Designation: ~~E2597/E2597M – 14~~ E2597/E2597M – 22

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 ~~standard~~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~~ safety, health, and ~~health~~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

[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.

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 *~~Other~~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
~~IEC 62220-1~~ISO 17636-2 ~~Medical Electrical Equipment Characteristics of Digital X-ray Imaging Devices Part 1: Determination of the Detective Quantum Efficiency~~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 the Detective Quantum Efficiency[5]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *achievable contrast sensitivity ~~(CSa)—~~(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—~~area, n—*the size and location of the DDA, which is recommended by the manufacturer as usable.

3.1.3 *bad ~~pixel—~~pixel, n—*a ~~pixel identified with a performance outside of the specification range for a pixel of a DDA~~ DDA pixel that does not conform to a specified performance as defined in 6.2.

3.1.4 *~~burn-in—~~burn-in, n—*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 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.~~

3.1.5 *~~digital detector~~DDA correction, ~~array~~ n—~~(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).~~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] Available from ~~American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.~~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/.

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

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

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

3.1.8 ~~*efficiency—*~~*efficiency, n—*~~*dSNRn*~~SNR_N (see ~~3.1.7~~3.1.16) divided by the square root of the dose (in ~~mGy) and~~mGy), this is used to measure the response of the detector at different beam energies and qualities.

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

3.1.10 *GlobalLag1f (global lag 1st* ~~*frame)—*~~*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)—*~~*s), n—*the projected value of GlobalLag1f for an integration time of ~~1 se.~~1 s.

3.1.12 *GlobalLag60s (global lag 60* ~~*s)—*~~*s), n—*the ratio between mean ~~gray~~pixel value of an image acquired with the DDA after ~~60 s~~ 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*.~~

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

3.1.14 ~~*iSRb*~~*ISO*^{detector}~~—~~ *material thickness limit (ISO-MTL), n—*~~the interpolated basic spatial resolution of the detector indicates the~~limit determined similar to SMTR, but using as thicker wall thickness limit the value where the normalized SNR (SNR_N ~~smallest geometric detail, which can be resolved spatially using a digital detector array with no geometric magnification.~~) is above 70 (basic technique) or 100 (enhanced technique).

~~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*^{detector} value is determined from the interpolated or approximated modulation depth of two, or several, neighbor wire pairs at 20 % modulation depth.~~

3.1.15 ~~*lag—*~~*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—*~~*phantom, n—*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*.~~

3.1.19 *saturation* ~~*gray value—*~~*pixel value, n—*the maximum possible ~~gray~~pixel 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.~~

3.1.20 *specific material thickness range* ~~*(SMTR)—*~~*(SMTR), n—*the penetrated material thickness range within ~~which~~ a given ~~image quality is achieved. As applied here, the~~minimum SNR in the image is achieved. The wall thickness range of a ~~DDA, whereby~~

DDA is limited for the thinner wall thickness ~~is limited~~ by 80 % of the ~~maximum gray value of the DDA~~saturation pixel value at this thickness 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.~~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 ~~*step-wedge—*~~*total image acquisition time, n—*~~a stepped block of a single metallic alloy with a thickness range that is to be manufactured in accordance with~~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 ~~5.2.~~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 ~~must~~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 ~~factors~~parameters that will be evaluated for each DDA are: interpolated basic spatial resolution ($iSR_b^{detector}$), efficiency ~~(Detector~~ (normalized Detector *SNR*~~-normalized~~ (~~*dSNRn*~~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 ~~radiation~~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:

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* ~~*iSRb*~~$iSR_b^{detector}$—The duplex wire quality indicator corresponds to the design specified in Practice E2002 for the measurement of ~~*iSRb*~~$iSR_b^{detector}$. ~~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

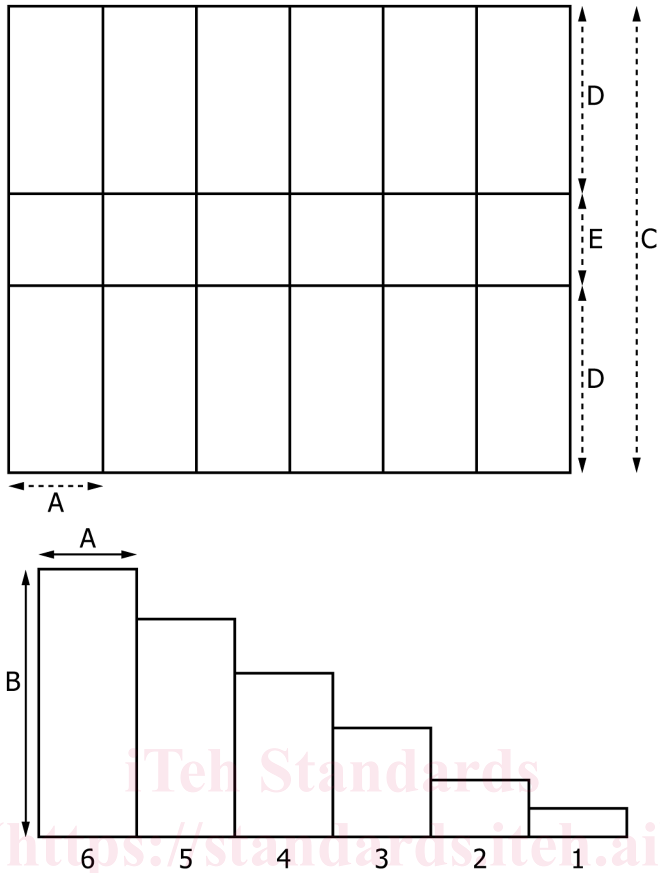

FIG. 1 Step-Wedge Drawing (~~dimensions are listed~~(Dimensions Are Listed in Table 1)

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~~should then extend ~~another 25.4 mm [1 in.] about~~ approximately 25 mm [1 in.] around the perimeter of the step-wedge, beyond the support. ~~The~~A slight overlap of the lead support with the edges of the step-wedge (no more than ~~6 mm [~0.25 in.]~~ approximately 6 mm [~0.25 in.]) assures a significantly reduced ~~number of X-rays to leak-through~~ of X-ray dose will leak through under the step-wedge ~~that~~and will ~~contaminate~~influence the data acquired on each step. The step-wedges shall be formed of ~~three~~two different materials: Aluminum ~~6061, Titanium Ti-6Al-4V, and Inconel 718~~ 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~~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].~~kV).

TABLE 1 Dimension of the ~~Three~~Two Step-Wedges for ~~Three~~Two Different Materials Used as Image Quality Indicators ~~in this~~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~~
Step-wedge (Steel SS 316L)	mm	35	1.5	3	6	9	12	15	175	70	35
~~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~~
Tolerance (±)	µm	200	50	50	50	50	50	50	200	200	200
~~5 % Groove~~	~~microns~~		~~125~~	~~250~~	~~375~~	~~500~~	~~1000~~	~~1500~~			
5 % Groove	µm		75	150	300	450	600	750			
~~Tolerance (±)~~	~~microns~~		~~10~~	~~10~~	~~10~~	~~10~~	~~10~~	~~10~~			
Tolerance (±)	µm		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~~
Step-wedge (Al-7022)	mm	35	10	20	40	60	80	100	175	70	35
~~Tolerance (±)~~	~~microns~~	~~200~~	~~100~~	~~100~~	~~300~~	~~300~~	~~300~~	~~300~~	~~200~~	~~200~~	~~200~~
Tolerance (±)	µm	200	100	100	300	300	300	300	200	200	200
~~5 % Groove~~	~~microns~~		~~500~~	~~1000~~	~~2000~~	~~3000~~	~~4000~~	~~5000~~			
5 % Groove	µm		500	1000	2000	3000	4000	5000			
~~Tolerance (±)~~	~~microns~~		~~13~~	~~25~~	~~50~~	~~50~~	~~50~~	~~50~~			
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 (Inconel 718)~~	~~inch~~	~~1.4~~	~~0.05~~	~~0.1~~	~~0.2~~	~~0.3~~	~~0.4~~	~~0.5~~	~~6.9~~	~~2.8~~	~~1.4~~
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~~	~~8.0~~	~~1.0~~	~~1.0~~	~~1.5~~	~~1.5~~	~~1.5~~	~~1.5~~	~~8.0~~	~~8.0~~	~~8.0~~
Tolerance (±)	mils	8	2	2	2	2	2	2	8	8	8
~~5 % Groove~~	~~mils~~		~~2.5~~	~~4.9~~	~~9.8~~	~~14.8~~	~~19.7~~	~~24.6~~			
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 (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~~
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~~	~~8.0~~	~~4.0~~	~~4.0~~	~~12.0~~	~~12.0~~	~~12.0~~	~~12.0~~	~~8.0~~	~~8.0~~	~~8.0~~
Tolerance (±)	mils	8	4	4	12	12	12	12	8	8	8
~~5 % Groove~~	~~mils~~		~~19.7~~	~~39.4~~	~~78.7~~	~~118.1~~	~~157.5~~	~~196.9~~			
5 % Groove	mils		20	40	80	120	155	195			
~~Tolerance (±)~~	~~mils~~		~~0.5~~	~~1.0~~	~~2.0~~	~~2.0~~	~~2.0~~	~~2.0~~			
Tolerance (±)	mils		0.5	1	2	2	2	2			

5.3.8 The filters shall be placed directly at the tube window. The aluminum filter shall be composed of ~~a~~Aluminum ~~6061.~~ 97 % purity or better. The copper shall be composed of 99.9 % purity or better. The iron filter shall be composed of Stainless Steel ~~304.~~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 ~~quality~~qualities in 5.3.6 ~~is~~are used also in Test Method E1815, Practice E2445, and Practice E2446.

5.4 *Filters for Measuring, Burn-In and Internal Scatter ~~Radiation—~~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 by 75 mm [4 by 3 in.]~~ 100 mm by 75 mm [4 in. by 3 in.] with a minimum of one sharp edge. If the DDA is smaller than ~~15~~15 cm by ~~15 cm~~ 15 cm [5.9 in. by 5.9 in.] use a plate that is dimensionally 25 % of the active DDA area.

6. ~~Calibration~~ Detector Correction and Bad Pixel ~~Standardization~~Classification

6.1 *DDA ~~Calibration~~Correction Method*—Prior to qualification testing, the DDA shall be ~~calibrated~~corrected for offset, ~~or gain, or both,~~ gain, and bad pixels (see ~~3.1.10~~3.1.7 and ~~3.1.9~~3.1.8) to generate corrected images per manufacturer's recommendation.

It is important that ~~the calibration~~this correction procedure be completed as would be done in practice during routine ~~calibration~~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 ~~Standardization~~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:*

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~~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 ~~gray~~ values are less than 0.6 times the median ~~gray~~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.~~ pixel in the corrected digital radiograph. The test should be performed on an image where the average ~~gray~~pixel value is at or above ~~75 %~~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 ~~and are~~ 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",~~ 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)~~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~~b~~, 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~~1×24 line24 and attached with a relevant cluster ~~Rel4×3 cluster 8-5.~~ 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.

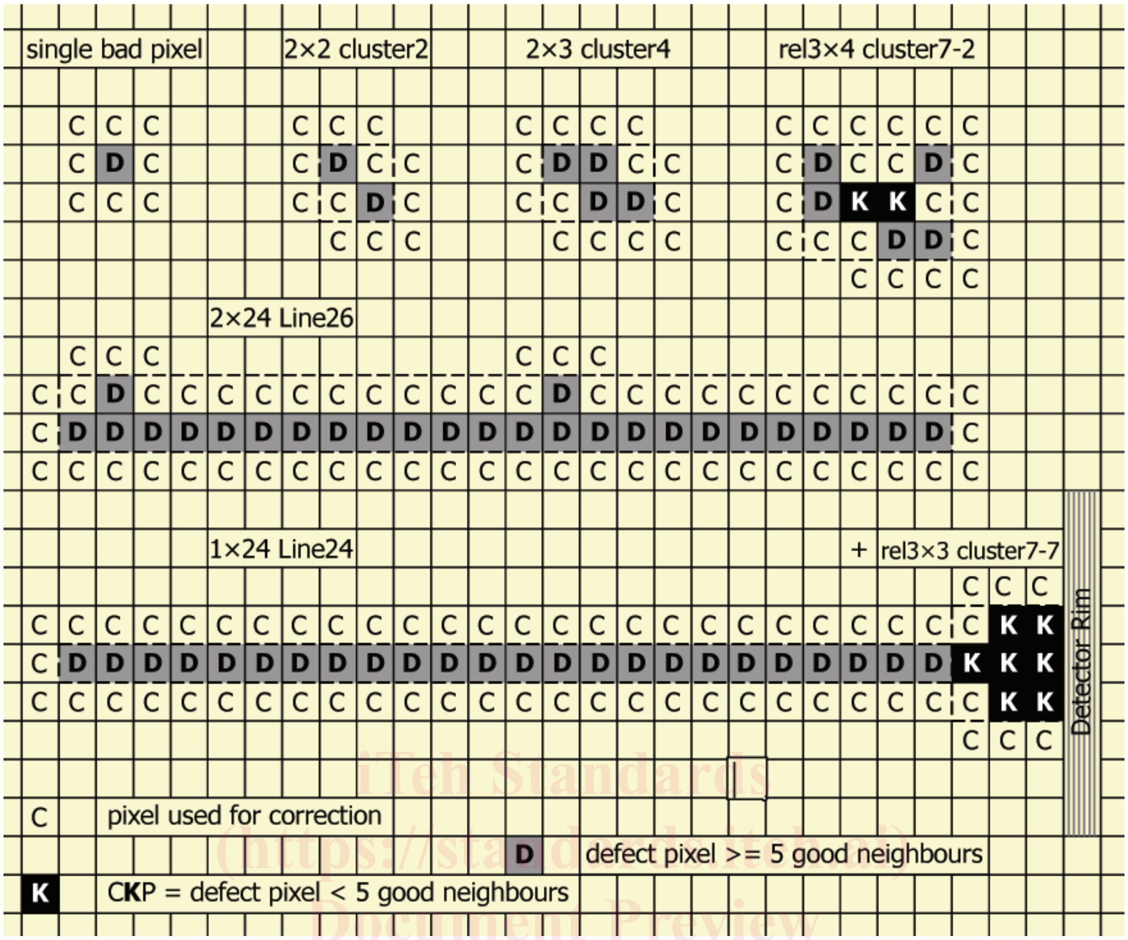

FIG. 2 ~~(2)~~ Different Types of Bad Pixel Groups: ~~Cluster, Relevant Cluster, and Bad Line. (b) Example of a~~Small Clusters, A Relevant Cluster And Bad Lines; At Bottom An Example of A Bad Line Segment ~~Separated from a~~Attached To A Relevant Cluster ~~at the End. The line Segment is a 1x51 Line51 and Attached to a Relevant Cluster rel 4x4 cluster 8-5.~~At The Detector Rim is Shown; The Line Segment Is A 1x24 line24 (Not Relevant), But Connected To A Relevant Cluster rel3x3 cluster7-7

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.

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

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 maximum size: 2 mm*
Duplex wire to active sensor area distance : distance: 2.5 mm
Source to Object distance : 1 000 Source-to-Object distance: 1000 mm
Maximum expected unsharpness : unsharpness: 2 mm / 1 000 1000 mm × 2.5 mm = 0.005 mm = 5 µm
Maximum unsharpness due to the limited focal spot size in percent 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 calibratedcorrected 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 ≥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). (with no added pre-filter). The mA of the X-ray tube shall be selected such that the graypixel 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 graypixel value of 80 % of full saturation is exceeded, the source to DDA distance shall be increased until the required grey levelpixel 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 graypixel values listed above to fall within the procedure listed in provide robust measurements.7.7.

TABLE 2 Quality Numbers for ~~Three~~Two Different Materials

~~Inconel~~ / Stainless Steel 316L					~~Quality Number~~ / Quality Number																		~~Quality Number Extended~~ / 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~~
$iSR_b^{detector}$ (interp. 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~~
CSa (contrast sensitivity)	%	0.010	3.2	SS, 160 kV, 4 s, (% Σ 1.5 to 15 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	0.063	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~~
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	0.063	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~~
Efficiency = SNR_N @ 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~~
Specific Material Thickness Range	mm	28	3	SS, 160 kV, 4 s, SNR > 130	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
~~$iSR_B^{detector}$ (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~~
ISO Material Thickness Limit	mm	28	3	SS, 160 kV, 4 s, SNR_N > 70	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Aluminum 7022					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~~
$iSR_b^{detector}$ (interp. 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~~

TABLE 2 *Continued*

CSa (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	0080	0.063	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~~
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	0.063	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~~
Efficiency = SNR_N @ 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
ISO Material Thickness Limit	mm	150	20	Al, 160 kV, 4 s, SNR_N > 70	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—

1. For extended Quality Numbers, beyond 16 additional plates below the ~~step wedge~~ step-wedge shall be used for measurement of Specific Material Thickness Range.

~~1. For Inconel measurement~~ 2. For Stainless Steel 316L measurement, the thickness of the ~~Inconel plate shall be 7.5 mm to extend the wedge for the scale by 10 quality values.~~SS 316L

~~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. Instead of the Stainless Steel wedges also the Titanium or Inconel wedges of the older versions of Practice E2597/E2597M could be used together with their quality numbers. They are radiographic equivalent.

5. For SMTR ~~measurement~~ and ISO-MTL measurements 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.