



# Standard Practice for Manufacturing Characterization of Digital Detector Arrays<sup>1</sup>

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 ( $\epsilon$ ) 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:<sup>2</sup>

**E1316** Terminology for Nondestructive Examinations

<sup>1</sup> This practice is under the jurisdiction of ASTM Committee E07 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.01 on Radiology (X and Gamma) Method.

Current edition approved Jan. 1, 2014. Published February 2014. Originally approved in 2007. Last previous edition approved in 2007 as E2597- 07<sup>ε1</sup>. DOI: 10.1520/E2597\_E2597M-14.

<sup>2</sup> For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org). For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

**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<sup>3</sup>

**IEC 62220-1** Medical Electrical Equipment Characteristics of Digital X-ray Imaging Devices Part 1: Determination of the Detective Quantum Efficiency<sup>4</sup>

## 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

<sup>3</sup> Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, <http://www.ansi.org>.

<sup>4</sup> Available from International Electrotechnical Commission (IEC), 3 rue de Varembe, 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 SR<sub>b</sub> 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 s.

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 *iSR<sub>b</sub><sup>detector</sup>*—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 *iSR<sub>b</sub><sup>detector</sup>* 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<sub>b</sub><sup>detector</sup>*), efficiency (Detector SNR-normalized (*dSNRn*) at 1 mGy, for different energies and beam qualities), achievable contrast sensitivity (CS<sub>a</sub>), 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 iSR<sub>b</sub><sup>detector</sup>*—The duplex wire quality indicator corresponds to the design specified in Practice E2002 for the measurement of *iSR<sub>b</sub><sup>detector</sup>* 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 wedge is used to

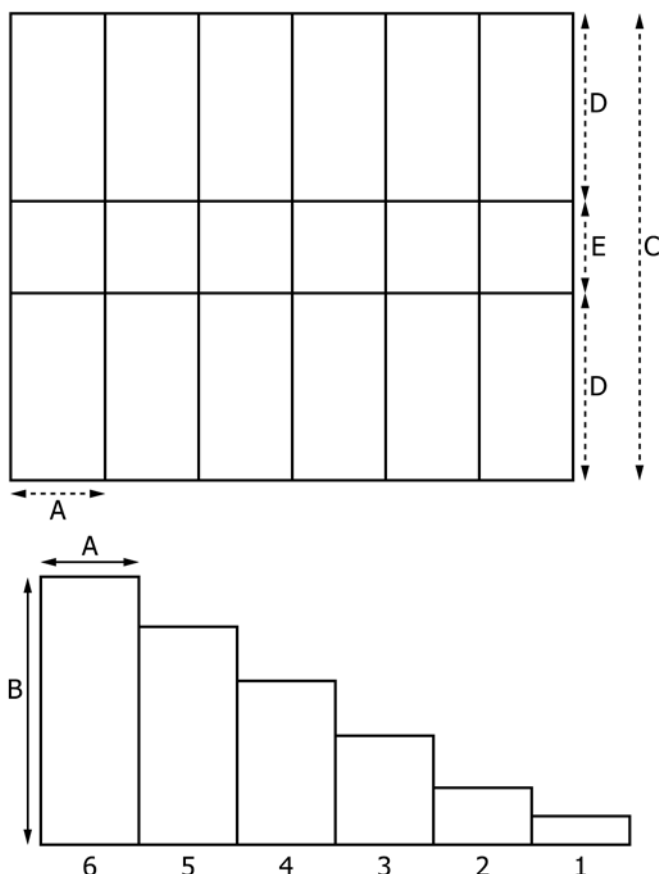


FIG. 1 Step-Wedge Drawing (dimensions are listed in Table 1)

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  $\pm 0.1$  mm [ $\pm 0.004$  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 Aluminum 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  $\pm 1$  % 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  $\geq 1000$  mm [ $\sim 40$  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.

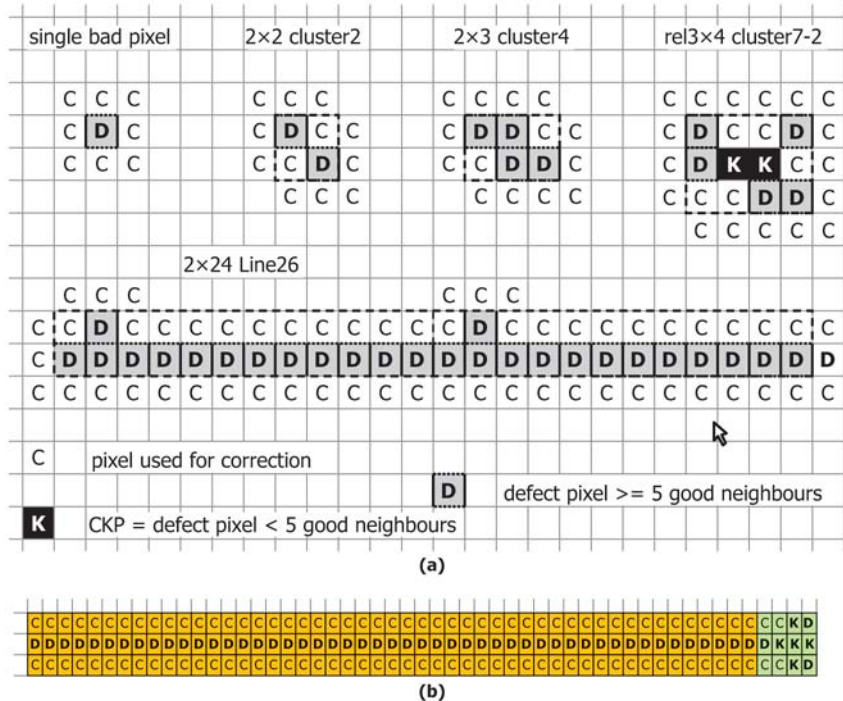


FIG. 2 (2) Different Types of Bad Pixel Groups: Cluster, Relevant Cluster, and Bad Line. (b) Example of a Bad Line Segment Separated from a Relevant Cluster at the End. The line Segment is a 1x51 Line51 and Attached to a Relevant Cluster rel 4x4 cluster 8-5.

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  $\mu m$  pixel size  $\rightarrow$  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 :  $2 \text{ mm} / 1\,000 \text{ mm} \times 2.5 \text{ mm} = 0.005 \text{ mm} = 5 \mu m$

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  $2^\circ$  and  $5^\circ$  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  $\mu m$  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  $\geq 1 \text{ m}$  [ $\geq 40 \text{ in.}$ ] 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  $\geq 100$  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 gray 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) | $\mu m$ | 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   |
|                                             | %       | 0,010 3,2 | In, 160 kV, 4 s, (% $\Sigma$ 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) | $\mu m$ | 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   |
|                                             | %       | 0,010 3,2 | Ti, 160 kV, 4 s, (% $\Sigma$ 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) | $\mu m$ | 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   |
|                                             | %       | 0,010 3,2 | Al, 160 kV, 4 s, (% $\Sigma$ 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.

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.

For Titanium measurement the thickness of the titanium plate shall be 10 mm to extend the wedge for the scale by 10 quality values.

For Aluminum measurement the thickness of the aluminum plate shall be 50 mm to extend the wedge for the scale by 10 quality values.

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.