Designation: E2104 – 09

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 and health practices and determine the applicability of regulatory limitations prior to use.*

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 Radiology

E1030 Test Method for Radiographic Examination of Metallic Castings

E1032 Test Method for Radiographic Examination of Weldments

E1079 Practice for Calibration of Transmission Densitometers

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

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)

2.2 *AWS Documents:*[3]

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

2.3 *AIA Documents:*[4]

NAS-410 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

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

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

[3] Available from American 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.

Sources, Energies up to 10 MeV[6]

NOTE 1—*DoD Contracts:* 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 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.

3.2.2 *component*—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.

3.2.3 *film system*—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.

3.2.4 *like section*—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.

3.2.5 *material group*—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.

3.2.6 *NDE facility*—the NDE agency performing the radiographic examination.

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

3.2.8 *radiographic technique*—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 E1030 and E1032 contain information to help develop detailed radiographic techniques.

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.

TABLE 2 Maximum Allowable Unsharpness (U_g) for Directional Exposures

Material Thickness (t), in. (mm)	U_g, in. (mm)
$t \leq 0.5$ (12.7)	0.008 (0.203)
0.5 (12.7) $< t \leq 1.0$ (25.4)	0.010 (0.254)
1.0 (25.4) $< t \leq 2.0$ (50.8)	0.020 (0.508)
2.0 (50.8) $< t \leq 4.0$ (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. Basis of Application

5.1 *Personnel Qualification*—Personnel performing examinations to this practice shall be qualified in accordance with NAS-410 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.

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.

[6] Available from National Institute of Standards and Technology (NIST), 100 Bureau Dr., Stop 1070, Gaithersburg, MD 20899-1070, http://www.nist.gov.

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, 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) 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.

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.

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.

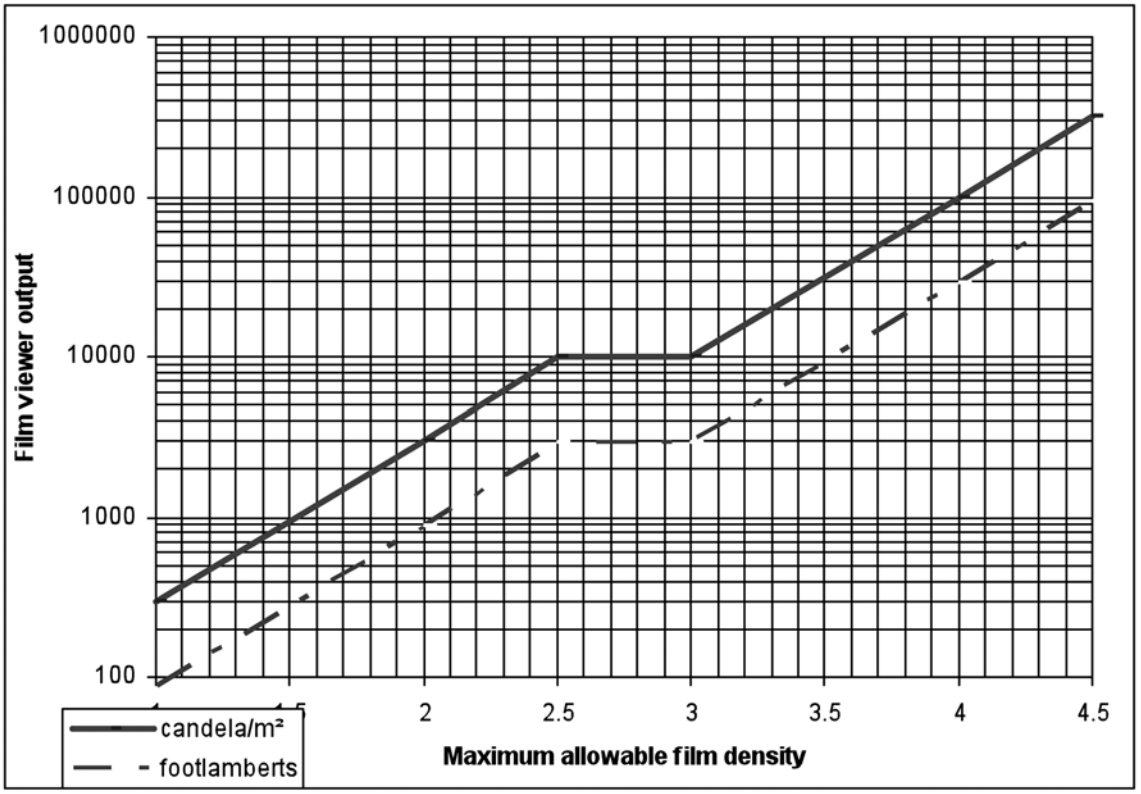
6.2.8 *Densitometers*—Densitometers shall be capable of measuring light transmitted through a radiograph with a film density up to the maximum utilized. The maximum measurable density shall be posted on each densitometer.

6.2.8.1 Densitometers shall be calibrated in accordance with Practice E1079 and Table 4 for the range of 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 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,



NOTE 1—Figure 1 is a depiction in graphical form of the data derived in ASTM 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 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 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 densities (<2.5) a transmittance of 30 candela/m^2 is required. Additionally, the increased brightness at lower film densities helps offset the lower contrast exhibited by the films at lower densities.

NOTE 2—NDT film systems classified corresponding to E1815 system classes "Special", I and II, with or without lead screens, are suitable for the extended viewing range above a 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 and W-C film systems. The operator should mask all film areas of lower 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 density and viewing time. The operator shall prevent overheating to protect the film integrity.

FIG. 1 Maximum Film Density Allowable with Film Viewer

either in footlamberts or candelas/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 density shall be determined in accordance with Fig. 1 and posted on the each viewer for each viewer port.

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

e. If the posted maximum readable film density exceeds the maximum allowable, 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.

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 III 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 III 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 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:

6.3.4.1 Two blocks of equal thickness, one of the material to be radiographed and one of the material of which the IQIs are made, shall be exposed together on the same film at the lowest energy level to be used for production radiographs.

6.3.4.2 The film density readings shall be between 2.0 and 4.0 for both materials.

6.3.4.3 IQI materials shall be considered radiographically similar if the following requirements are satisfied. Two blocks of equal thickness, one of the material to be radiographed and one of the material of which the IQI's are made, shall be exposed together on the same film at the lowest energy level to be used for production radiographs. If the film density of the IQI material to be radiographed is within the range from -10 % to +10 % of the material to be radiographed, it shall be considered radiographically similar. The film density readings shall be between 2.0 and 4.0 for both materials. An IQI with a lower radiographic attenuation may be used.

6.3.5 *IQI Control*—IQIs shall be procured or fabricated to the requirements of Practice E747 or E1025, or Annex A1, as applicable, with certification of compliance for material and dimensions. IQIs shall be dimensionally verified to be within drawing tolerances in accordance with Table 4. Users shall visually examine the physical condition of IQIs for damage and cleanliness in accordance with the verification schedule in Table 4.

7. Detail Requirements

7.1 *Radiographic Technique*—It shall be the responsibility of the NDE facility to develop and document a workable radiographic technique that is capable of consistently producing the desired results and radiographic quality level. Material and components shall be examined to an approved radiographic technique.

7.1.1 The radiographic technique shall be approved by the NDE facility's Level III radiographer.

7.1.2 When required by contract or purchase order, the radiographic technique shall be submitted to the Level III radiographer of the cognizant engineering organization for approval.

7.1.3 Unless otherwise specified by the purchase order or contract, the radiographic technique shall include the following information:

7.1.3.1 A drawing, sketch, or photograph showing the positions of the component, film and IQI with respect to the radiation source for each exposure.

7.1.3.2 The angle of the radiation beam in relation to the component, the source-to-film distance, and any blocking or masking material, if used.

7.1.3.3 The exposure parameters for X-ray machines; voltage, milliamperes, time (or mAs, as applicable), and focal spot size or effective focal spot size as required by contract. For radioisotope sources, the isotope type, curie strength, time and source size.

7.1.3.4 Film size and designation, speed or classification, including the film load sequence for exposures with multiple film loads, intensifying screen type, thickness and location, filters used and the film density range.

7.1.3.5 Material and thickness range of the area or region to be examined.

7.1.3.6 The IQI type, size and the required radiographic quality level. If alternate IQIs are used, include details of the design or reference to applicable documents.

7.1.3.7 Material type and thickness for blocks or shims.

7.1.3.8 Identification of the NDE facility, radiographic technique identification and the date, or revision, of the procedure.

7.1.3.9 Radiographic identification scheme used to correlate technique to customer part number and part to film.

7.2 *Examination Sequence*—The sequence for radiographic examination in the production operation shall be specified in the manufacturing or assembly process specification, contract or purchase order. If not specified, radiographic examination shall be performed at a stage in the process of manufacturing or assembly at which relevant discontinuities can be detected.

7.3 *Examination and Coverage*—The number of parts examined, and the radiographic coverage of each part shall be as specified by drawings, radiographic techniques, radiographic manuals or other specifications, as applicable. Areas to be examined shall be identified on the drawing by using the symbols in accordance with ANSI/AWS A2.4 or other systems of designations that are easily identified on the drawing.

7.3.1 *Acceptance Requirements*—When examination is performed in accordance with this practice, engineering drawings, specifications, or other applicable documents shall indicate the criteria by which the components are judged acceptable. Components may be divided into zones and separate criteria assigned to each zone in accordance with its design requirements. When used, direct references to ASTM reference radiological images (reference radiographs or digital reference images) shall include the grade level for each type of discontinuity permitted for each part or zone.

7.3.2 *Fatigue Crack Detection*—When parts are radiographed to detect fatigue cracks, only the area of the film that falls within a 10° cone of radiation (solid angle measurement) shall be considered valid for interpretation. An alternate technique may be qualified in another manner when approved by the cognizant engineering organization.

7.4 *Nonfilm Techniques*—Non-film examination methods may be used when approved by the cognizant engineering organization.

7.5 *Multi-Film Techniques*—Film techniques with two or more films of the same or different speeds in the same or separate film holder(s) shall be permitted provided that the applicable radiographic quality level and film density requirements are achieved for the area of interest. Interpretation of superimposed radiographs is prohibited.

7.6 *Surface Preparation*—Components may be examined without surface preparation or conditioning except as required to remove surface conditions that may interfere with proper interpretation of radiographs.

7.7 *Radiographic Identification*—Unless otherwise specified by the purchase order or contract, the radiograph shall include the following information:

7.7.1 An alpha, numeric or alpha-numeric identification traceable to the part number.

7.7.2 For serialized components, a serial number or assigned radiographic number traceable to the component under examination.

7.7.3 For non-serialized components, marking of the radiographic film and component shall be provided so that the radiograph may be traced to the component while being examined.

7.7.4 View identification markers, when multiple views are taken.

7.7.5 Identification of the NDE facility performing the examination.

7.7.6 Date of the exposure.

7.7.7 Radiographs of a repair/rework area shall be uniquely identified (for example, R1, R2, R3, …) indicating the number of times that repair/rework was attempted during a repair/rework cycle.

7.7.8 *Location Markers*—Location markers used for the correlation of a component to its radiographic image shall be placed in such a manner as to ensure that the image of the marker does not interfere with the interpretation of the radiograph, and that the required coverage has been obtained. The location marker positions shall be established on the component and the position of the markers shall be maintained for the duration of the examination. If the entire component can be radiographed with one film for each view and the orientation of the component with respect to the film is obvious, then location markers are not required.

7.7.8.1 As an alternative to location markers, view identification markers (see 7.7.4) may be used provided that the orientation of the radiographs to the part can demonstrate the required radiographic coverage, and location of indications can be correlated to the component.

7.8 *Lead Intensifying Screens*—Intensifying screens of the lead foil type shall be used, in accordance with Table 1, unless otherwise approved by the cognizant engineering organization.

7.9 *Filters*—Use of filtration at the tube head shall require approval by the cognizant engineering organization.

7.10 *Source-to-Film Distance*—The minimum allowable source-to-film distance shall be calculated by the following equation using the appropriate unsharpness value from Table 2, unless otherwise approved by the Level III radiographer of the cognizant engineering organization:

$$SFD = (F \cdot d / U_g) + d \quad (1)$$

where:

SFD = source-to-film distance,
U_g = geometric unsharpness,
F = size of the radiation source (using manufacturer's nominal size or the effective focal spot size in accordance with Test Method E1165), and
d = distance from the source side of the object to the film (regardless of whether or not the object is in contact with the film).

NOTE 3—Unit of measurement for SFD, U_g, F and d may be in either English or SI units as long as they are consistent (not mixed).

NOTE 4—For panoramic exposures, the SFD may be calculated using a U_g value twice that stated in Table 2.

7.11 *Back Scatter Radiation*—During each exposure the film shall be monitored for back scatter radiation. Each film holder shall have a lead letter "B" a minimum of 0.5 in. (12.7 mm) high and a minimum of 0.063 in. (1.6 mm) thick positioned behind the film and within the general area of the film to be viewed. Should the image of the lead letter "B" appear on the film as a light image, the film shall be considered unacceptable and the component shall be reexamined after appropriate measures (for example, the addition of screens, lead backing, etc.) have been implemented to prevent discernible back scatter radiation on subsequent exposures. The appearance of a dark image (higher density "B" image) may be disregarded unless the dark image could interfere with interpretation in the area of interest.

7.11.1 When identical parts or segments of parts are to be examined by the same radiographic technique, the lead letter "B" may be used to qualify the initial exposure and then may be omitted for subsequent exposures provided the proximity and nature of backscattering sources remains unchanged.

7.12 *Radiographic Technique Modifications*—Modifications-Modifications to approved radiographic techniques shall utilize only one of the following options:

(*1*) A change not to exceed ±15 % kV.

(*2*) A change not to exceed ±15 % mAs.

(*3*) A change not to exceed ±5 % kV and ±10 % mAs.

This modification shall be allowed provided the density, contrast and radiographic quality requirements are still met. Exceeding these limits shall require submittal to the cognizant engineering organization for approval.

7.13 *Processed Radiographs*—Radiographs shall be free from artifacts and blemishes which may interfere with the evaluation of the area of interest.

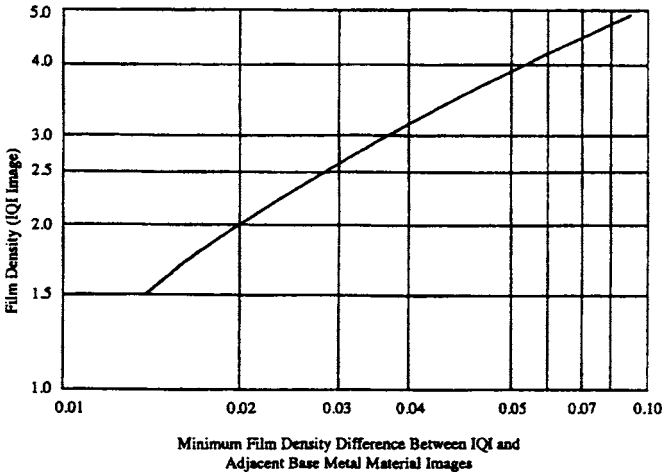


FIG. 2 Minimum Contrast of Radiographs at Various Film Densities

7.13.1 *Re-radiography*—Whenever there is a reasonable doubt as to the interpretation or clarity of the radiograph, re-radiography is required.

7.13.2 *Film Holders*—In the event that light leaks or damaged screens produce images on the radiograph, the radiograph need not be rejected unless the images obscure or interfere with the area of interest. Damaged film holders and screens shall be repaired or discarded as necessary.

7.14 *Film Density*—Film density shall be in the range from 1.5 to 4.0 in the area of interest. Film densities above 4.0 are permitted when agreed upon between the cognizant engineering organization and the NDT facility. In no case shall the maximum density exceed 4.5 or the maximum calibrated density of the densitometer, whichever is less. The maximum readable density depends on the film viewer used and its maximum luminance. The maximum readable density shall be posted on the viewer.

7.15 *Radiographic Quality Levels*—Table 3 provides radiographic quality levels based upon IQI thickness and the associated IQI hole diameter which must be imaged on the radiograph. Unless otherwise specified in the contractual documents or drawings the quality level shall be 2-2T.

7.16 *Contrast*—The contrast of the radiograph shall be determined by measuring the difference in density of the film through the IQI and through the adjacent material. The minimum density difference shown in Fig. 2 shall be achieved between the IQI and the base metals for Radiographic Quality Levels 2-1T and 2-2T.

7.17 *General Use of Image Quality Indicators (IQIs)*:

7.17.1 *IQI Selection*—The IQI thickness shall be based on a thickness not greater than the nominal thickness to be radiographed.

7.17.1.1 Hole-type IQIs used for the examination of material 0.25 in. (6.35 mm) or less in thickness shall be 0.005 in. (0.127 mm) ± 10 % thick. IQI thicknesses less than this minimum may be used but are not mandatory unless required by contract or purchase order.

7.17.1.2 IQI thicknesses that are between the thickness increments in Annex A1 (for example, a hole-type IQI that is 0.006 in. (0.15 mm) thick) may be used but are not mandatory.

7.17.1.3 For fabrication welds the IQI shall be selected as specified in 7.18.2.

7.17.2 *Placement of IQIs*—IQI(s) shall be used on each exposure. Where multiple film cassettes are utilized, the IQIs must appear on the films from at least one of those cassettes and the condition of 7.17.2.1 apply.

7.17.2.1 IQIs shall be placed at the outer edge of the cone of radiation or farthest extremity of the exposure setup (that is, farthest from the radiation beam centerline).

7.17.2.2 IQIs shall be placed on the source side of the component unless otherwise approved by the cognizant engineering organization.

7.17.2.3 *Panoramic Exposure*—When the source is placed on the axis of the object and the complete circumference is radiographed with a single exposure, at least three equally spaced IQIs are to be used.

7.17.2.4 *Block, or Like-Section IQI Technique*—Where it is impractical to place the IQI upon the part radiographed, the IQI may be placed on the source side of a separate block, or like section, from the same material group (or material that is radiographically similar, see 6.3.4). The block, or like section and IQI shall be placed on the outer edge of the cone of radiation. The block, or like section shall exceed the IQI dimensions so that at least three sides of the IQI shall be visible on the radiograph. If required by the customer, the block shall be placed on a low absorptive material (such as polystyrene or equivalent) to ensure that the IQI shall not be closer to the film than the source side of the part, or area of interest being evaluated.

7.17.3 *IQI Coverage of the Area of Interest*—An IQI shall represent an area of interest within which radiographic densities do not vary more than +30 to -15 percent from the density measured through the body of the IQI. At least one IQI per radiograph shall be used, except as specified in 7.17.3.1 and 7.17.4. Accept/reject decisions shall not be made directly beneath the IQI identification or the IQI/block combination.

7.17.3.1 *Radiograph Qualification Using Two IQIs*—When the film density varies by more than is specified in 7.17.3, two IQIs used in the following manner are acceptable. If one IQI shows an acceptable sensitivity in the most dense portion of the

radiograph, and the second IQI shows an acceptable sensitivity in the least dense portion of the radiograph, the two IQIs shall serve to qualify the radiograph within these density limits provided they both meet the density requirements of 7.14.

7.17.4 *Non-Requirement of IQIs*—IQIs are not required when:

7.17.4.1 Examining assemblies for debris.

7.17.4.2 Conducting radiography for defect removal provided final examination of the area includes an IQI.

7.17.4.3 Examining to show material details or contrast between two or more dissimilar materials in component parts or assemblies including honeycomb areas for the detection of fabrication irregularities or the presence or absence of material.

7.17.4.4 Surfaces are inaccessible and an alternate method of qualification has been approved by the cognizant engineering organization.

7.18 *Fabrication Welds*:

7.18.1 *Weld Preparation*—Accessible weld surfaces to be radiographed shall be prepared, as necessary, in accordance with the welding process specification, if applicable. The valleys between beads, weld ripples, or other surface irregularities shall be blended to a degree such that the resulting radiographic contrast due to surface condition cannot mask or be confused with that of any indication.

7.18.2 *IQI Selection for Welds*—For butt joints on simple structures such as pipe or plate, the thickness on which the IQI is based shall be the single-wall thickness plus actual reinforcement thickness up to the maximum allowed. For T-joints, lap joints, corner joints, fillet welds, weld surfacing, or for joints in complex assemblies where both sides of the joint are not accessible, the thickness on which the IQI is based shall be the total thickness through which the X-ray beam will pass. If different size sections are joined, the IQI shall be based on the thinner wall section. Backing strips or rings are not considered as a part of the weld, base material or reinforcement (bead) thickness upon which the IQI is based. If subsequent machining reduces the thickness of the weld area of interest and follow-up NDE (ultrasonic, liquid penetrant, or radiography) is not required, IQI size selection shall be based on final product thickness. If the required sensitivity cannot be obtained, radiographic examination shall be required after final machining.

7.18.2.1 *IQI Placement for Welds*—IQI placement for weld examination shall meet the following requirements unless otherwise approved by the Level III radiographer of the cognizant engineering organization. The IQIs shall be placed on the source side adjacent to, and at least 0.125 in. (3.175 mm), and not more than 1.25 in. (31.75 mm) from the weld being radiographed. When the weld is not radiographically similar or where part geometry precludes placement, the IQI wire or hole of the required sensitivity, as applicable, may be placed over the weld, but outside of the area of interest. When weld-reinforcement (weld bead), backing rings or strips are not removed, a shim of the same material group or radiographically similar material (see 6.3.4) shall be placed between the IQI and base material to provide approximately the same thickness of material under the IQI as the average thickness of the weld reinforcement plus the wall thickness and backing strip or ring.

7.18.2.2 *Examination Coverage for Welds*—Unless otherwise specified on the engineering drawing, contractual documents or approved by the Level III radiographer of the cognizant engineering organization, welded parts requiring radiography shall be radiographed for 100 % of the length of the weld zone, including the heat affected zone as defined by the cognizant engineering organization.

7.18.3 *Junctures of Longitudinal and Circumferential Welds*—Where portions of longitudinal welds adjoining a circumferential weld are being examined simultaneously with the circumferential weld, additional IQIs shall be placed on the longitudinal weld at the outer edge of the cone of radiation used to radiograph the circumferential weld.

7.18.4 *Longitudinal Welds*—For longitudinal welds, an IQI shall be placed at the extreme end of the area to be interpreted. The long axis of the IQI shall be adjacent to and at least 0.125 in. (3.175 mm), but not more than 1.25 in. (31.75 mm) from the weld edge.

7.18.5 *Circumferential Welds*—Except as provided in 7.18.5.1 and 7.18.5.2, radiography shall be performed in which the radiation passes through only one wall. When double-wall techniques are used, either superimposed (minimum of 3 evenly spaced angular views) or elliptical (offset) projections (minimum of two orthogonal views) may be used.

7.18.5.1 *Double-Wall Exposure, Double-Wall Viewing*—Welds in pipe, tubes and other similar hollow items 3.5 in. (88.9 mm) and less in nominal size (diameter) may be radiographed using the double-wall method where the radiation passes through both walls and both walls are viewed together for acceptance. An IQI, based on the double-wall thickness plus twice the weld reinforcement, as applicable, shall be placed on the source side wall, on top of a shim approximately equal to twice the weld reinforcement. As an alternate, the same IQI and shim may be placed on the source side of a like section that is placed adjacent to the weld being radiographed. When impractical to do the above, the IQI may be placed on top of a block that is approximately equal to twice the wall thickness plus twice the weld reinforcement, as applicable. The IQI and block shall be placed on a low-density material (such as polystyrene plastic or its equivalent), adjacent to the weld being examined, so that the top of the block is level with the upper surface of the tube or pipe.

7.18.5.2 *Double-Wall Exposure, Single-Wall Viewing*—For welds in pipe, tubes and other similar hollow items greater than 3.5 in. (88.9 mm) in nominal size (diameter), only the weld closest to the film shall be viewed for acceptance. An IQI, corresponding to the single-wall thickness plus any single-wall weld reinforcement, shall be placed adjacent to the weld on the inner wall on top of a shim equal to the weld reinforcement. When this is not possible, the same IQI and shim may be placed on the inner wall of a like section of a tube or pipe placed adjacent to the weld being radiographed. When a like section of the tube or pipe is unavailable, the IQI may be placed on a block adjacent to the weld being radiographed. The block thickness shall be equivalent to twice the wall thickness

plus any single-wall weld reinforcement. The top of the block shall not be any closer to the film than the inner wall of the tube or pipe.

7.18.6 *Electron Beam (EB) Welds*—To establish the correct angle for exposure during examination of EB welds the following black-line technique shall be used unless otherwise approved by the cognizant engineering organization. An unwelded part (tacked, clamped or similarly assembled) shall be setup such that the radiation beam is coplanar with the fusion line of the weld. The resulting radiograph must show a single, sharp, continuous black line of the weld fit-up as evidence that the radiation beam is coplanar with the fusion line. During examination of EB welded components, the beam to weld groove angle shall not exceed ± 2° from the established angle without approval from the cognizant engineering organization.

7.19 *Dark Adaptation*—The interpreter, after entering the viewing area, shall wait a sufficient period of time for the eyes to adapt before interpreting radiographs such that the required features of the IQI are clearly discernible (that is, required T-hole or wire and IQI outline). If the eyes are momentarily subjected to the full brightness of the illuminator, a minimum 30-second readaptation period shall be required.

7.20 *Interpretation of Radiographs*—Radiographs shall be initially viewed without magnification for indications and film artifacts. However, magnification of 2.5 to 10× may be used as an aid in interpretation. In addition, fabrication welds and all components with acceptance criteria requiring evaluation of indications 0.025 in. (0.635 mm) or less shall be interpreted using 2.5 to 10× magnification unless otherwise approved by the cognizant engineering organization.

7.21 *Marking*—Parts shall be marked in accordance with the applicable drawing, purchase order, contract, or as specified herein. Markings shall be applied in a manner and location as to be harmless to the part. Identification shall not be smeared or obliterated by subsequent handling. When subsequent processing would remove identification, the applicable marking shall also be contained in the records accompanying the parts.

7.21.1 *Part Marking*—Impression stamping, laser marking, vibro engraving, etching, ink stamping or dyeing shall be used as directed by the cognizant engineering organization.

7.21.2 *Other Identification*—Other means of identification, such as tagging, may be applied to parts for which construction, finish, or functional requirement preclude the use of impression stamping, laser marking, vibro engraving, etching, ink stamping or dyeing.

7.21.3 *Symbols*—Each part that has successfully passed radiographic examination shall be marked as follows:

7.21.3.1 When impression stamping, laser marking, vibro engraving, etching, ink stamping or dyeing is applicable, symbols shall be used. The symbol shall contain an identification symbol of the NDE facility.

7.21.3.1.1 Except for specialized applications, the symbol "X" enclosed in a circle shall be used to denote 100 % radiographic examination.

7.21.3.1.2 When sampling is used, parts actually radiographed and accepted shall be marked as specified in 7.21.3.1.1. All items in the lot accepted on a sampling basis (part of the lot but not actually radiographed) shall be marked using the symbol "X" enclosed in an ellipse.

7.21.3.2 When dyeing is applicable, blue dye shall be used to indicate 100 % radiographic examination. When sampling is used, orange dye shall be used to indicate parts accepted on a sampling basis while the parts of the lot actually examined shall receive blue dye.

8. Quality Assurance Provisions

8.1 *Responsibility for Examination*—The NDE facility is responsible for furnishing all supplies in conformance to contract or purchase order requirements and, unless otherwise specified in the contract or purchase order, the performance of all examination requirements contained herein. The examination provisions contained herein shall become a part of the NDE facility's overall examination system or quality program, unless otherwise specified by the cognizant engineering organization.

8.2 *Examination Report*—The results of all radiographic examinations shall be recorded and kept on file in accordance with the contract or purchase order. The examination reports shall reference this practice, or the applicable specification, and provide for traceability to the specific part or lot examined and shall include the examiner's identification, the date of the examination, the disposition of the component (accept or reject), and the reason for rejection of any items.

8.3 *Reexamination of Repaired/Reworked Items*—When required, material and components which are repaired or reworked shall be reexamined in the repaired area using the initial radiographic technique as a minimum requirement. Additional examination requirements may also be imposed by the cognizant engineering organization.

8.4 *Process Control Checks*—Process control checks shall be performed according to Table 4. All calibrations and verification checks shall be documented unless noted otherwise. Verification checks required on a daily or per shift basis that are required do not need to be performed when the system is not in use, but must be documented as "Not in Use".

8.5 *Retention of Radiographs*—Retention and delivery of radiographs and other records (see 7.1, radiographic technique; and 8.2, examination report) shall be in accordance with the provisions specified in the contract. For DoD contracts, they shall be in accordance with the contract data requirements list (see 9.1). If no specific requirements are specified for retention or delivery of radiographs, they shall become the property of the purchaser of the component.

8.5.1 *Film Archival Testing*—When required, archival testing shall be conducted using a conditioned processor (that is, film to be checked shall be processed after not less than twenty production radiographs, of typically utilized size, have been processed through the film processor). The archival quality of the film shall be determined using the residual thiosulfate test technique (kits are available from film manufacturers) and conducted using the manufacturer's instructions.

8.5.2 *Archival Results*—Results of the film archival test shall be recorded and shall include data such as date, film type, test results or other information as directed by the cognizant engineering organization.

8.5.3 *Storage of Radiographs*—Radiographs shall be stored in accordance with Guide E1254 unless otherwise specified by the cognizant engineering organization.

9. Notes

9.1 *Government Contracts*:

9.1.1 *Data Requirements*—The following Data Item Descriptions (DIDs) must be listed, as applicable on the Contract Data Requirement List (DD Form 1423) when this practice is applied on a contract, in order to obtain the data, except where DoD FAR Supplement 27.475-1 exempts the requirement for a DD Form 1423.

9.1.2 The current issue of DOD 5010.12-L, Acquisition Management Systems and Data Requirements Control List (AMSDL), must be researched to ensure that only current, cleared DIDs are cited on the DD Form 1423 (see 6.1, 6.28.2 and 6.28.8). Reference DID number DI-MISC-80653, Test Reports.

10. Keywords

10.1 image quality indicator; nondestructive testing; penetrating radiation; radiographic examination; radiography; radiology; radioscopy; X-ray

ANNEX

(Mandatory Information)

A1. IMAGE QUALITY INDICATOR (IQI) DESIGN—MILITARY CONFIGURATION

A1.1 *Hole-Type IQIs (Military)*—Military configuration hole-type IQIs used to determine radiographic quality levels (see 3.2.7) shall conform to the following requirements:

A1.1.1 IQI dimensions shall be in accordance with Fig. A1.1.

A1.1.2 IQI holes shall be true and normal to the surface of the IQI. Do not chamfer.

A1.1.3 IQI holes are not 1T, 2T and 4T for IQI thicknesses less than 0.010 in. (0.254 mm).

A1.1.4 IQI thicknesses are not 2 % for material thickness less than 0.25 in. (6.35 mm) or 1 % for material thickness less than 0.5 in. (12.7 mm).

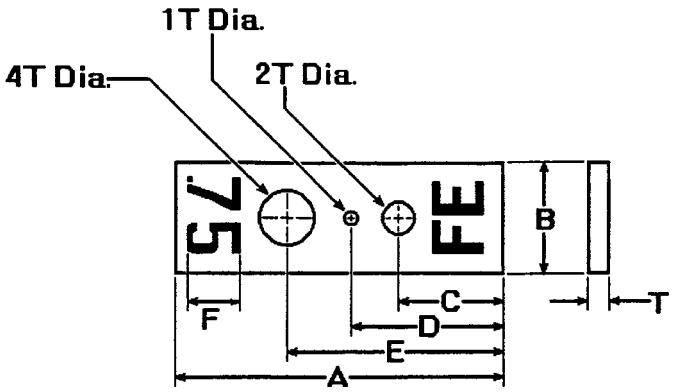
A1.1.5 The IQIs shall be fabricated from the same material group (see 3.2.5) or a radiographic similar material (see 6.3.4) as the object to be radiographed. Material groups and their designations are listed in Fig. A1.1. Steel IQIs (FE) and stainless steel IQIs (SS) shall be considered to be from the same material group.

A1.1.6 The IQIs shall be identified with the material group and thickness of the specimen to be radiographed. Lead numbers and letters, or a material of similar radiographic opacity, shall be used for identification.

A1.1.7 The IQI thickness shall consist of a two-digit number that expresses the material thickness in one hundredths of an inch. For example, a specimen thickness of 0.75 in. (19.05 mm) requires a .75 IQI.

A1.1.8 For identification of materials not listed in Fig. A1.1, the chemical symbol of the predominant element shall be used. When the material is a composite or does not have a predominant element, a controlled system for IQI identification shall be established and referenced in the radiographic technique (see 7.1).

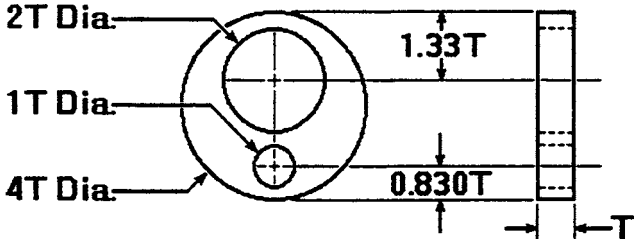
A1.1.9 Identification on rectangular design IQIs shall be permanently attached to the IQI. Identification on circular design IQIs shall be placed adjacent to the IQI to provide identification of the IQI on the radiograph.



T	Increments	A	B	C	D	E	F
0.005 - 0.020 incl.	0.0025	2.000	0.500	0.520	0.800	1.150	0.250
0.025 - 0.050 incl.	0.005	2.000	0.500	0.520	0.800	1.150	0.250
0.060 - 0.160 incl.	0.010	2.850	1.000	0.800	1.250	1.900	0.375

Minimum IQI Thickness = 0.005
Minimum Diameter for 1T Hole = 0.010
Minimum Diameter for 2T Hole = 0.020
Minimum Diameter for 4T Hole = 0.040

Design for IQI Thicknesses Up To and Including 0.160 in.



NOTE—(*1*) All dimensions are in inches. To convert inch dimensions to millimeters, multiply by 25.4.
(*2*) Tolerances on IQI thicknesses and hole diameters shall be ±10 percent or ½ of the thickness increment between IQI sizes, whichever is smaller.

FIG. A1.1 IQI Design—Military Configuration