Designation: ~~E2104 – 15~~ E2104 – 22

Standard Practice for Radiographic Examination of Advanced Aero and Turbine Materials and Components[1]

This standard is issued under the fixed designation E2104; 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 establishes the minimum requirements for radiographic examination of metallic and nonmetallic materials and components used in designated applications such as gas turbine engines and flight structures.

1.2 The requirements in this practice are intended to control the radiographic process to ensure the quality of radiographic images produced for use in designated applications such as gas turbine engines and flight structures; this practice is not intended to establish acceptance criteria for material or components. When examination is performed in accordance with this practice, engineering drawings, specifications, or other applicable documents shall indicate the acceptance criteria.

1.3 All areas of this practice may be open to agreement between the cognizant engineering organization and the supplier, or specific direction from the cognizant engineering organization.

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

1.5 *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]

E543 Specification for Agencies Performing Nondestructive Testing

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

E999 Guide for Controlling the Quality of Industrial Radiographic Film Processing

E1025 Practice for Design, Manufacture, and Material Grouping Classification of Hole-Type Image Quality Indicators (IQI) Used for Radiography

~~E1030~~E1030/E1030M Practice for Radiographic Examination of Metallic Castings

E1032 Practice for Radiographic Examination of Weldments Using Industrial X-Ray Film

E1079 Practice for Calibration of Transmission Densitometers

[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.

E1165 Test Method for Measurement of Focal Spots of Industrial X-Ray Tubes by Pinhole Imaging
E1254 Guide for Storage of Radiographs and Unexposed Industrial Radiographic Films
E1316 Terminology for Nondestructive Examinations
E1390 Specification for Illuminators Used for Viewing Industrial Radiographs
~~E1316 Terminology for Nondestructive Examinations~~
E1815 Test Method for Classification of Film Systems for Industrial Radiography
E1817 Practice for Controlling Quality of Radiological Examination by Using Representative Quality Indicators (RQIs)
E2033 Practice for Radiographic Examination Using Computed Radiography (Photostimulable Luminescence Method)
E2698 Practice for Radiographic Examination Using Digital Detector Arrays

2.2 *AWS Documents:*[3]

ANSI/AWS A2.4 Symbols for Welding and Nondestructive Testing

2.3 *AIA Documents:*[4]

~~NAS-410~~NAS410 Certification and Qualification of Nondestructive Test Personnel

2.4 *NCRP Documents:*[5]

NCRP 51 Radiation Protection Design Guidelines for 0.1-100 MeV Particle Accelerator Facilities
NCRP 91 Recommendations on Limits for Exposures to Ionizing Radiation

2.5 *Other Government Documents:*

NIST Handbook 114 General Safety Standard for Installations Using Non-Medical X-ray and Sealed Gamma-ray Sources, Energies up to 10 MeV[6]

NOTE 1—*DoD Contracts:* ~~Unless~~ Unless otherwise specified, the issues of the documents that are DoD adopted are those listed in the issue of the Department of Defense Index of Specifications and Standards (DoDISS) cited in the solicitation.

NOTE 2—*Order of Precedence:* ~~Contractual~~ Contractual requirements and specific direction from the cognizant engineering organization shall take precedence over the requirements in this practice. In the event of conflict between the text of this practice and the references cited herein, the text of this practice shall take precedence. However, nothing in this practice shall supersede applicable laws and regulations unless a specific exemption has been obtained.

3. Terminology

3.1 *Definitions*—Definitions relating to radiographic examination which appear in Terminology E1316 shall apply to the terms used in this practice.

3.2 *Definitions of Terms Specific to This Standard:*

~~3.2.1 *cognizant engineering organization*—the company, government agency or other authority responsible for the design, or end use, of the material or component for which radiographic examination is required. This, in addition to design personnel, may include personnel from engineering, material and process engineering, stress analysis, NDE, quality assurance and others, as appropriate.~~

3.2.1 ~~*component*—~~*component, n*—the part(s) or element of the system assembled or processed to the extent specified by the drawing, purchase order, or contract for which radiographic examination is required.

3.2.2 *film* ~~*system*—~~*system, n*—the combination of a film and a processing system. A processing system is defined by the chemistry used and the specified developer immersion time and temperature.

3.2.3 *like* ~~*section*—~~*section, n*—a separate section of material that is similar in shape and cross section to the component or part being radiographed, and is made of the same or radiographically similar material.

3.2.4 *material* ~~*group*—~~*group, n*—materials that have the same predominant alloying elements and which can be examined using the same IQI. A listing of common material groups is given in Practices E747 and E1025.

3.2.5 *NDE* ~~*facility*—~~*facility, n*—the NDE agency performing the radiographic examination.

[3] Available from American Welding Society (AWS), 550 NW LeJeune Rd., Miami, FL 33126, http://www.aws.org.
[4] Available from Aerospace Industries Association of America, Inc. (AIA), 1000 Wilson Blvd., Suite 1700, Arlington, VA 22209-3928, http://www.aia-aerospace.org.
[5] Available from National Council on Radiation Protection and Measurements (NCRP), NCRP Publications, 7910 Woodmount Ave., Suite 800, Bethesda, MD 20814.
[6] Available from National Institute of Standards and Technology (NIST), 100 Bureau Dr., Stop 1070, Gaithersburg, MD 20899-1070, http://www.nist.gov.

TABLE 1 Lead Screen Thickness[A]

Energy Range/ Isotopes	Lead Thickness, in. ~~(mm)~~ Front Screen (Maximum)	Back Screen[B,C] (Minimum)
~~0 – 100 keV~~	~~0.001 (0.025)~~	~~0.005 (0.127)~~
~~101 – 200 keV~~	~~0.005 (0.127)~~	~~0.005 (0.127)~~
~~201 – 320 keV~~	~~0.010 (0.254)~~	~~0.005 (0.127)~~
~~Se-75~~	~~0.010 (0.254)~~	~~0.005 (0.127)~~
~~321 – 450 keV~~	~~0.015 (0.381)~~	~~0.010 (0.254)~~
~~Ir-192~~	~~0.015 (0.381)~~	~~0.010 (0.254)~~
~~451 keV – 2 MeV~~	~~0.020 (0.508)~~	~~0.010 (0.254)~~
~~Co-60~~	~~0.020 (0.508)~~	~~0.010 (0.254)~~
~~>2 MeV~~	~~0.125 (3.175)~~	~~0.010 (0.254)~~

TABLE 1 Lead Screen Thickness[A]

Energy Range/ Isotopes	Lead Thickness, in. [mm] Front Screen (Maximum)	Back Screen[B,C] (Minimum)
0 – 100 keV	0.001 [0.025]	0.005 [0.127]
101 – 200 keV	0.005 [0.127]	0.005 [0.127]
201 – 320 keV	0.010 [0.254]	0.005 [0.127]
Se-75	0.010 [0.254]	0.005 [0.127]
321 – 450 keV	0.015 [0.381]	0.010 [0.254]
Ir-192	0.015 [0.381]	0.010 [0.254]
451 keV – 2 MeV	0.020 [0.508]	0.010 [0.254]
Co-60	0.020 [0.508]	0.010 [0.254]
>2 MeV	0.125 [3.175]	0.010 [0.254]

[A] Pre-packed film, with or without lead screens, may be used provided radiographic quality level, contrast, density, and back scatter requirements are met.
[B] Back scatter radiation shall still be monitored per the requirements of 7.11.
[C] A back screen is not required provided the back scatter requirements of 7.11 are met through the use of alternate measures.

3.2.6 *radiographic quality ~~level~~—level, n—*the ability of a radiographic procedure to demonstrate a specified IQI sensitivity (see Table 3).

3.2.7 *radiographic ~~technique~~—technique, n—*a procedure which details the exact radiographic setup to be used for each exposure to be made (see 7.1).

4. Significance and Use

4.1 The requirements for radiographic examination in this practice are applicable to all types of metallic and nonmetallic material used in designated applications such as gas turbines and flight structures.

4.2 This practice establishes the basic parameters for the application and control of the radiographic process. This practice may be specified on an engineering drawing, specification, or contract; however, it is not a detailed radiographic technique and must be supplemented. Section 7 and ~~Test Methods~~ Practices ~~E1030~~E1030/E1030M and E1032 contain information to help develop detailed radiographic techniques.

5. Basis of Application

5.1 *Personnel Qualification*—Personnel performing examinations to this practice shall be qualified in accordance with ~~NAS-410~~NAS410 and certified by the employer. Other qualification documents may be used when specified in the contract or purchase order. The applicable revision shall be the latest unless otherwise specified in the contractual agreement.

5.2 *Qualification of Nondestructive Examination Agencies*—NDE agencies shall be approved by the cognizant engineering organization. Specification E543 may be used to facilitate this approval.

5.3 *Timing of Examination*—The timing of examination shall be in accordance with 7.2, unless otherwise specified.

TABLE 2 Maximum Allowable Unsharpness (U_g) for Directional Exposures

Material Thickness (t), in. ~~(mm)~~	U_g, in. ~~(mm)~~
~~t ≤ 0.5 (12.7)~~	~~0.008 (0.203)~~
~~0.5 (12.7) < t ≤ 1.0 (25.4)~~	~~0.010 (0.254)~~
~~1.0 (25.4) < t ≤ 2.0 (50.8)~~	~~0.020 (0.508)~~
~~2.0 (50.8) < t ≤ 4.0 (101.6)~~	~~0.030 (0.762)~~
~~4.0 (101.6) < t~~	~~0.040 (1.016)~~

TABLE 2 Maximum Allowable Unsharpness (U_g) for Directional Exposures

Material Thickness (t), in. [mm]	U_g, in. [mm]
t ≤ 0.5 [12.7]	0.008 [0.203]
0.5 [12.7] < t ≤ 1.0 [25.4]	0.010 [0.254]
1.0 [25.4] < t ≤ 2.0 [50.8]	0.020 [0.508]
2.0 [50.8] < t ≤ 4.0 [101.6]	0.030 [0.762]
4.0 [101.6] < t	0.040 [1.016]

TABLE 3 Quality Levels of Examination

Radiographic Quality Level	Maximum IQI Thickness, %[A]	Minimum Visible Hole Diameter[B]	Equivalent IQI Sensitivity, %[C]
1-1T	1	1T	0.7
1-2T	1	2T	1.0
2-1T	2	1T	1.4
2-2T	2	2T	2.0
2-4T	2	4T	2.8

[A] Expressed as a percentage of material thickness.
[B] Expressed as a multiple thickness of IQI.
[C] Equivalent IQI sensitivity is that thickness of the IQI expressed as a percentage of the specimen thickness in which a 2T hole would be clearly visible under the same radiographic conditions.

5.4 *Extent of Examination*—The extent of examination shall be in accordance with 7.3 or 7.18.2.2, as applicable, unless otherwise specified.

5.5 *Reporting Criteria/Acceptance Criteria*—Reporting criteria for the examination results shall be in accordance with 8.2, unless otherwise specified. Since acceptance criteria are not specified in this ~~standard,~~practice, they shall be specified in the engineering drawing, specification, or contractual agreement.

5.6 *Reexamination of Repaired/Reworked Items*—Reexamination of repaired and reworked items shall be in accordance with 7.7.7 and 8.3, unless otherwise specified.

6. General Practice

6.1 *Facilities:*

6.1.1 *Safety*—The work environment and equipment shall be designed and utilized to ensure the safety of personnel and property. NCRP 51, NCRP 91, and NIST Handbook 114 may be used as guides to ensure that radiographic procedures are performed such that personnel do not receive a radiation dosage exceeding the maximum permitted by city, state, or national codes.

6.1.2 *Radiographic Exposure Areas*—Radiographic exposure areas shall be clean and equipped so that acceptable radiographs may be produced in accordance with the requirements of this practice.

6.1.3 *Darkroom*—Darkroom facilities, including equipment and materials, shall be clean and maintained in such a manner as to be capable of consistently producing radiographs free of blemishes or artifacts which might interfere with interpretation in the area of interest.

6.1.4 *Film Viewing Area*—Subdued lighting in the viewing room is preferred rather than total darkness. Background illumination lighting shall be arranged such that light reflections do not interfere with review of radiographs.

6.2 *Equipment and Materials:*

6.2.1 *Radiation Sources:*

6.2.1.1 *X-Radiation Sources*—X-ray sources that are used shall be capable of demonstrating the required radiographic quality level.

6.2.1.2 *Gamma Radiation Sources*—Isotope sources that are used shall be capable of demonstrating the required radiographic quality level.

6.2.2 *Film Systems*—Only film systems (see ~~3.2.3~~3.2.2) having cognizant engineering organization approval or meeting the requirements of Test Method E1815 Class I, Class II, or special shall be used.

6.2.3 *Non-film Recording Media*—Analog and digital recording media or radioscopic devices may be used when approved by the cognizant engineering organization.

6.2.4 *Film Holders and Cassettes*—Film holders and cassettes shall be light tight, constructed of materials that do not interfere with the quality or sensitivity of the radiographs and shall be in appropriate working condition.

6.2.5 *Intensifying Screens:*

6.2.5.1 *Lead Foil Screens*—Intensifying screens of the lead foil type shall be used in accordance with 7.8. Screens shall have approximately the same area dimensions as the film used and shall be in intimate contact with the film during exposure. Screens shall be free from any cracks, creases, scratches, or foreign material that could produce undesirable, nonrelevant images on the radiograph.

6.2.5.2 *Other Metallic Screens*—Other metallic screens may be used provided the specified radiographic quality level, density, and contrast are obtained and use is approved by the cognizant engineering organization.

6.2.5.3 *Fluorescent and Fluorometallic Screen/Film Combinations*—Fluorescent and fluorometallic screen/film combinations are not allowed unless approved by the cognizant engineering organization.

6.2.6 *Film Processors*—Film processors shall be capable of producing radiographs that meet the requirements of this practice and shall be maintained and used in accordance with manufacturers' recommendations. Film processing shall be controlled and monitored as recommended in Guide E999 and as scheduled in Table 4.

6.2.7 *Film Digitizers*—The use of film digitizers is acceptable when approved by the cognizant engineering organization.

6.2.8 *Densitometers*—Densitometers shall be capable of measuring light transmitted through a radiograph with ~~a film~~an optical density up to the maximum utilized. The maximum measurable optical density shall be posted on each densitometer.

6.2.8.1 Densitometers shall be calibrated in accordance with Practice E1079 and Table 4 for the range of optical densities to be utilized. Calibration shall be performed using a calibrated density strip traceable to NIST. Verification checks using high, low, and intermediate densities shall be made in accordance with Practice E1079 and as scheduled in Table 4.

6.2.9 *Film Viewers*—Viewers used for final interpretation shall meet the following requirements:

6.2.9.1 Maximum readable ~~film~~optical density shall be determined as follows:

a. The maximum light intensity for each viewing port shall be determined using a light meter that measures luminance, either in footlamberts or ~~candelas/m~~candela/m^2 and controlled in accordance with Table 4. (Divide candela/m^2 by 3.426 for conversion to footlamberts.)

b. Readings shall be taken at the center of spot viewers, and at the visually dimmest area of the viewing surface for all other types of viewers.

c. The maximum readable ~~film~~optical density shall be determined in accordance with Fig. 1 and posted on ~~the~~ each viewer for each viewer port.

d. Maximum readable ~~film~~optical density values shall be re-established when the viewer is repaired, altered, or the bulb is changed.

TABLE 4 Process Control Checks

Device or Condition	Calibration	Verification	Paragraph Ref.
Image Quality Indicators			6.3.5
Material	When Procured		
Dimensional	When Procured	Annually (3)	
Physical Condition		Prior to Each Use (2)	
Indication Measuring Devices	When Procured	Prior to Each Use (2)	6.2.10
Densitometers	Annually	Each Shift and (1)	6.2.8.1
Visible Light Meters (footlamberts or candelas)	Semi-annually		
Viewer Intensity	When Procured	Monthly and (1)	
Schedule 1		(1)	6.2.9.1
Schedule 2		daily (2)	6.2.9.1
Thermometers	Semi-annually		
Automatic Film Processors			6.2.6
Developer Temperature		Prior to Each Use (2)	
Processor Performance		Daily	
Base + Fog		Daily	
Replenishing Rate		(1)	
Developer Immersion Time		(1)	
Manual Film Processing			6.2.6
Developer Temperature		Prior to Each Use (2)	
Processing Performance		Daily	
Base + Fog		Daily	
Usage Log		Daily	
Replenishment Log		(1)	

(1) Immediately after preventative maintenance, repair and changes in configuration, bulb(s), or setup.
(2) Does not need to be documented.
(3) Annual Dimensional and Alloy Verifications of IQI's are not required when they are permanently attached to shims, blocks, or stepwedges, and/or encased in clear plastic or similar material, provided there is no physical evidence of damage.

(1) Immediately after preventative maintenance, repair and changes in configuration, bulb(s), or setup.
(2) Does not need to be documented.
(3) Annual Dimensional and Alloy Verifications of IQI's are not required when they are permanently attached to shims, blocks, or stepwedges, and/or encased in clear plastic or similar material, provided there is no physical evidence of damage.

e. If the posted maximum readable film density exceeds the maximum allowable, film viewer output exceeds the required output of the maximum posted optical density of the viewing screen and high intensity viewing port, as determined by Fig. 1, by 15 % or more when the bulb was first installed, the intensity will be verified in accordance with Schedule 1, Table 4. Otherwise, Schedule 2 will be used.

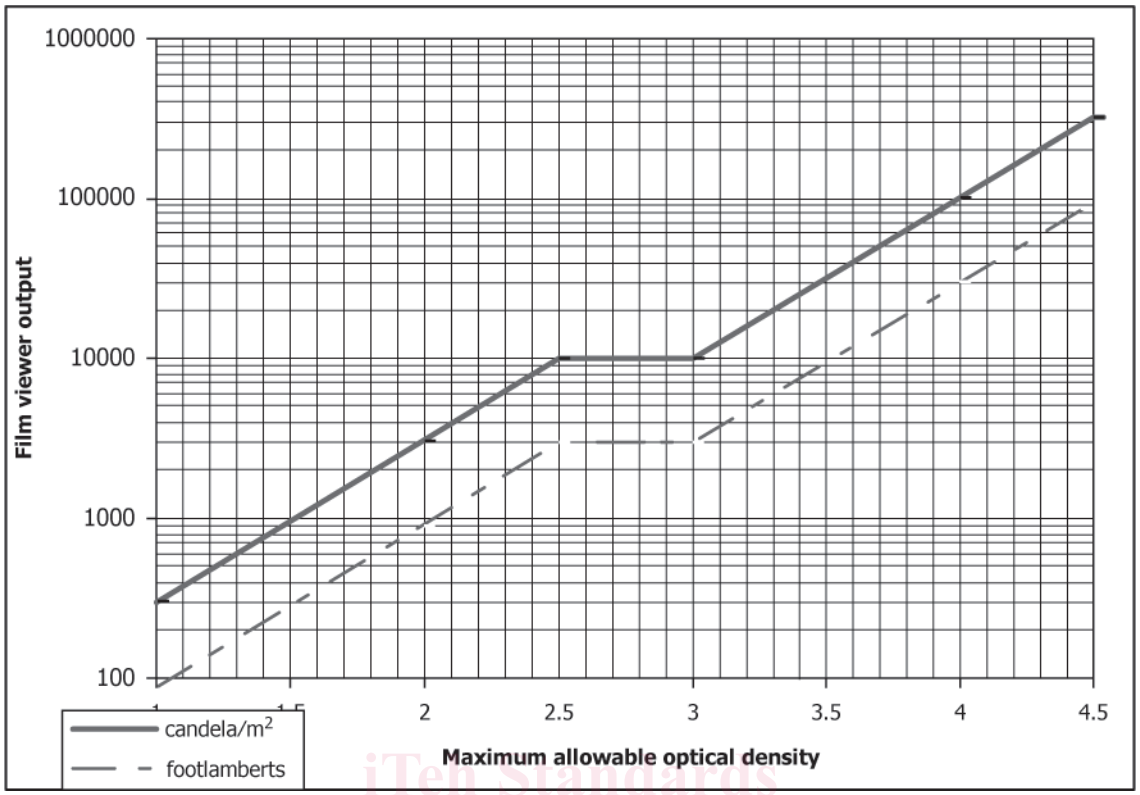
6.2.9.2 The light enclosure shall be designed to provide a visually uniform brightness level over the entire viewing screen.

6.2.9.3 Viewers shall be equipped with a fan or other means of preventing thermal damage to the radiographic film while being viewed.

6.2.9.4 Except for localized high-intensity viewing ports, viewers shall be equipped with a translucent material in each viewing port.

6.2.9.5 A set of opaque masks, an iris-type aperture, or any other method to reduce the viewing port to suit the size of the area of interest may also be provided.

6.2.10 *Film Viewing Aids*—Magnifiers may be used to aid interpretation and determine indication size. Magnification no greater than 10× may be used unless otherwise approved by the cognizant engineering organization. The specific magnifier used shall be determined by the interpretation requirements. Devices used for measuring indication size shall be calibrated and verified (that is, visually examined for damage and cleanliness) in accordance with Table 4.



NOTE 1—Figure 1 is a depiction in graphical form of the data derived in ~~ASTM~~Specification E1390 and ISO 5580 (identical to EN 25580) for viewer brightness. Conversion from tabular data to a graph reveals a step in the line. These requirements derive from two sources. The minimum luminance level required for the average human eye to achieve photopic eye response ~~(where~~ (where the maximum resolution and contrast discrimination occurs) is at 10 candela/m^2. At levels below this value, the eye responds scotopically which results in lower contrast discrimination and resolution. While photopic vision typically occurs at a threshold of 10 candela/m^2 for the average human eye, this curve takes advantage of the fact that at lower ~~film~~optical densities, most viewers can achieve an amount of light that guarantees that virtually all operators (not just the average) will be viewing film in the photopic vision mode. Thus, for lower ~~film~~optical densities ~~(<2.5)~~(<2.5), a transmittance of 30 candela/m^2 is required. Additionally, the increased brightness at lower ~~film~~optical densities helps offset the lower contrast exhibited by the films at lower optical densities.

NOTE 2—NDT film systems classified corresponding to Test Method E1815 system classes "Special", I and II, with or without lead screens, are suitable for the extended viewing range above ~~a~~ an optical density of 4, due to their high gradient ($G_{D\text{-}D_0}$ = 4 > 6) at D = 4 above fog and base. These double sided NDT film systems have a high silver content and do not saturate as early as medical and classes III, W-A, ~~W-B~~W-B, and W-C film systems. The operator should mask all film areas of lower optical density to avoid blinding (dazzling). Blinding reduces the eye perception and requires longer eye adaptation time. High brightness viewing stations also heat films depending on the optical density and viewing time. The operator shall prevent overheating to protect the film integrity.

FIG. 1 Maximum ~~Film~~Optical Density Allowable with Film Viewer

6.3 *Image Quality Indicators (IQIs):*

6.3.1 *Hole-Type IQIs*—Hole-type IQIs in accordance with Practice E1025 or Annex A1 shall be used unless otherwise specified by contract requirements. Other IQI types, if used, shall be in accordance with the requirements of 6.3.2 and 6.3.3.

6.3.2 *Wire-Type IQIs*—Wire-type IQIs in accordance with Practice E747 may be used only with approval from the Level ~~II~~3 radiographer of the cognizant engineering organization.

6.3.3 *Other IQI Types*—The use of other types of IQIs, modifications to the types specified above, or Representative Quality Indicators (RQIs) in accordance with Practice E1817 is permitted upon approval of the Level ~~II~~3 radiographer of the cognizant engineering organization. Details of the design, material designation, and thickness identification of the IQI or RQI shall be in the written radiographic technique or documented on a drawing that shall be referenced in the written radiographic technique (see 7.1).

6.3.4 *Radiographically Similar ~~IQI~~ IQI/and/or Block Material*—IQIs of material different from the material to be radiographed may be used provided the IQI material is determined to be radiographically similar. Materials shall be considered radiographically similar if the following requirements are satisfied: