_b^{detector}$ value the 20 % modulation depth (dip) value shall be approximated from the modulation depth (dip) values of the neighbor duplex wire modulations as described in Practice E2002.

8.3 *Calculations for Efficiency:*

8.3.1 The efficiency is calculated by using the difference images, where the bad pixels are corrected using the manufacturer's methods for correcting bad pixels prior to differencing. No offset or gain correction shall be used for the difference images. The resultant of the difference images avoids all geometrical distortions and measures only behavior in time and dose. The noise (standard deviation) in a 50×50 pixel area is computed over five regions of the differenced image and is represented as σ*[difference image]*. The five areas of 50×50 pixels shall be placed on the image such that one is at the center of the image and four are at the corners with a distance to the edge of 10 % of the effective DDA range. The mean signal of the 50×50 pixel areas averaged over the same five locations in one of the non-differenced images shall be represented as *Mean PV[first image]*. *Mean OV* is the average in the same areas of an offset image (without radiation). SNR_N can be calculated using Eq 1 (the value is corrected by the square root of 2 since the difference of two images are used for noise calculations, and by the normalized resolution 88.6 µm/$iSR_b^{detector}$). The SNR_N obtained for the five regions are to be averaged to obtain the final SNR_N value.

NOTE 8—This is a similar procedure to Practices E2445 and E2446 for

[6] The sequence of 7.11.1 may be used for Bad Pixel evaluation also.