



# Standard Practice for Design, Manufacture, and Material Grouping Classification of Hole-Type Image Quality Indicators (IQI) Used for Radiology<sup>1</sup>

This standard is issued under the fixed designation E1025; 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<sup>2</sup> covers the design, material grouping classification, and manufacture of hole-type image quality indicators (IQI) used to indicate the quality of radiologic images.

1.2 This practice is applicable to X-ray and gamma-ray radiology.

1.3 The values stated in inch-pound units are to be regarded as standard.

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

## 2. Referenced Documents

### 2.1 ASTM Standards:<sup>3</sup>

- [B139/B139M Specification for Phosphor Bronze Rod, Bar, and Shapes](#)
- [B150/B150M Specification for Aluminum Bronze Rod, Bar, and Shapes](#)
- [B164 Specification for Nickel-Copper Alloy Rod, Bar, and Wire](#)
- [B166 Specification for Nickel-Chromium-Iron Alloys \(UNS N06600, N06601, N06603, N06690, N06693, N06025, N06045, and N06696\), Nickel-Chromium-Cobalt-Molybdenum Alloy \(UNS N06617\), and Nickel-Iron-Chromium-Tungsten Alloy \(UNS N06674\) Rod, Bar, and Wire](#)

<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 Dec. 15, 2011. Published January 2012. Originally approved in 1984. Last previous edition approved in 2005 as E1025 - 05. DOI: 10.1520/E1025-11.

<sup>2</sup> For ASME Boiler and Pressure Vessel Code applications see related Practice SE-1025 in Section II of that Code.

<sup>3</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.

[E746 Practice for Determining Relative Image Quality Response of Industrial Radiographic Imaging Systems](#)

[E747 Practice for Design, Manufacture and Material Grouping Classification of Wire Image Quality Indicators \(IQI\) Used for Radiology](#)

[E1735 Test Method for Determining Relative Image Quality of Industrial Radiographic Film Exposed to X-Radiation from 4 to 25 MeV](#)

[E1316 Terminology for Nondestructive Examinations](#)

[E2662 Practice for Radiologic Examination of Flat Panel Composites and Sandwich Core Materials Used in Aerospace Applications](#)

### 2.2 Department of Defense (DoD) Documents:

[MIL-I-24768 Insulation, Plastics, Laminated, Thermosetting; General Specification for](#)<sup>4</sup>

## 3. Terminology

3.1 *Definitions*—The definitions of terms relating to gamma and X-radiology in Terminology E1316, Section D, shall apply to the terms used in this practice.

## 4. Hole-Type IQI Requirements

4.1 Image quality indicators (IQIs) used to determine radiologic-image quality levels shall conform to the following requirements.

4.1.1 All image quality indicators (IQIs) shall be fabricated from materials or alloys identified or listed in accordance with 7.3. Other materials may be used in accordance with 7.4.

### 4.1.2 Standard Hole-Type IQIs:

4.1.2.1 Standard Hole-Type Image quality indicators (IQIs) shall dimensionally conform to the requirements of Fig. 1.

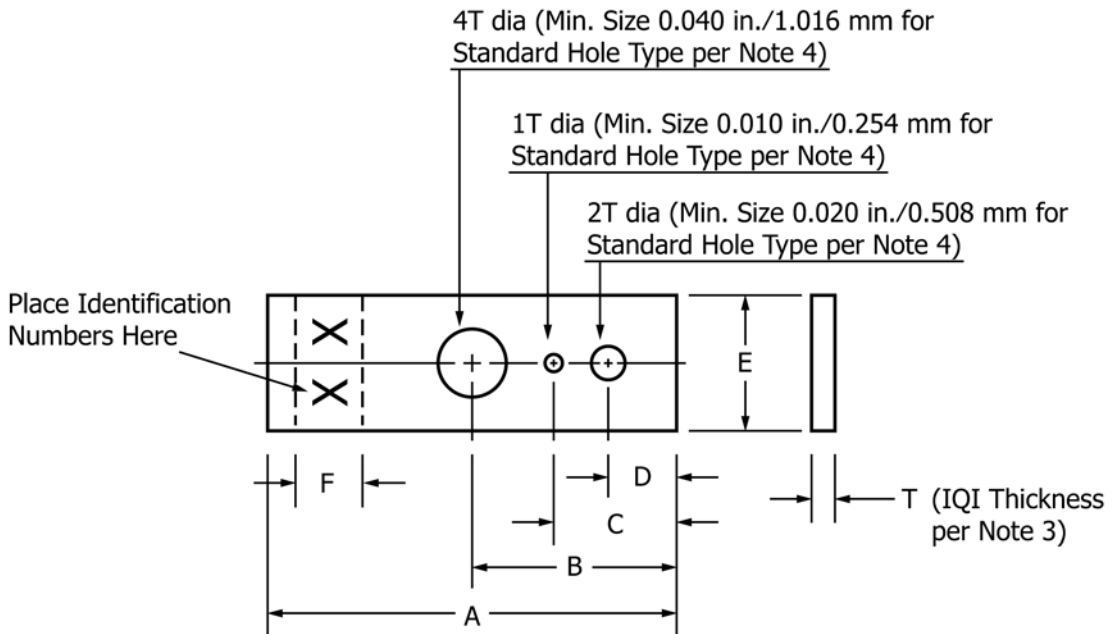
### 4.1.3 Modified Hole-Type IQI:

4.1.3.1 The rectangular IQI may be modified in length and width as necessary for special applications, provided the hole size(s) and IQI thickness conform to Fig. 1 or 4.1.4, as applicable.

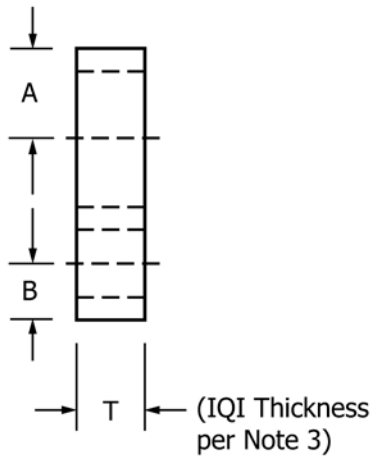
<sup>4</sup> Available from Standardization Documents Order Desk, DODSSP, Bldg. 4, Section D, 700 Robbins Ave., Philadelphia, PA 19111-5098, <http://dodssp.daps.dla.mil>.

\*A Summary of Changes section appears at the end of this standard

(A) Design for IQIs up to 160



(B) Design for IQIs over 160



- NOTE 1—Tolerances for IQI thickness and hole diameter.
- NOTE 2—Tolerances for True T-hole Diameter IQI thickness and hole diameter shall be  $\pm 10\%$ .
- NOTE 3—XX identification number equals T in .001 inches.
- NOTE 4—IQIs No. 1 through 9 for Standard Hole Type IQI's (4.1.2) are not 1T, 2T, and 4T.
- NOTE 5—Holes shall be true and normal to the IQI. Do not chamfer.

Identification Number T (Note 3)	A in. (mm)	B in. (mm)	C in. (mm)	D in. (mm)	E in. (mm)	F in. (mm)	Tolerances (Note 2)
1-4	1.500 (38.1) $\pm 0.015$ (0.38)	0.750 (19.05) $\pm 0.015$ (0.38)	0.438 (11.13) $\pm 0.015$ (0.38)	0.250 (6.35) $\pm 0.015$ (0.38)	0.500 (12.7) $\pm 0.015$ (0.38)	0.250 (6.35) $\pm 0.030$ (0.76)	$\pm 10\%$
5-20	1.500 (38.1) $\pm 0.015$ (0.38)	0.750 (19.05) $\pm 0.015$ (0.38)	0.438 (11.13) $\pm 0.015$ (0.38)	0.250 (6.35) $\pm 0.015$ (0.38)	0.500 (12.7) $\pm 0.015$ (0.38)	0.250 (6.35) $\pm 0.030$ (0.76)	$\pm 0.0005$ (0.127)
21-50	1.500 (38.1) $\pm 0.015$ (0.38)	0.750 (19.05) $\pm 0.015$ (0.38)	0.438 (11.13) $\pm 0.015$ (0.38)	0.250 (6.35) $\pm 0.015$ (0.38)	0.500 (12.7) $\pm 0.015$ (0.38)	0.250 (6.35) $\pm 0.030$ (0.76)	$\pm 0.0025$ (0.635)
51-160	2.250 (57.15) $\pm 0.030$ (0.762)	1.375 (34.93) $\pm 0.030$ (0.762)	0.750 (19.05) $\pm 0.030$ (0.762)	0.375 (9.53) $\pm 0.030$ (0.762)	1.000 (25.4) $\pm 0.030$ (0.762)	0.375 (9.53) $\pm 0.030$ (0.762)	$\pm 0.005$ (0.127)
Over 160	1.330T $\pm 0.005$ (0.127)	0.830T $\pm 0.005$ (0.127)	...	...	...	...	$\pm 0.010$ (0.254)

FIG. 1 IQI Design

4.1.3.2 The IQI's shall be identified as specified in 4.1.5 to 4.1.5.2, as applicable, except that the identification numbers may be placed adjacent to the IQI if placement on the IQI is impractical.

4.1.3.3 When modified IQI's are used, details of the modification shall be documented in the records accompanying the examination results.

4.1.4 True T-hole Diameter IQI:

4.1.4.1 It may be desirable for non-film applications to use true T-hole diameter IQI's for numbers 1 through 9.

4.1.4.2 Hole sizes for true T-hole diameter IQI's may be made by using laser or an electric discharge machining (EDM) process and shall be within ±10 % of 1T, 2T and 4T (See Fig. 1, Note 3 for T)

4.1.4.3 When true T-hole-diameter IQI's are used, details of the modifications shall be documented in the records accompanying the examination results.

4.1.5 Both the rectangular and the circular IQIs shall be identified with number(s) made of lead or a material of similar radiation opacity. The number shall be bonded to the rectangular IQI's and shall be placed adjacent to circular IQI's to provide identification of the IQI on the image. The identification numbers shall indicate the thickness of the IQI in thousandths of an inch, that is, a number 10 IQI is 0.010 in. thick, a number 100 IQI is 0.100 in. thick, etc. Additional identification requirements are provided in 7.2.

4.1.5.1 Alternative Identification Method—It may be desirable for non-film applications to eliminate the lead number identifiers and replace them with either material addition or material removal methods as stated below:

(1) Material Addition Method—Numbers may be made of the same material as that of the IQI and of sufficient thickness to be clearly discernable within the radiologic image.

(2) Material Removal Method—Numbers may be cut into the IQI in such a manner as to be clearly discernable in the radiologic image. Processes such as laser etching, chemical etching, precision stamping, etc., may be used to create the numbers within the IQI.

4.1.5.2 Alloy-group identification shall be in accordance with 7.2. Rectangular IQI's shall be notched as shown in Fig. 2, except the corner notch for Group 001 is at a 45 degree angle. Round IQI's shall be vibrotooled or etched as shown in Fig. 3.

4.1.5.3 True T-hole diameter IQI identification numbers shall be rotated 90° as compared to Standard Hole Type IQIs. See Fig. 4.

5. IQI Procurement

5.1 When selecting IQI's for procurement, the following factors should be considered:

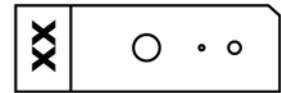
5.1.1 Determine the alloy group(s) of the material to be examined.

5.1.2 Determine the thickness or thickness range of the material(s) to be examined.

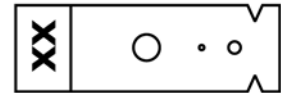
5.1.3 Determine the Image Quality Level requirements as described in Section 6 and Table 1.

5.1.4 Select the applicable IQI's that represent the required IQI thickness and alloy(s).

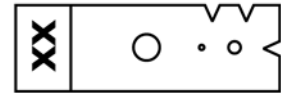
Group 001 IQI for Non-Metals



Group 03 IQI for Magnesium



Group 02 IQI for Aluminum



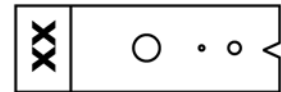
Group 01 IQI for Titanium



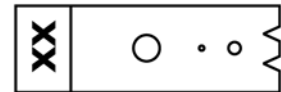
Group 1 IQI for Carbon Alloy and Stainless Steel



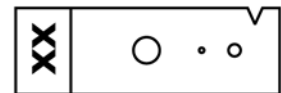
Group 2 IQI for Aluminum Bronze



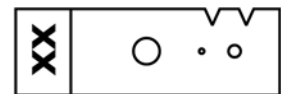
Group 3 IQI for Nickel-Chromium-Iron



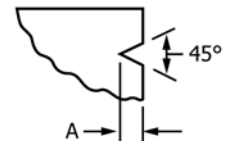
Group 4 IQI for Nickel-Copper (70-30)



Group 5 IQI for Tin Bronze



Detail of Notch



A = 1/16 in. (1.588 mm)

NOTCH TOLERANCES

Width +15°

-0°

(A) Depth +1/16 in. (1.588mm)

-1/32 in. (0.794 mm)

FIG. 2 Rectangular IQI Notch Identification and Material Grouping

NOTE 1—This practice does not recommend or suggest specific IQI sets to be procured. Section 5 is an aid in selecting IQI's based on specific needs.

6. Image Quality Levels

6.1 Image quality levels are designated by a two part expression; X-YT. The first part of the expression, X, refers to the IQI thickness expressed as a percentage of the specimen thickness. The second part of the expression, YT, refers to the diameter of the required hole and is expressed as a multiple of

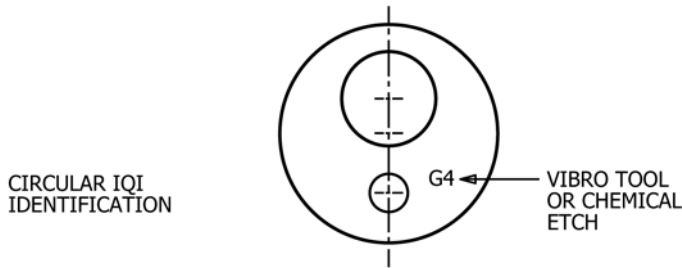


FIG. 3 Circular IQI Identification

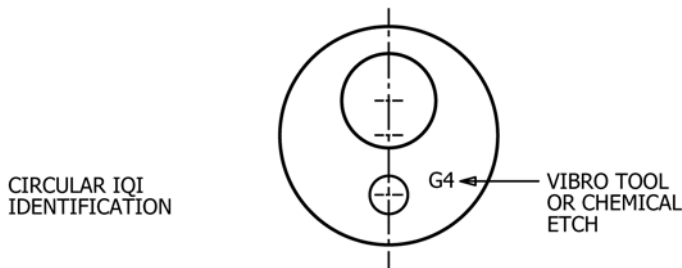


FIG. 4 True T-hole Diameter Type IQI Identification Orientation

the IQI thickness,  $T$  (for example, the image quality level 2-2T means that the IQI thickness,  $T$ , is no more than 2 % of the specimen thickness and that the diameter of the required IQI hole is  $2 \times T$ ).

NOTE 2—Standard Hole Type Image Quality Indicators (IQI's) less than number 10 have hole sizes 0.010, 0.020, and 0.040 in. diameter regardless of the IQI thickness. Therefore, Standard Hole Type IQI's less than number 10 do not represent the quality levels specified in 6.1 and Table 1. The equivalent IQI sensitivity (EPS) can be calculated using the equation in Appendix X1.

6.2 Typical image quality level designations are shown in Table 1. The level of inspection specified should be based on service requirements of the product. Care should be taken in specifying True T-hole Diameter Type IQI's (4.1.4) and/or image quality levels 2-1T, 1-1T, and 1-2T by first determining that these levels can be maintained in production.

6.3 In specifying image quality levels, the contract, purchase order, product specification, or drawing should state the proper two-part expression and clearly indicate the thickness of the material to which the level refers. In place of a designated two-part expression, the IQI number and minimum discernible hole size shall be specified.

6.4 Appendix X1 of this practice provides a method for determining equivalent IQI sensitivity (EPS) in percent. Under certain conditions (as described within the purchaser-supplier agreement), EPS may be useful in relating a discernible hole size of the IQI thickness with the section thickness radiographed for establishing an overall technical image quality equivalency. This is not an alternative IQI provision for the originally specified IQI requirement of this practice, but may be a useful tool for establishing technical image equivalency on a case basis need with specific customer approvals.

6.5 Practice E747 contains provisions for wire IQI's that use varying length and diameter wires to effect image quality requirements. The requirements of Practice E747 are different

TABLE 1 Typical Image Quality Levels

Standard Image Quality Levels				
Image Quality Levels	IQI Thickness	Minimum Perceptible Hole Diameter	Equivalent IQI Sensitivity, % <sup>A</sup>	
2-1T	$\frac{1}{50}$ (2 %) of Specimen Thickness	1T	1.4	
2-2T <sup>B</sup>		2T	2.0	
2-4T		4T	2.8	
Special Image Quality Levels				
1-1T	$\frac{1}{100}$ (1 %) of Specimen Thickness	1T	0.7	
1-2T		2T	1	
4-2T		2T	4	

<sup>A</sup>Equivalent IQI sensitivity is that thickness of the IQI, expressed as a percentage of the part thickness, in which the 2T hole would be visible under the same conditions.

<sup>B</sup>For Level 2-2T Radiologic—The 2T hole in an IQI,  $\frac{1}{50}$  (2 %) of the specimen thickness, is visible.

from this standard; however, Practice E747 (see Table 4) contains provisions whereby wire sizes equivalent to corresponding 1T, 2T and 4T holes for various plaque thicknesses are provided. Appendix X1 of Practice E747 also provides methods for determining equivalencies between wire and hole type IQI's. This is not an alternative IQI provision for the originally specified IQI requirements of this practice, but may be useful for establishing technical image equivalency on a case basis need with specific customer approvals.

6.6 Test Methods E746 and E1735 provide additional tools for determining relative image quality response of industrial radiological systems when exposed to energy levels described within those test methods. Both of these test methods use the “equivalent penetrometer sensitivity” (EPS) concept to provide statistical image quality information that allows the imaging system or other exposure components to be assessed on a relative basis. These test methods are not alternative IQI provisions for the originally specified IQI requirements of this practice, but may be useful on a case basis with specific customer approvals, for establishing technical image equivalency of certain aspects of the radiological imaging process.

## 7. Material Groups

### 7.1 General:

7.1.1 Materials have been designated in nine groups based on their radiation absorption characteristics: Group 001 for non-metals. Groups 03, 02, and 01 for light metals and Groups 1 through 5 for heavy metals.

7.1.2 The non-metals group, typically in the form of fiber-reinforced phenolic resin, are identified as 001 since these materials have the least radiation absorption of all the material groups.

7.1.3 The light metal groups, magnesium (Mg), aluminum (Al), and titanium (Ti) are identified 03, 02, and 01 respectively for their predominant alloying constituent. The materials are listed in order of increasing radiation absorption.

7.1.4 The heavy metal groups, steel, copper base, nickel base, and kindred alloys are identified 1 through 5. The materials increase in radiation absorption with increasing numerical designation.

NOTE 3—The metals groups were established experimentally at 180 kV on  $\frac{3}{4}$ -in. (19-mm) thick specimens. They apply from 125 kV to the

multivolt range. The non-metal group was established experimentally at a range of 15 to 60 kV on 0.100-in to 0.250-in (2.54-mm to 6.35-mm) thick specimens using MIL-I-24768 thermosetting plastic laminated insulation materials type FBE and FBG.

7.1.5 Common trade names or alloy designations have been used for clarification of the pertinent materials.

7.1.6 The materials from which the IQI for the group are to be made are designated in each case, and these IQI's are applicable for all materials listed in that group. In addition, any group IQI may be used for any material with a higher group number, provided the applicable quality level is maintained.

## 7.2 Identification System:

7.2.1 A notching system has been designated for the nine materials groups of IQI's and is shown in Fig. 2 for rectangular IQI's.

7.2.2 For circular IQI's, a group designation shall be vibro-tooled or etched on the IQI to identify it by using the letter "G" followed by the group number, for example, G4 for a Group 4 IQI. For identification of the group on the image, corresponding lead characters shall be placed adjacent to the circular IQI, just as is done with the lead numbers identifying the thickness. An identification example is shown in Fig. 3.

## 7.3 Materials Groups:

### 7.3.1 Materials Group 001:

7.3.1.1 Image quality indicators (IQI's) may be made from phenolic resin laminate materials specified in MIL-I-24768, or any of the materials listed in Practice E2662.

7.3.1.2 Use on polymer matrix composite materials or other low density non-metal materials at low energies, typically below 50 kV.

### 7.3.2 Materials Group 03:

7.3.2.1 Image quality indicators (IQI's) shall be made of magnesium or magnesium shall be the predominant alloying constituent.

7.3.2.2 Use on all alloys of which magnesium is the predominant alloying constituent.

### 7.3.3 Materials Group 02:

7.3.3.1 Image quality indicators (IQI's) shall be made of aluminum or aluminum shall be the predominant alloying constituent.

7.3.3.2 Use on all alloys of which aluminum is the predominant alloying constituent.

### 7.3.4 Materials Group 01:

7.3.4.1 Image quality indicators (IQI's) shall be made of titanium or titanium shall be the predominant alloying constituent.

7.3.4.2 Use on all alloys of which titanium is the predominant alloying constituent.

### 7.3.5 Materials Group 1:

7.3.5.1 Image quality indicators (IQI's) shall be made of carbon steel or Type 300 series stainless steel.

7.3.5.2 Use on all carbon steel, all low-alloy steels, all stainless steels, manganese-nickel-aluminum bronze (Superston).<sup>5</sup>

### 7.3.6 Materials Group 2:

7.3.6.1 Image quality indicators (IQI's) shall be made of aluminum bronze (Specification B150/B150M).

7.3.6.2 Use on all aluminum bronzes and all nickel-aluminum bronzes.

### 7.3.7 Materials Group 3:

7.3.7.1 Image quality indicators (IQI's) shall be made of nickel-chromium-iron alloy (UNS No. NO6600) (Inconel).<sup>6</sup> (Specification B166.)

7.3.7.2 Use on nickel-chromium-iron alloy and 18 % nickel-maraging steel.

### 7.3.8 Materials Group 4:

7.3.8.1 Image quality indicators (IQI's) shall be made of 70 to 30 nickel-copper alloy (Monel)<sup>7</sup> (Specification B164) or equivalent.

7.3.8.2 Use on nickel, copper, all nickel-copper series, or copper-nickel series of alloys, and all brasses (copper-zinc alloys). Group 4 IQI's may be used on the leaded brasses, since leaded brass increases in attenuation with increase in lead content. This would be equivalent to using a lower group IQI.

### 7.3.9 Materials Group 5:

7.3.9.1 Image quality indicators (IQI's) shall be made of phosphor bronze (Specification B139/B139M).

7.3.9.2 Use on bronzes including gun-metal and valve bronze, leaded-tin bronze of higher lead content than valve bronze. Group 5 IQI's may be used on bronze of higher lead content since leaded bronze increases in attenuation with increase in lead content. This would be equivalent to using a lower group IQI.

NOTE 4—In developing the nine listed materials groups, a number of other trade names or other nominal alloy designations were evaluated. For the purpose of making this practice as useful as possible, these materials are listed and categorized, by group, as follows:

(1) Group 2—Haynes Alloy IN-100.<sup>8</sup>

(2) Group 3—Haynes Alloy No. 713C, Hastelloy D,<sup>9</sup> G.E. Alloy SEL, Haynes Stellite Alloy No. 21,<sup>9</sup> GMR-235 Alloy, Haynes Alloy No. 93, Inconel X,<sup>6</sup> Inconel 718, and Haynes Stellite Alloy NO. S-816.

(3) Group 4—Hastelloy Alloy F, Hastelloy Alloy X, and Multimeter Alloy Rene 41.

(4) Group 5—Alloys in order of increasing attenuation: Hastelloy Alloy B, Hastelloy Alloy C, Haynes Stellite Alloy No. 31, Thetaloy, Haynes Stellite No. 3, Haynes Alloy No. 25. IQIs of any of these materials are considered applicable for the materials that follow it.

(5) Group 001—Garolite

NOTE 5—The committee formulating these recommendations, recommended other materials may be added to the materials groups listed as the need arises or as more information is gained, or that additional materials groups may be added.

## 7.4 Radiologically Similar IQI Materials:

7.4.1 For materials not herein covered, IQI's of radiographically similar materials may be used when the following requirements are met. Two blocks of equal thickness, one of the material to be examined (production material) and one of the IQI material, shall be radiographed on one film by one

<sup>6</sup> Inconel is a registered trademark of The International Nickel Co., Inc., Huntington, WV 25720.

<sup>7</sup> Monel is a registered trademark of The International Nickel Co., Inc., Huntington, WV 25720.

<sup>8</sup> All Haynes alloys are registered trademarks of Union Carbide Corp., New York, NY.

<sup>9</sup> All Hastelloys and Haynes Stellite alloys are registered trademarks of Cabot Corp., Boston, MA.

<sup>5</sup> Superston is a registered trademark of Superston Corp., Jersey City, NJ.

exposure at the lowest energy level to be used for production radiography. Film density readings shall be between 2.0 and 4.0 for both materials. If the film density of the material to be radiographed is within the range of 0 to +15 % of the IQI material, the IQI material shall be considered radiographically similar and may be used to fabricate IQI's for examination of the production material.

7.4.1.1 Radiological similarity tests may be performed with non-film radiological systems, however, the minimum and maximum pixel values for both materials shall be within the range established for production examinations.

7.4.2 It shall always be permissible to use IQI's of radiologically less dense material than the subject material being examined.

## 8. IQI Certification

8.1 Records shall be available that attest to the conformance of the material type, grouping (notches), and dimensional tolerances of the IQI's specified by this practice.

## 9. Precision and Bias

9.1 *Precision and Bias*—No statement is made about the precision or bias for indicating the quality of radiological images since the results merely state whether there is conformance to the criteria for success specified in this practice.

## 10. Keywords

10.1 density; image quality level; IQI; radiologic; radiology; X-ray and gamma radiation

# APPENDIX

## (Nonmandatory Information)

### X1. EQUIVALENT IQI (PENETRATOR) SENSITIVITY (EPS)<sup>10</sup>

X1.1 To find the equivalent IQI sensitivity (percent), the hole size (diameter in inches), of the IQI thickness (inches), for a section thickness (inches), the following equation may be used:

where:

$$\alpha = \frac{100}{X} \sqrt{\frac{TH}{2}}$$

$\alpha$  = equivalent IQI sensitivity, %,  
 $X$  = section thickness to be examined, in.,  
 $T$  = IQI Thickness, in., and  
 $H$  = hole diameter, in.

<sup>10</sup> O'Connor, D. T., and Criscuolo, E. L., "The Quality of Radiographic Inspection," *ASTM Bulletin*, ASTM, Vol 213, 1956, p. 52.

## SUMMARY OF CHANGES

Committee E07 has identified the location of selected changes to this standard since the last issue (E1025 - 05) that may impact the use of this standard. (December 15, 2011)

- (1) Section 2: Updated Reference Documents.
- (2) Section 4: Defined the current IQI (with minimum hole sizes per Fig 1) as a "Standard Hole Type IQI"; Added "Modified Hole Type IQI" to allow for modifications in length and width which are may be used for geometric magnification applications where the entire IQI is required to be in the image; Added "True T-hole Diameter IQI" for which may be used for geometric magnification applications where true 2 % EPS is desired; Added alternative identification method other than lead numbers and to require True T-hole Diameter IQI identification numbers rotated 90 degrees.
- (3) Section 5: Added 5.1.3 to consider Image Quality requirement for IQI procurement.
- (4) Section 6: Editorial clarifications.

- (5) Section 7: Added non-metals materials Group 001 for low energy applications and compliance for Practice E2662; Editorial clarifications; Reworded Section 7.4 for Radiographic Similar Materials to clarify calculation.
- (6) Section 9: Editorially changed "radiographs" to "radiological images."
- (7) Figure 1: Added metric units and notes to drawing; Updated Notes Section; Updated Table to include metric units.
- (8) Figure 2: Added drawing for notch detail for non-metals group 001.
- (9) Table 1: Spelling correction.
- (10) Figure 4: New drawing to show IQI identification orientation for True T-hole Diameter IQIs.

(11) Appendix X1: Editorial clarifications; Deleted Nomo-graph since the provided equation is more accurate.

*ASTM International takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.*

*This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, at the address shown below.*

*This standard is copyrighted by ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States. Individual reprints (single or multiple copies) of this standard may be obtained by contacting ASTM at the above address or at 610-832-9585 (phone), 610-832-9555 (fax), or [service@astm.org](mailto:service@astm.org) (e-mail); or through the ASTM website ([www.astm.org](http://www.astm.org)). Permission rights to photocopy the standard may also be secured from the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923, Tel: (978) 646-2600; <http://www.copyright.com/>*