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.

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

1.4 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

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 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

E1815 Test Method for Classification of Film Systems for Industrial Radiography

E2002 Practice for Determining Total Image Unsharpness in Radiology

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

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

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

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

3.1.5 *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.

3.1.6 *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 image areas are the step-wedge groove and base material. The

[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 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.

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.

3.1.7 *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.

3.1.8 *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).

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

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

3.1.11 *efficiency*—*dSNRn* (see 3.1.7) 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.

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

3.1.13 *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.

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

3.1.15 *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.

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

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

3.1.18 $iSRb^{detector}$—the interpolated basic spatial resolution of the detector indicates the smallest geometric detail, which can be resolved spatially using a digital detector array with no geometric magnification.

NOTE 1—It is equal to 1⁄2 of the measured detector unsharpness and it is determined from a digital image of the duplex wire IQI (Practice E2002), directly placed on the DDA without object. The $iSRb^{\text{detector}}$ value is determined from the interpolated or approximated modulation depth of two, or several, neighbor wire pairs at 20 % modulation depth.

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

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

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

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

3.1.23 *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.

3.1.24 *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.

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

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: interpolated basic spatial resolution ($iSR_b^{detector}$), 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* $iSRb^{detector}$—The duplex wire quality indicator corresponds to the design specified in Practice E2002 for the measurement of $iSRb^{detector}$ 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 lead 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

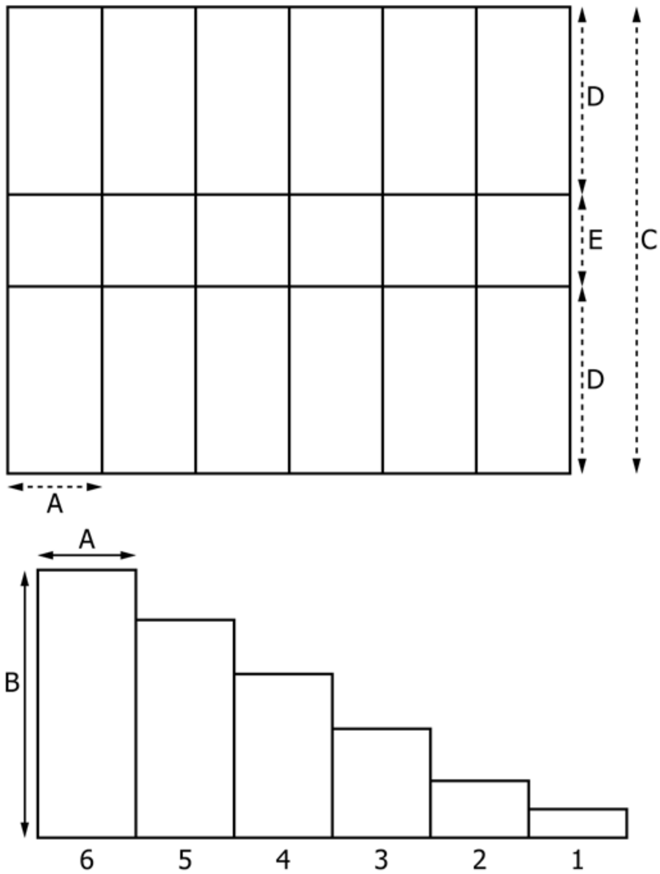


FIG. 1 Step-Wedge Drawing (dimensions are listed in Table 1)

lead 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 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 aAluminum 6061. The copper shall be composed of 99.9 % purity or better. The iron filter shall be composed of Stainless Steel 304.

NOTE 2—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 copper plate (5.3.7) 100 by 75 mm [4 by 3 in.] with a minimum of one sharp edge. 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, or gain, or both, (see 3.1.10 and 3.1.9) 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 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. 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 two of the median value of its 9×9 neighbors in the first image after X-ray shut down and are exceeds six times the median noise value in the dark image (refer to 7.11.1).

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			
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 (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			

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).

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", 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. 2b 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 1×51 Line51 and attached with a relevant cluster Rel4×3 cluster 8-5.

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 [~ 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.

NOTE 3—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.

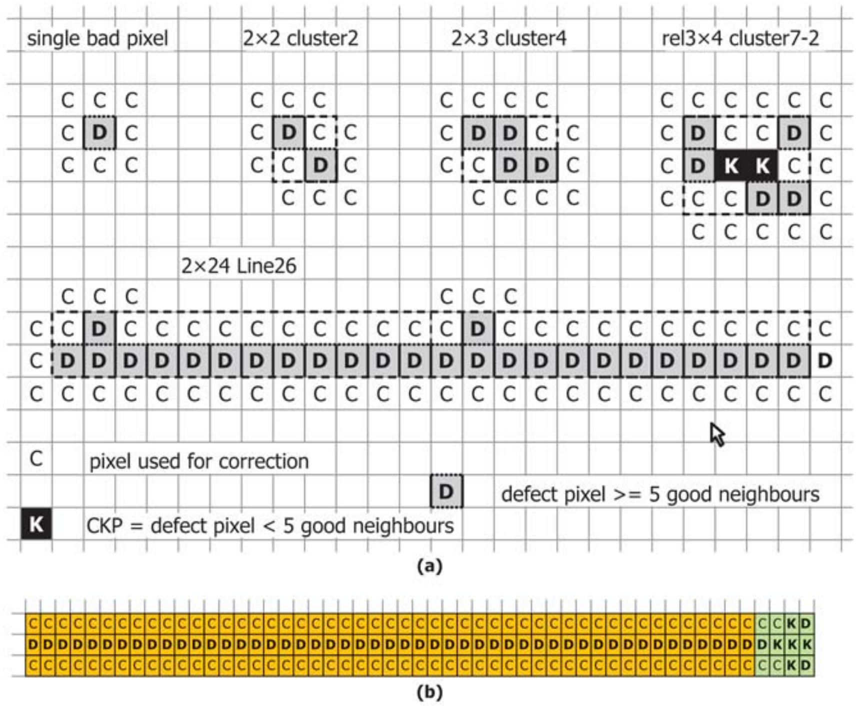


FIG. 2 (2) Different Types of Bad Pixel Groups: Cluster, Relevant Cluster, and Bad Line. (b) Example of a Bad Line Segment Separated from a Relevant Cluster at the End. The line Segment is a 1x51 Line51 and Attached to a Relevant Cluster rel 4x4 cluster 8-5.

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→focal spot size maximum 2 mm
Duplex wire to active sensor area distance : 2.5 mm
Source to Object distance : 1 000 mm
Maximum expected unsharpness : 2 mm / 1 000 mm × 2.5 mm = 0.005 mm = 5 µm
Maximum unsharpness due to the limited focal spot size in percent : 5 %

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 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.

NOTE 4—For the extended quality numbers (> 15) listed in Table 2 as discussed in Section 9 there are no duplex wires defined in Practice E2002. A special gage will be needed with wire pairs smaller than 50 µm to report in this extended quality regime. Any other gages used to perform the measurement shall be documented along with the test results

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 (no pre-filtering or a filter of up to 0.5 mm Copper in front of the tube port). The mA of the X-ray tube shall be selected such that the gray 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 gray value of 80 % of full saturation is exceeded the source to DDA distance shall be increased until the required grey level is reached.

NOTE 5—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 gray values listed above to fall within the procedure listed in 7.7.

TABLE 2 Quality Numbers for Three Different Materials

Inconel					Quality Number																Quality Number Extended									
Parameter	Unit	High	Low	Condition	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
$iSR_B^{detector}$ (basic spatial resolution)	µm	3,2	1000	220 kV no filter	1000	800	630	500	400	320	250	200	160	130	100	80	63	50	40	32	25	20	16	13	10	8	6,3	5	4	3,2
CS (contrast sensitivity)	%	0,010	3,2	In, 160 kV, 4 s, (% Σ 1.25 to 12.5 mm)/6	3,2	2,5	2	1,6	1,3	1	0,8	0,63	0,5	0,4	0,32	0,25	0,2	0,16	0,13	0,1	0,080	0,053	0,050	0,040	0,032	0,025	0,020	0,016	0,013	0,010
Image Lag	%	0,010	3,2	1st frame, normalized to [1 s]	3,2	2,5	2	1,6	1,3	1	0,8	0,63	0,5	0,4	0,32	0,25	0,2	0,16	0,13	0,1	0,080	0,053	0,050	0,040	0,032	0,025	0,020	0,016	0,013	0,010
Efficiency = dSNRn @ 1 mGy	–	1200	200	@ 160 kV, 10 mm Fe	200	240	280	320	360	400	440	480	520	560	600	640	680	720	760	800	840	880	920	960	1000	1040	1080	1120	1160	1200
Specific Material Thickness Range	mm	12,5	2,5	In, 160 kV, 4 s, SNR > 130	2,5	3,17	3,83	4,5	5,17	5,83	6,5	7,17	7,83	8,5	9,17	9,83	10,5	11,2	11,8	12,5	13,2	13,8	14,5	15,2	15,8	16,5	17,2	17,8	18,5	19,2
Titanium					Quality Number																Quality Number Extended									
Parameter	Unit	High	Low	Condition	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
$iSR_B^{detector}$ (basic spatial resolution)	µm	3,2	1000	220 kV no filter	1000	800	630	500	400	320	250	200	160	130	100	80	63	50	40	32	25	20	16	13	10	8	6,3	5	4	3,2
CS (contrast sensitivity)	%	0,010	3,2	Ti, 160 kV, 4 s, (% Σ 2.5 to 30 mm)/6	3,2	2,5	2	1,6	1,3	1	0,8	0,63	0,5	0,4	0,32	0,25	0,2	0,16	0,13	0,1	0,080	0,053	0,050	0,040	0,032	0,025	0,020	0,016	0,013	0,010
Image Lag	%	0,010	3,2	1st frame, normalized to [1 s]	3,2	2,5	2	1,6	1,3	1	0,8	0,63	0,5	0,4	0,32	0,25	0,2	0,16	0,13	0,1	0,080	0,053	0,050	0,040	0,032	0,025	0,020	0,016	0,013	0,010
Efficiency = dSNRn @ 1 mGy	–	1200	200	@ 160 kV, 10 mm In	200	240	280	320	360	400	440	480	520	560	600	640	680	720	760	800	840	880	920	960	1000	1040	1080	1120	1160	1200
Specific Material Thickness Range	mm	38	5	Ti, 160 kV, 4 s, SNR > 130	5	6,33	7,67	9	10,3	11,7	13	14,3	15,7	17	18,3	19,7	21	22,3	23,7	25	26,3	27,7	29	30	31,7	33	34,3	35,7	37	38,3
Aluminum					Quality Number																Quality Number Extended									
Parameter	Unit	High	Low	Condition	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
$iSR_B^{detector}$ (basic spatial resolution)	µm	3,2	1000	220 kV no filter	1000	800	630	500	400	320	250	200	160	130	100	80	63	50	40	32	25	20	16	13	10	8	6,3	5	4	3,2
CS (contrast sensitivity)	%	0,010	3,2	Al, 160 kV, 4 s, (% Σ 10 to 100 mm)/6	3,2	2,5	2	1,6	1,3	1	0,8	0,63	0,5	0,4	0,32	0,25	0,2	0,16	0,13	0,1	0,080	0,053	0,050	0,040	0,032	0,025	0,020	0,016	0,013	0,010
Image Lag	%	0,010	3,2	1st frame, normalized to [1 s]	3,2	2,5	2	1,6	1,3	1	0,8	0,63	0,5	0,4	0,32	0,25	0,2	0,16	0,13	0,1	0,080	0,053	0,050	0,040	0,032	0,025	0,020	0,016	0,013	0,010
Efficiency = dSNRn @ 1 mGy	–	1500	250	@ 120 kV, 40 mm Al	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000	1050	1100	1150	1200	1250	1300	1350	1400	1450	1500
Specific Material Thickness Range	mm	150	20	Al, 160 kV, 4 s, SNR > 130	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150

NOTE 1—For extended Quality Numbers, beyond 16 additional plates below the step wedge shall be used for measurement of Specific Material Thickness Range.
1. For Inconel measurement the thickness of the Inconel plate shall be 7.5 mm to extend the wedge for the scale by 10 quality values.
2. For Titanium measurement the thickness of the titanium plate shall be 10 mm to extend the wedge for the scale by 10 quality values.
3. For Aluminum measurement the thickness of the aluminum plate shall be 50 mm to extend the wedge for the scale by 10 quality values.
4. For SMTR measurement in the extended range the X-ray dose (mA) still shall be set that no saturation occurs on the thinnest step without the extension plate.

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, 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 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 6—The ionization gage 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 three 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 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.] 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 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. If this test 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 Table 2; 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 gray value for a minimum of 5 min. Immediately following this, imagery shall be captured leading to a single image for a total exposure time of 4 s.

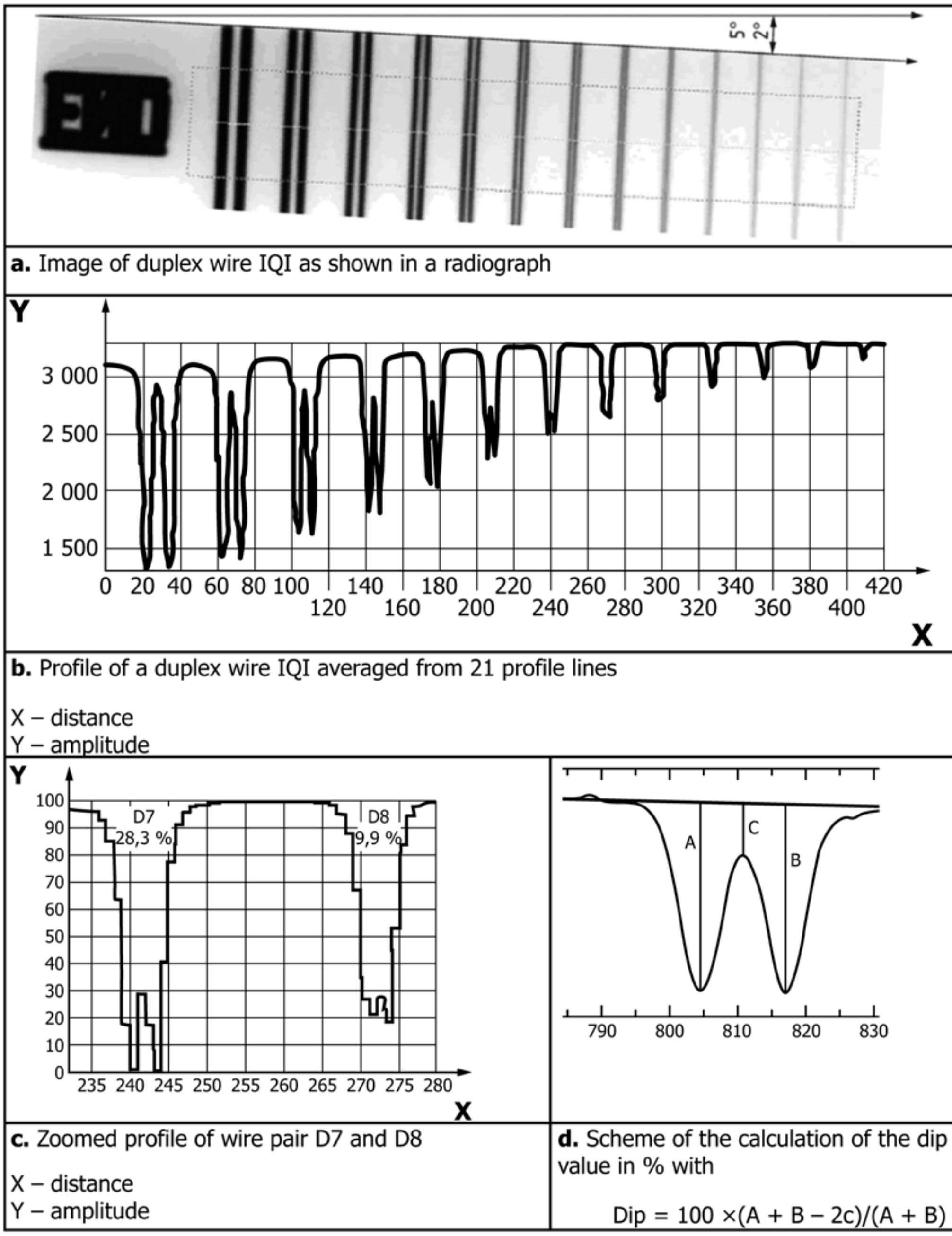
7.11.1.3 A sequence of images shall then be captured for about 70 s while shutting down the X-rays after approximately 5 s.

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 gray 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 effective exposure 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 exposure 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



a. Image of duplex wire IQI as shown in a radiograph

b. Profile of a duplex wire IQI averaged from 21 profile lines

X – distance
Y – amplitude

c. Zoomed profile of wire pair D7 and D8

X – distance
Y – amplitude

d. Scheme of the calculation of the dip value in % with

Dip = 100 ×(A + B – 2c)/(A + B)

NOTE 1—Schematic of the measurement is shown at lower right.

FIG. 3 Wire-Pair Image Analysis for Calculation of Interpolated Basic Spatial Resolution of the detector ($iSR_b^{detector}$).

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 gray value is 50 % of the saturation gray 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 gray value is 10 % of the saturation gray 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 gray value is 80 % of the saturation gray 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 gray 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.[5]

7.13 *Measurement Procedure for Internal Scatter Radiation*—A 16-mm copper plate in accordance with 7.11 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 gray 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 (Fig. 3a). A next neighbor interpolation for the line profile calculation may be used. The line defining the 100 % dip shall be calculated as the piecewise interpolation between the maximum gray values between the wire pairs (see Fig. 3 b-d).

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. Fig. 4a and Fig. 4b visualize the corresponding procedure for a high resolution system.

8.2.3 The $\mathrm{iSR_b}^{\mathrm{detector}}$ is calculated as the second order polynomial approximation of the modulation depth (dip) versus the wire pair spacing of neighbored wire pairs with at least two wire pairs with more than 20 % dip between the wires in the profile, and at least two wire pairs with less than 20 % dip between the wires in the profile (Fig. 4), if their values are larger than zero. If no values are available with dip less than 20%, one the next wire pair value with the dip of zero shall be used. If the measured $iSR_b^{detector}$ is smaller than the pixel size, e.g. due to aliasing effects, $iSR_b^{detector}$ shall be qualified as $iSR_b^{detector}$ = pixel size.

8.2.4 The calculation of the modulation depth (dip) shall be performed as shown in Fig. 4b. The resulting approximated or interpolated basic spatial resolution value shall be documented as "interpolated SRb detector-value" or iSRb detector.

NOTE 7—The dependence of modulation depth (dip) from wire pair spacing shall be fitted with a polynomial function of second order for calculation of the intersection with the 20 % line as indicated in Figure Fig. 4b.

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 GV[first image]*. *Mean OV* is the average in the same areas of an offset image (without radiation). *dSNRn* 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/*iSRb*). The *dSNRn* obtained for the five regions are to be averaged to obtain the final *dSNRn* value.

NOTE 8—This is a similar procedure to Practices E2445 and E2446 for *SNRn, but may produce different results.*

$$dSNRn = \frac{(Mean\ GV[first\ image] - Mean\ OV)}{\sigma[difference\ image]} \times \frac{(\sqrt{2} \times 88.6)}{SRb} \quad (1)$$

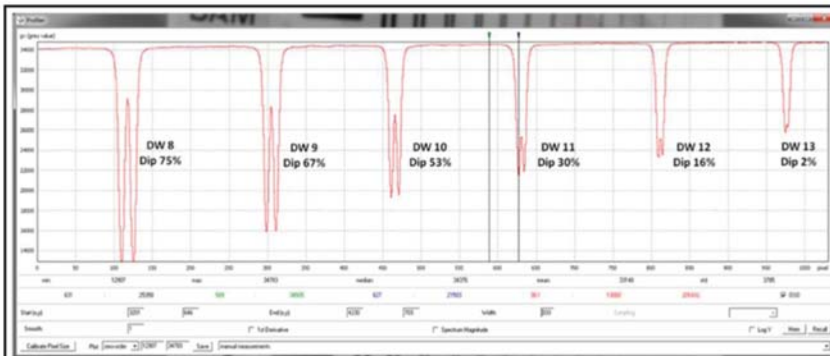
8.3.2 Fig. 5 provides a diagram where *dSNRn* of the difference images is shown as a function of the square root of the dose. A number of plots are shown for different radiation qualities. The slopes of the straight lines in Fig. 5 define the efficiency; it is the same value as the *dSNRn* at 1 mGy exposure level. Although measuring and computing the efficiency, as a function of dose is not required, the data may be collected and plotted at the discretion of the manufacturer. This data will provide information on the maximum *dSNRn* possible as well as information on the linear response of the detector.

8.4 *Calculations for Achievable Contrast Sensitivity (CSa):*

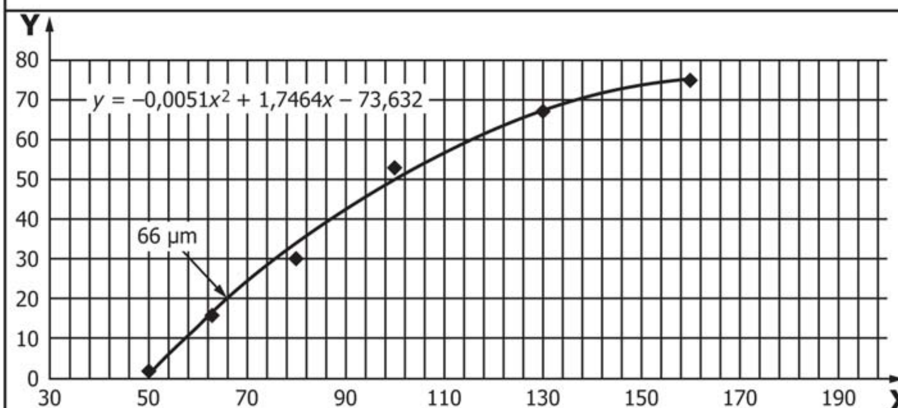
8.4.1 The images shall be corrected for gain, offset and bad pixels for this test.

8.4.2 The signal (mean gray value) and noise (standard deviation) on each step shall be computed in three rectangular regions as shown in Fig. 6. The minimum size of the rectangular region of interest for evaluation is 1 100 pixels (20×55 pixels). For pixel sizes larger than 250 µm each, ROI should be a minimum of 5 % of the area of the complete step of the step wedge. The noise shall be computed in the same rectangular

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



a) Profile plot of measured profile of a high resolution system with determined modulation depth (dip)



X – wire pair spacing in µm
Y – modulation depth (dip) in %

b) Interpolation of modulation depth vs. duplex wire pair spacing. The 20 % value is determined from the intersection with the 20 % line resulting in $iSR_b^{detector}$ = 66 µm.

FIG. 4 Wire-Pair Image Analysis for Calculation of interpolated Basic Spatial Resolution of the detector ($iSR_b^{detector}$).

region using the median of the single line standard deviations as described in Practice E2446. *CNR(5 %)* shall be computed as the ratio between contrast (difference in signal between the region on the groove and those off the groove) and noise of those regions off the groove, as shown in Eq 2. This is computed for each step of the step-wedge images.

$$CNR(5\%) = \frac{0.5 \times (signal(area\ 1) + signal(area\ 3)) - signal(area\ 2)}{0.5 \times (noise(area\ 1) + noise(area\ 3))} \quad (2)$$

8.4.3 With a groove thickness of 5 % of the base step thickness, the *CSa* can be calculated as:

$$CSa = \left[\frac{5}{CNR(5\%)}\right] \times 100\% \quad (3)$$

8.4.4 The results shall be documented as shown in the output data sheet in Appendix X1. An example plot of the achievable contrast sensitivity is shown in Fig. 7. The contrast sensitivity reported here is the best achievable contrast sensitivity as scatter from the part is greatly reduced. In practice the achievable contrast sensitivity curve may differ from these results as geometrical unsharpness and scattered radiation may be different at the user facility.

8.5 *Calculations for Specific Material Thickness Range:*

8.5.1 *SNR* shall be computed for each step as described in 8.4.1 and 8.4.2. The signal and the noise shall be calculated from both areas 1 and 3 (Fig. 6) using the mean value of both. For 2 % sensitivity applications the *SNR* should be 130 or higher.

NOTE 9—This is to be considered a convention, as not all conditions where a *SNR* of 130:1 will result in 2 % contrast sensitivity.

8.5.2 In the example in Fig. 8 the specific material thickness range for "2 % sensitivity" is from 10 mm [0.39 in.], not shown on plot, to 83.8 mm [3.3 in.] aluminum with 4 s exposure time.

8.5.3 For 1 % sensitivity applications the *SNR* should be 250 or higher. Note, this is to be considered a convention, as not all conditions where a *SNR* of 250:1 will result in 1 % contrast sensitivity.

8.5.4 In the example in Fig. 8 the specific material thickness range for "1 % sensitivity" would be 10 mm [0.39 in.], not shown on plot, to 74.6 mm [2.94 in.] at 16 s for 1 % sensitivity.

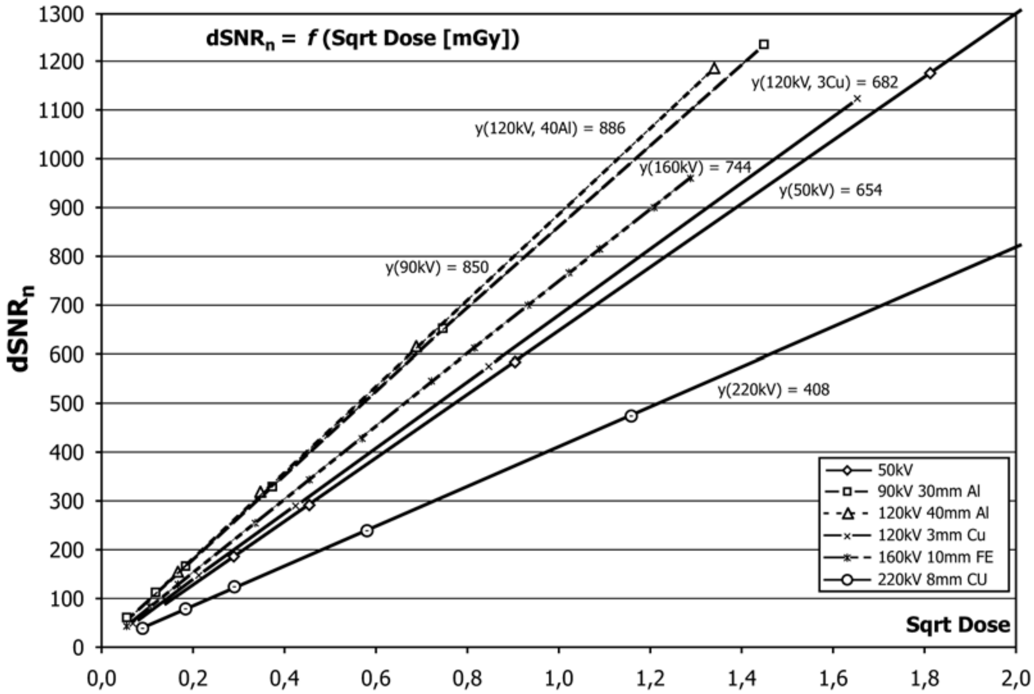


FIG. 5 Example Chart for Efficiency Test with Difference Images at Different Energy Levels

FIG. 6 Areas on the Step-Wedge Marked as Area 1, Area 2, and Area 3, which will be Used for Extracting Signal and Noise

8.6 *Calculations for Lag and Burn-In:*

8.6.1 *Lag Calculations:*

8.6.1.1 The offset image is referred as *image0*. The first image acquired for the 4 s integration time is *image1*. From the sequence of images acquired, locate the first image where it is completely dark (after shutting down X-rays), and this will be referred to as *image2*. *Image2* is the second frame after the last frame with full exposure. The image after 60 s of *image2* is to be referred to as *image3*.

8.6.1.2 In all the images the mean signal of the center 90 % of the DDA shall be measured.

GV0 = mean signal for center 90 % of *image0*.

GV1 = mean signal for center 90 % of *image1*.

GV2 = mean signal for center 90 % of *image2*.

GV3 = mean signal for center 90 % of *image3*.

8.6.1.3 The parameters GlobalLag1f, GlobalLag1s and GlobalLag60s can be calculated as shown in Eq 4. Fig. 9 shows typical lag measurement data.

$$GlobalLag2f(\%) = \frac{GV_2 - GV_0}{GV_1 - GV_0} \times 100 \quad (4)$$

$$GlobalLag1f(\%) = GlobalLag2f(\%) = \times 2$$

$$GlobalLag1s = \frac{GlobalLag1f}{framerate}$$

$$GlobalLag60s = \frac{(GV_3 - GV_0)}{(GV_1 - GV_0)} \times 100$$

8.6.2 *Calculations for Burn-in*—Burn-in shall be computed as shown in Eq 5. Fig. 10 shows typical measurement data for burn-in. *Mean GV[off the plate]* is the mean gray value outside the plate area and *Mean GV[on plate]* is the mean gray value on the plate.

$$Burn - in(time\ t)\ (\%) = \frac{Mean\ GV[off\ plate] - Mean\ GV[on\ plate]}{Mean\ GV[on\ plate]} \times 100 \quad (5)$$

8.6.2.1 Report the values for 1 min, 1 h, 4 h, and 24 h.

8.7 *Calculations for Bad Pixels*—The five categories of single bad pixels, and the three categories of cluster bad pixels are to be reported in the Output Data sheet, for which a template is provided in Appendix X1. These results are to be based on a group of at least three individual detectors for a particular model number. The methodology for computing bad pixels is included below.

8.7.1 *Dead Pixel*—Identify the number of dead pixels in each detector and take the average.

8.7.2 *Over-Responding Pixel*—Identify and document over-responding pixels from each detector in a group for a given model number using the following steps:

8.7.2.1 Test all pixels in *badpixdata1* using a 21×21 pixel mask over the image to locate pixels whose value is greater than 130 % the median gray value over the mask. Report the average number of over-responding pixels for all detectors tested.

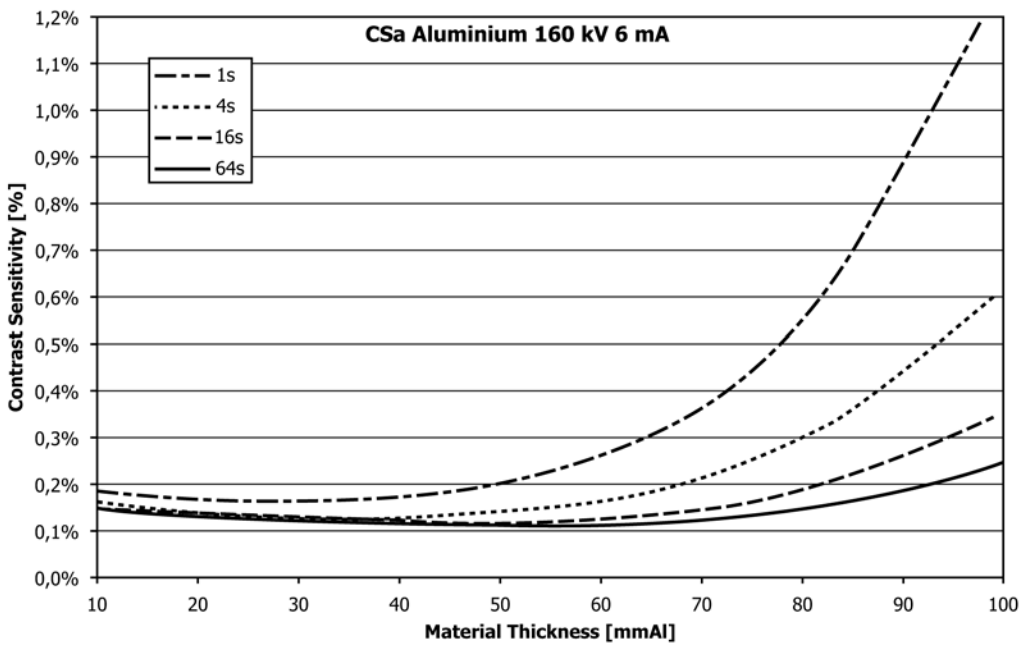


FIG. 7 Result of Achievable Contrast Sensitivity Test with Different Image Acquisition Times

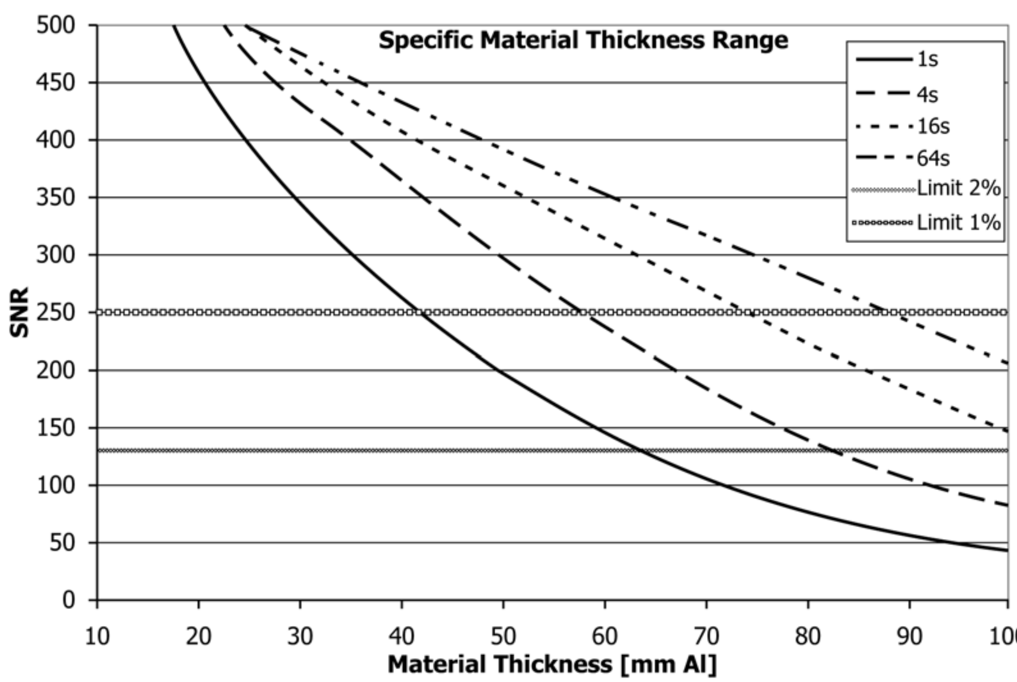


FIG. 8 Specific Material Thickness Range for 2 % Sensitivity at SNR of 130:1 (0 to 84 mm [0 to 3.3 in.] at 4 s exposure time)

8.7.3 *Under-Responding Pixel*—Identify and document under-responding pixels from each detector.

8.7.3.1 Test all pixels in *badpixdata1* using a 21×21 mask over the image to locate pixels whose value is less than 60 % the median gray value over the mask.

8.7.3.2 Report the average number of over-responding pixels for all detectors tested.

8.7.4 *Noisy Pixel*—The pixel sigma for each pixel across the dark image sequence and the median pixel sigma are calculated. This is completed for each detector under test. The average is the number to report. The following procedure may be followed to compute the number of noisy pixels.

8.7.4.1 Compute the standard deviation value at every pixel location from the image sequence to create a standard deviation image, where every pixel value is replaced with the standard deviation at that location. Compute a median of the standard deviation image over the effective DDA range (σ_m). Any pixel in the standard deviation image, whose value is greater than six times the median value σ_m is marked as a noisy pixel.

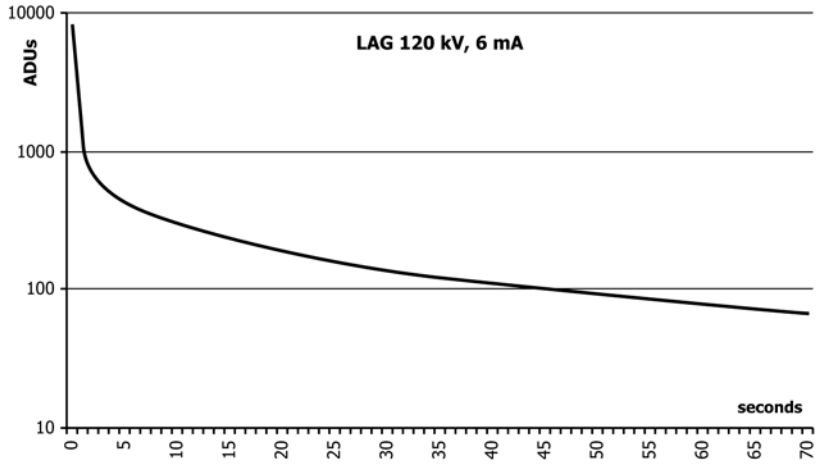


FIG. 9 Result of Image Lag Measurement Sequence

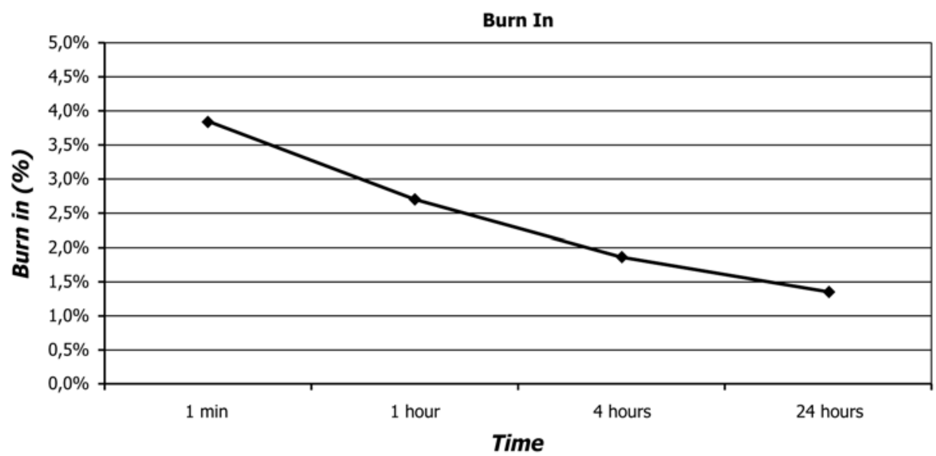


FIG. 10 Result of Burn-In Measurement

8.7.5 *Non-Uniform Pixel*—A pixel is marked as bad if after applying offset and gain correction, its value exceeds a deviation of more than ±1 % of the median value of its 9×9 neighbors. *Badpixdata2* and *Badpixdata3* shall be used for this test. The following procedure may be followed to compute the number of non-uniform pixels.

8.7.5.1 Use a mask of 9×9 pixels over the effective DDA range in *Badpixdata2* and *Badpixdata3* to locate pixels where the pixel value is greater than 1.01 times or less than 0.99 times the median in the 9×9 neighborhood pixels. These pixels are marked as non-uniform pixels.

8.7.6 *Persistence/Lag Pixel*—The first image where the complete image is dark (the image after the one with large dark and bright areas, or the first completely dark image) shall be selected for the evaluation. The following procedure may be followed to compute the persistence/lag pixel.

8.7.6.1 Use a 9×9 mask over the image to locate if the pixel value is greater than two times the median value in 9×9 neighboring pixels and greater than six times the median value σ_m as computed in 8.7.4.1. Such pixels are defined as persistence/lag pixels.

8.7.7 *Bad Neighborhood Pixel*—A correctly-responding pixel where all eight neighboring pixels are bad pixels.

8.8 *Calculation of Internal Scatter Radiation*—A line profile shall be done over the sharp edge of the copper plate in the acquired image (Fig. 11). The result shall be extracted from the line profile as:

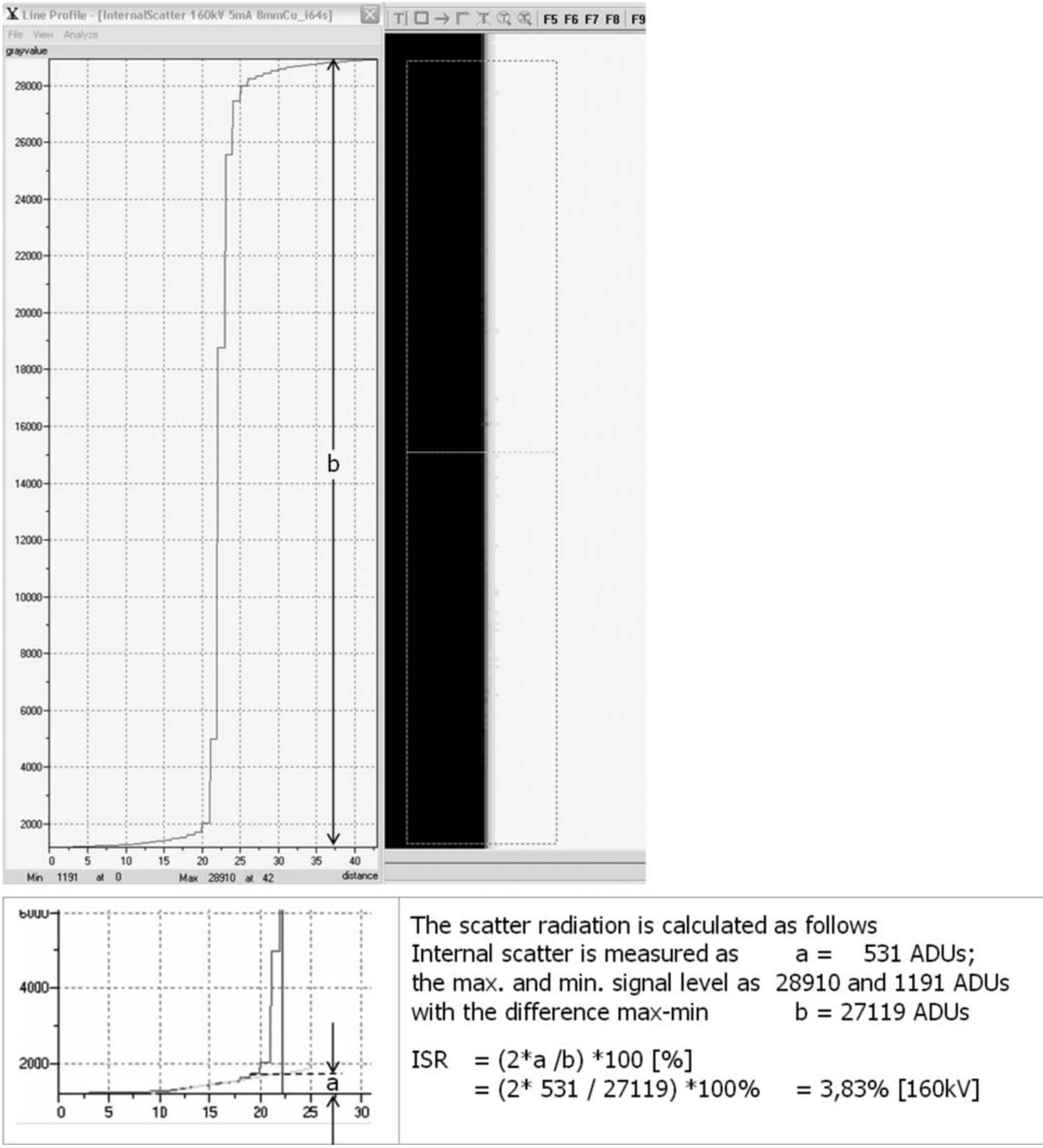
$$ISR = (2 \times a/b) \times 100\,\% \tag{6}$$

where:

ISR = measure of internal scatter radiation,
a = long-range unsharpness contribution, and
b = signal level beside the copper plate.

9. Display of the Results of the Manufacturer Tests

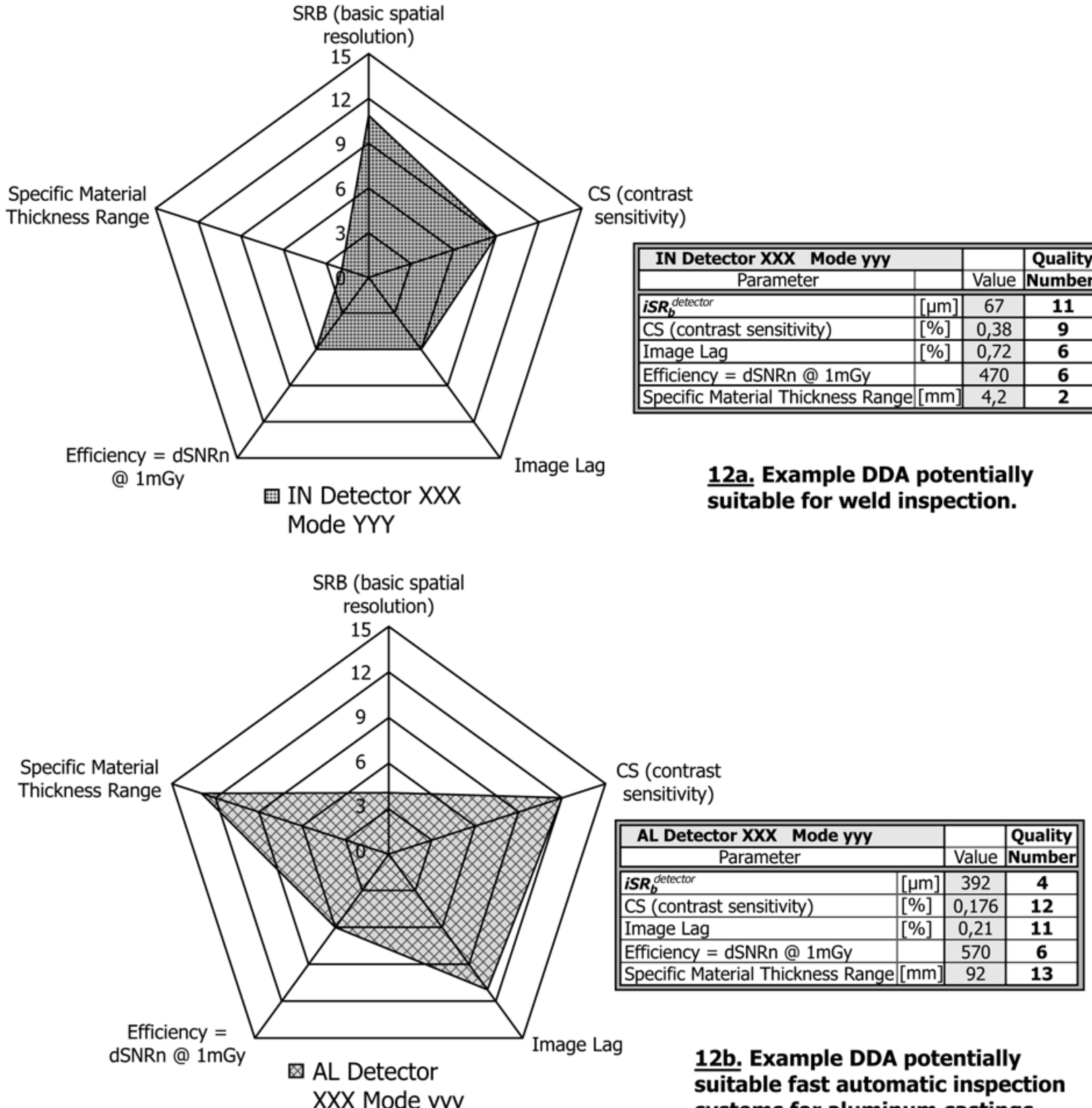
9.1 All results shall be made available, including complete data sheets and graphs/tables of the testing in accordance with Appendix X1. Similarly, summary charts and tables can be provided that list the results under a standard set of parameters. To make the results more digestible, the results can also be presented in the net diagram described below. As an example, five of the seven parameters are included: Basic Spatial Resolution, Efficiency, Achievable Contrast Sensitivity, Specific Material Thickness Range, and Lag of the DDA from Section 8. These parameters are weighted in a range from 0 (low) to 25 (high) to arrive at a quality factor. Table 2



NOTE 1—"a" is the long range unsharpness contribution and "b" is the signal level outside the copper plate.

FIG. 11 Internal Scatter Radiation Measurement

represents the quality factor representation of the measured parameters for the three different materials. The measured value for each of the parameters shall be mathematically rounded to the quality factor of the nearest bounding value. The bad pixel information is not included as its importance is highly dependent on the application. The internal scatter results are not included for similar reasons. Two examples are shown in Fig. 12a-d. Fig. 12a refers to a DDA suitable for inspection of flat material with high resolution with a moderate efficiency, for example for small welds. Fig. 12b refers to a DDA suitable



IN Detector XXX Mode yyy			Quality
Parameter		Value	Number
$iSR_b^{detector}$	[µm]	67	11
CS (contrast sensitivity)	[%]	0,38	9
Image Lag	[%]	0,72	6
Efficiency = dSNRn @ 1mGy		470	6
Specific Material Thickness Range	[mm]	4,2	2

12a. Example DDA potentially suitable for weld inspection.

AL Detector XXX Mode yyy			Quality
Parameter		Value	Number
$iSR_b^{detector}$	[µm]	392	4
CS (contrast sensitivity)	[%]	0,176	12
Image Lag	[%]	0,21	11
Efficiency = dSNRn @ 1mGy		570	6
Specific Material Thickness Range	[mm]	92	13

12b. Example DDA potentially suitable fast automatic inspection systems for aluminum castings

FIG. 12 Net Summary Plots of Some of the Measured Parameters

for fast automatic inspection systems for aluminium castings with the requirement of high contrast sensitivity, large specific material thickness range and moderate image lag.

10. Classification of the DDAs

10.1 The manufacturer shall report the *dSNRn* and the *iSRb* for each detector type using the following guidelines to match results from CR and film classification standards (Test Method E1815 and Practice E2446).

10.1.1 *dSNRn* with beam quality of 220 kV (8 mm copper) as defined in 7.8 and basic spatial resolution (*iSRb*) in accordance with 7.7.

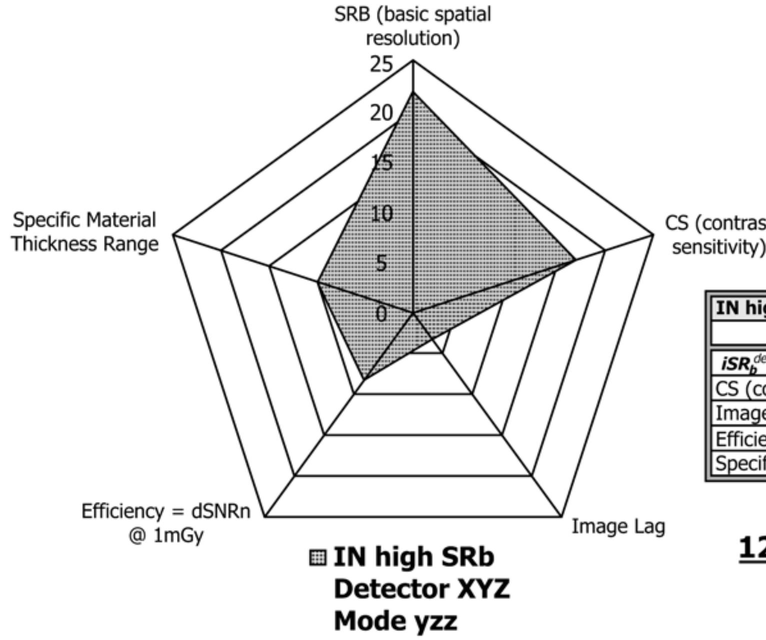
10.1.2 DDAs that cannot be used at X-ray voltage of 220 kV (8 mm copper) due to manufacturer's restriction may be classified at lower, but maximum permissible radiation energy, with a beam filter of no less than 3 mm of copper.

10.1.3 A classification requires the statement of two values:

10.1.3.1 The minimum required *dSNRn* value in accordance to Table 1 of Practice E2446 and the corresponding dose (or equivalence value as given by distance, X-ray tube current (mA) × exposure time (s) and material thickness) at the detector.

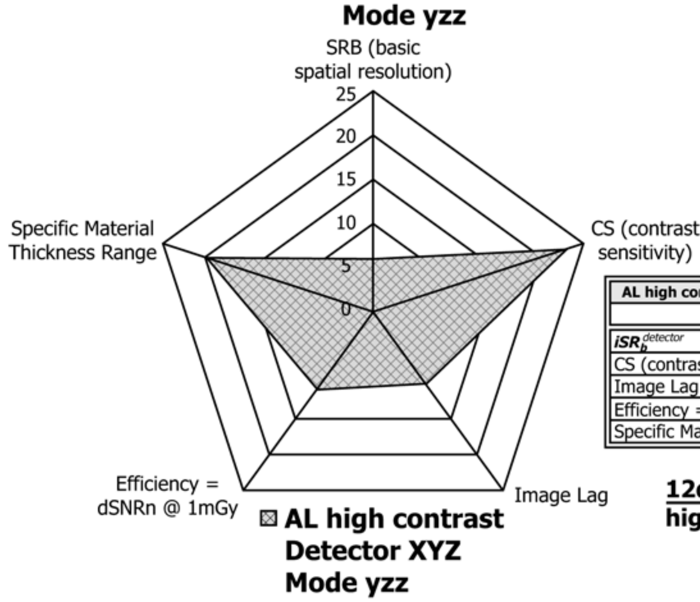
10.1.3.2 The statement of the *iSRb* value of this practice (see 7.7 and 8.2).

NOTE 10—The classification values of *dSNRn* are shown in Table 3 but shall be given always with *iSRb*.



IN high SRb Detector XYZ Mode yzz			Quality
Parameter		Value	Number
$iSR_b^{detector}$	[µm]	5,8	22
CS (contrast sensitivity)	[%]	0,054	17
Image Lag	[%]	1,52	3
Efficiency = dSNRn @ 1mGy		537	8
Specific Material Thickness Range	[mm]	9,23	10

12c. Example DDA with extreme high spatial resolution and CS



AL high contrast Detector XYZ Mode yzz			Quality
Parameter		Value	Number
$iSR_b^{detector}$	[µm]	241	6
CS (contrast sensitivity)	[%]	0,015	23
Image Lag	[%]	0,29	10
Efficiency = dSNRn @ 1mGy		817	11
Specific Material Thickness Range	[mm]	127	20

12d. Example DDA with extreme high CS and SMTR (e.g. for CT)

FIG. 12 Net Summary Plots of Some of the Measured Parameters *(continued)*

TABLE 3 Minimum *dSNRn* Values for DDA Classes to Compare with CR-Systems and Film Systems

DDA System Classes	Minimum *dSNRn* Values	Necessary Dose	mAs @ 1 m Distance
DDA Special	130		
DDA I	65		
DDA II	52		
DDA III	43		

11. Precision and Bias

11.1 No statement is made about either the precision or bias of this practice for characterizing DDA systems. The results merely state whether there is conformance to the criteria for success specified in the procedure.

12. Keywords

12.1 bad pixels; basic spatial resolution; burn-in; contrast sensitivity; DDA; efficiency; image lag; normalized SNR; SNR; specific material thickness range

APPENDIX

(Nonmandatory Information)

X1. INPUT AND OUTPUT DATA SHEETS

X1.1 Input data sheet should be documented using the following format for each test:

Data Sheet (Input)

Detector	
Make	____________
Model	____________
Detector Internal Settings	____________
X-ray Tube	
Make	____________
Model	____________
Target material	____________
Focal spot dimension used	____________
Inherent beam filtration (material and thickness)	____________
Geometry	
Source-Detector distance	____________
Source-Object (center) distance	____________
Exposure	
Pre-filter material and thickness	____________
X-ray tube voltage	____________
X-ray tube current	____________
Exposure time (per frame)	____________
Number of frames averaged	____________
Total (effective exposure time)	____________
Radiation Quality	**Dose Rate**
No filter	____________
30 mm [1.2 in.] aluminum filter and 90 kV	____________
40 mm [1.6 in.] aluminum filter and 120 kV	____________
3 mm [0.12 in.] copper filter and 120 kV	____________
10 mm [0.4 in.] iron filter and 160 kV	____________
8 mm [0.3 in.] copper filter and 220 kV	____________
16 mm [0.6 in.] copper filter and 220 kV	____________
Calibration	
Offset subtraction	____________
Gain correction (flat field)	____________
Bad-pixel correction	____________
Any other calibrations or corrections	____________

X1.2 Output data sheet should be documented using the following format:

Data Sheet (Output)

A Basic spatial resolution *iSRb*, measured as described in section 7.7 and calculated as shown in section 8.2.

Example: iSRb = 189 µm.

B Efficiency at different energies as described in section 7.8 and calculated in section 8.3.
The *dSNRn* values at 1 mGy for the 5 or 6 different energy levels shall be documented.

Example:

Energy	50 kV	90 kV 30 Al	120 kV 40 Al	120 kV 3 Cu	160 kV 10 Fe	220 kV 8 Cu
dSNRn @ 1 mGy	654	850	886	682	744	408

C Achievable Contrast Sensitivity, measured as described in section 7.9 and calculated as shown in section 8.4, is presented in a tabular form.
The data can be plotted for each material, CSa as a function of thicknesses or be displayed in a table. See Fig. 7.

Example Aluminium: X-ray tube setting: 160 kV, 6 mA and pre-filter used 0.5 mm Cu.

[mm Al]	1 s	4 s	16 s	64 s
10	0,187%	0,157%	0,152%	0,152%
20	0,165%	0,140%	0,133%	0,133%
40	0,171%	0,131%	0,118%	0,115%
60	0,258%	0,163%	0,125%	0,114%
80	0,551%	0,293%	0,184%	0,144%
100	1,272%	0,616%	0,354%	0,247%

D Specific Material Thickness Range, measured as described in section 7.10 and calculated as shown in section 8.5, for 1% and 2% sensitivity with each material.

Example: See Fig. 8.

E1 Image Lag, normalized to 1 s and after 60 s, measured as described in section 7.11.1 and calculated as shown in section 8.6.1.

Example: GlobalLag1s = 0.73%; GlobalLag60s = 0.027%.

E2 Burn-In, measured as described in section 7.11.2 and calculated as shown in section 8.6.2.

Example:

Burn-in after	1 minute	1 hour	4 hours	24 hours
[%]	3.8	2.7	1.8	1.4

F Bad Pixels are measured as described in section 7.12 and evaluated as shown in section 8.6.1.
The manufacturer creates a list of the test of several systems and presents the results in a table.
Number of detectors used for reporting a typical value should be documented.

Example: (each detector has 4.000.000 pixel; bad pixels summary given is a mean value obtained from 10 detectors).

Bad Pixel reason	No Response	Out of Range	Noise	Lag	Bad Neighbors
Typical values [%]	0.002	0.025	0.002	0.05	0

Additionally, the manufacturer presents the typical values of Relevant Clusters (RCl), Irrelevant Clusters (ICl) and Bad Line Segments (BLS).

Example:

Groups of Bad Pixel	Relevant Cluster	Irrelevant Clusters	Bad Line Segments
Typical values	2,72	47,6	0.53 full lines

G Displaying the results of Internal Scatter Radiation measurement as described in sections 7.13 and 8.8.

Example: ISR = 3.83% [at 160 kV].

H Displaying the results of A, C, E1, B, and D in a net diagram as shown in Section 9.

Examples: See Fig. 12.

Note—The manufacturer may present the results of tests with 1, 2, or all 3 different materials: Aluminum, Steel and Titanium.