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INTERNATIONAL

Designation: E 545 – 99

An American National Standard

Standard Test Method for Determining Image Quality in Direct Thermal Neutron Radiographic Examination[1]

This standard is issued under the fixed designation E 545; 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] This test method is under the jurisdiction of ASTM Committee E-7 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.05 on Neutron Radiography.

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1. Scope

1.1 This test method covers the use of an Image Quality Indicator (IQI) system to determine the relative[2] quality of radiographic images produced by direct, thermal neutron radiographic examination. The requirements expressed in this test method are not intended to control the quality level of materials and components.

1.2 *This standard does not purport to address 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.*

1.3 The values stated in SI units are regarded to be standard.

2. Referenced Documents

2.1 *ASTM Standards:*

E 543 Practice for Evaluating Agencies that Perform Performing Nondestructive Testing[3]

E 748 Practices for Thermal Neutron Radiography of Materials[3]

E 803 Test Method For 803 Method for Determining the L/D Ratio of Neutron Radiography Beams[3]

E 1316 Terminology for Nondestructive Examinations[3]

E 2003 Practice for Fabrication of Neutron Radiographic Beam Purity Indicators[3]

E 2023 Practice for Fabrication of Neutron Radiographic Sensitivity Indicators[3]

3. Summary Terminology

3.1 *Definitions*— For definitions of Method

~~3.1 The judgment of the quality of a neutron radiograph is based upon evaluation of images obtained from indicators that are exposed along with the test object, or in cases of limited film size or extended sample size, immediately prior to or following the test object under exactly the same conditions (see Section 9). Two basic indicators are used: (*1*) a device (beam purity indicator) for quantitative determination of radiographic quality, and (*2*) a device (sensitivity indicator) for qualitative determination of the sensitivity of detail visible on the neutron radiograph. The beam purity indicator consists of a polytetrafluoroethylene block containing two boron nitride disks, two lead disks, and two cadmium rods. A key feature of the device is the ability to make a visual analysis of its image for subjective quality information. Densitometric measurements of the image of the device permit quantitative determination of radiographic contrast, low-energy photon contribution, pair production contribution, image unsharpness, and information regarding film and processing quality. The sensitivity indicator consists of a step wedge containing gaps and holes of known dimensions. Visual inspection of the image of this device provides subjective information regarding total radiographic sensitivity with respect to the step block material as well as subjective data regarding detrimental levels of gamma exposure.~~

3.2 Neutron radiography practices are discussed in Practices E 748 and the terms are defined used in this test method, see Terminology E 1316. The agency performing the examination shall meet the requirements of Practice E 543. E 1316, Section H.

4. Significance and Use Summary of Test Method

4.1 The beam purity indicator (BPI) is designed to yield quantitative information concerning judgment of the quality of a neutron beam and image system parameters radiograph is based upon the evaluation of images obtained from indicators that

[2] The numerical values obtained in the calculations described herein may vary between different film processing systems, film types, and within one processing system if processing variables changes.

[3] *Annual Book of ASTM Standards*, Vol 03.03.

contribute to film exposure and thereby affect overall image quality. are exposed along with the test object. In caddses of limited film size or extended object size, the beam purity indicator can indicators may be u exposed on another film immediately prior to verify the day-to-day consistency or following exposure of the test object under exactly the same conditions (refer to Process Control Radiographs, Section 10). The IQI values must be determined from films with an optical density between 2.0 to 3.0. Two types of IQIs are used.

4.1.1 *Beam Purity Indicator (BPI)* —The BPI is a device used for quantitative determination of radiographic quality. Metallic conversion screens It is a polytetrafluoroethylene block containing two boron nitride disks, two lead disks, and single emulsion silver halide films, exposed together in two cadmium wires. A key feature of the neutron imaging beam, were used in BPI is the development ability to make a visual analysis of its image for subjective information, such as image unsharpness and film and processing quality. Densitometric measuremengts of the beam purity indicator. Use image of al the device permit quantitative determination of the effective value for the thermal n syseutron content, gamsmay content, pair production content, and scattered nsieutromn content. The BPI shall be constructed in accordance with Practice E 2003. Optionally, any BPI fabricated prior to publicationgs of Practice E 2003 which are not directly comparable conforms to these values.

4.2 *The only truly valid sensitivity indicator Test Method E 545 - 81 through 91 may be used.*

4.1.2 *Sensitivity Indicator (SI)* —The SI is a material or component, equivalent to one of several devices used for qualitative determination of the part being sensitivity of detail visible on a neutron radiographed, with radiograph. The SI is a step-wedge device containing gaps and holes of known standard discontinuity (reference standard comparison part). The sensitivity indicator was designed to substitute for dimensions. Visual inspection of the reference standard, providing qualitative image of this device provides subjective information on hole and gap regarding total radiographic sensitivity with respect to the step-block material. The SI shall be in a single unit.

4.3 The number accordance with Practice E 2023. Optionally, any SI fabricated prior to publication of areas or parts Practice E 2023 which conforms to Test Method E 545-81 through 91 may be radiographed and the acceptance standard to be used should be specified used.

4.2 Neutron radiography practices are discussed in the contract, purchase order, specification, or drawings. Practices E 748.

5. Image Quality Indicators (IQI) Significance and Use

5.1 The quality levels of all thermal BPI is designed to yield quantitative information concerning neutron radiographs shall be determined by beam and image quality indicators system parameters that conform contribute to film exposure and thereby affect overall image quality. In addition, the following specifications:

5.1.1 The beam purity indicator shall BPI can be constructed used to verify the day-to-day consistency of polytetrafluoroethylene, cadmium, lead, the neutron radiographic quality. Gadolinium conversion screens and boron nitride as shown single-emulsion silver-halide films, exposed together in Fig. 1.

5.1.2 The sensitivity indicator shall be constructed of cast acrylic resin, lead, and aluminum as shown the neutron imaging beam, were used in Fig. 2.

5.1.3 The lead step the development and testing of the BPI. Use of alternative detection systems may produce densitometric readings that are not valid for the equations used in Section 9.

5.2 *The only truly valid sensitivity indicator m is ay b reference standard part. A reference standard part is a material or component that is the same as the object being neutron radiographed except with a blank, cast acrylic resin step. known standard discontinuity, inclusion, omission, or flaw. The lead provides a visual indication sensitivity indicators were designed to substitute for the reference standard and provide qualitative information on hole and gap sensitivity.*

5.3 The number of beam gamma content (see 6.14). However, areas or objects to be radiographed and the lead image is not film acceptance standard used for any of should be specified in the sensitivity indicator calculations (image quality levels, Section 7). contract, purchase order, specification, or drawings.

6. Basis of Application

6.1 *Qualification of Nondestructive Agencies*—If specified in the contractual agreement, NDT agencies shall be qualified and evaluated in accordance with Practice E 543. The applicable revision of Practice E 543 shall be specified in the contractual agreement.

6.2 *Procedures and Techniques*—The procedures and techniques to be utilized shall be as described in this test method unless otherwise specified. Specific techniques may be specified in contractual documents.

6.3 *Extent of Examination*—The extent of examination shall be in accordance with Section 7 unless otherwise specified.

6.4 *Reporting Criteria/Acceptance Criteria*—Reporting criteria for the examination results shall be in accordance with Section 11 unless otherwise specified. Acceptance criteria (for example, for reference radiographs) shall be specified in the contractual agreement.

7. Procedure

6.1 Unless otherwise specified, the

7.1 The direction of the beam of radiation shall should be as perpendicular as possible to the plane of the film.

67.2 Use c Conversion screens that respond to neutrons of thermal energies and produce radiographs which meet specified quality level requirements.

~~6.3 Areas of interest shall be free of extraneous materials that may interfere with subsequent film evaluation. Areas of interest normally shall be located~~ energies, such as ~~close to the film as is practicable and shall be suitably identified so that defects in the area of interest may be correlated with the part.~~

~~6.4 Each~~ metallic gadolinium.

7.3 Each radiograph shall include a beam purity indicator ~~(see Fig. 1)~~ and a sensitivity indicator ~~(see Fig. 2). (See~~ (refer to Section ~~9~~ 10 for ~~possible exceptions.)~~ exceptions). The ~~two~~ indicators shall be located no less than ~~25.4~~ 25 mm ~~(1 in.)~~ from any edge of the exposed area of the film when feasible. The indicators shall be located such that the image of the indicators on the film do not overlap the image of the object.

7.4 The SI should be oriented parallel to and as close as possible to the ~~film. Sensitivity indicators shall~~ film.

7.5 The SI should be ~~enclosed in aluminum boxes with walls no more than 0.41 mm (0.016 in.) thick. The BPI shall~~ oriented such that its thickest step is not ~~be enclosed in a dust-cover. **Precaution**—In addition~~ adjacent to ~~other precautions,~~ the BPI or the objects being radiographed.

7.6 The BPI surface must be parallel against the film cassette face during exposure or density readings will be ~~meaningless.~~

~~6.5 The~~ invalid.

7.7 The cadmium ~~rods~~ wires in the BPI ~~should~~ shall be oriented such that their longitudinal axis is perpendicular to the nearest film ~~edge. The thickest step in~~ edge.

7.8 Measure the ~~sensitivity indicator should be placed away from the part or the BPI.~~

~~6.6 Identify each~~ film ~~with the radiographing facility, date, radiograph number, and part identification. This identification shall appear on the film image.~~

~~6.7 Measure film~~ densities using a diffuse transmission densitometer. The densitometer shall be accurate to ~~± 0.04 and repeatable to ± 0.02~~ ±0.02 density units.

~~6~~7.~~8~~9 For the purpose of determining image quality, the background optical density ~~(resulting from the unattenuated beam) closest to the area of interest~~ shall be between 2.0 and ~~3.0. Production radiographs may be made~~ 3.0 measured at ~~any appropriate density agreed upon by customer and vendor.~~ the hole in the center of the BPI.

7.10 The only true measurement of the beam uniformity is with a radiograph made without objects. Background film optical density in the range from 2.0 to 3.0 across the film should not vary more than ±5 % from the numerical mean of five measurements: one measurement at the center and one measurement ~~25.4~~ approximately 25 to 30 mm ~~(1 in.)~~ toward the center from each ~~corner.~~

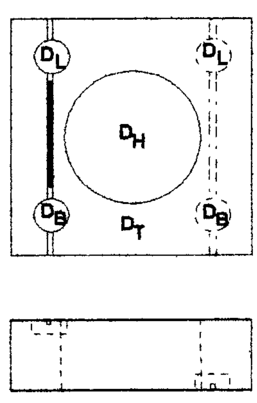
~~6.9 Radiographs~~ corner of the film. If the beam diameter is smaller than the film, the four outside measurements shall be taken 25 to 30 mm from the edge of the beam located at 90° intervals.

7.11 Radiographs shall be free of any blemish that may interfere with subsequent examination of the image.

7.12 Determine the thermal neutron content (NC), scattered neutron content (S), gamma content (γ), and pair production content (P) by densitometric analysis of ~~interest.~~

~~6.10 Make~~ the BPI image. Make a determination of the constituents of film exposure by measuring the densities in the ~~beam purity indicator~~ BPI image as shown in Table 1~~.~~

~~6.11 Determine~~. Calculate the ~~sensitivity of detail visible on~~ various exposure contributors by the ~~neutron radiograph~~ equations given in Section 9.



Beam Purity Indicator

TABLE 1 Definitions of *D* Parameters

D_B	Film densities measured through the images of the boron nitride disks.
D_L	Film densities measured through the images of the lead disks.
D_H	Film density measured at the center of the hole in the BPI.
D_T	Film density measured through the image of the polytetrafluoroethylene.
ΔD_L	Difference between the D_L values.
ΔD_B	Difference between the two D_B values.

7.13 Determine the sensitivity level by ~~evaluating~~ visually analyzing the image of the ~~sensitivity indicator and assigning a numerical value~~ SI. Determine the values for *G* and ~~and *H* based on Table~~ using Tables 2 ~~and Table 3~~ and 3.

7.14 Determine the neutron radiographic category from Table 4.

~~6.12 Determine the neutron radiographic category by the method detailed in Section 10.~~

~~6.13 Visually~~

7.15 Visually compare the images of the cadmium ~~rods~~ wires in the ~~beam purity indicator.~~ BPI. An obvious difference in image sharpness indicates an ~~*L/D* ratio that is probably too low for general inspection. Detailed analysis~~ *L/D* ratio of ~~the rod images is possible using a scanning microdensitometer. Reference Test~~ 35 or less. Use Method E 803 for quantifying the *L/D* ~~ratio determination.~~

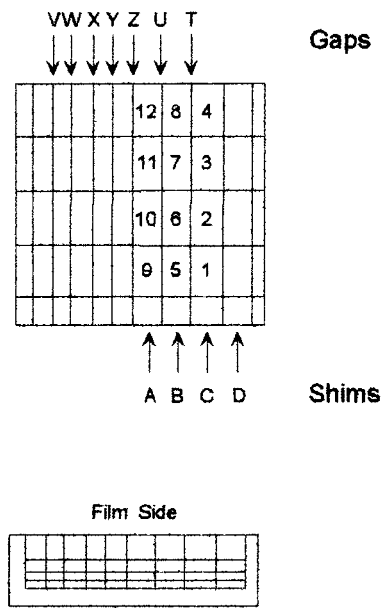
~~6.14 Visually~~ ratio.

7.16 If a lead shim is in the sensitivity indicator, visually inspect the image of the lead ~~steps in the sensitivity indicator.~~ steps. If the ~~0.25-mm~~ holes are not visible, the exposure contribution from gamma radiation is very ~~high. An evaluation should then be made to determine if the radiographic quality is sufficient for the required examination.~~

~~7.~~ high.

8. Image Quality Levels

~~7.1 The thermal neutron content (NC), scattered neutron content (S), gamma content (γ), and pair production content (P) are determined by densitometric analysis of the beam purity indicator image calculations detailed in Section 8. Sensitivity level is~~



Sensitivity Indicator

TABLE 2 Determination of *H*

NOTE 1—The value of *H* reported is the largest consecutive numbered hole that is visible in the image.

NOTE 2—For hole sizes and shim thicknesses, refer to Practice E 2023.

NOTE 3—The dots on the SI represent holes in the optional lead shim.

Value of *H*	Shim
1	C
2	C
3	C
4	C
5	B
6	B
7	B
8	B
9	A
10	A
11	A
12	A

TABLE 4 3 NDeuteromin Radtiographic Categn oriesf G

NOTE 1—It should be recognized that these categories favor contrast factors because the sensitivity indicators do not permit accurate determination of sharpness alone. It may, therefore, be advantageous to use a lower number category when sharpness is a more important factor than contrast. *G* reported is the smallest gap that can be seen at all absorber thicknesses.

NOTE 2—For gap sizes, refer to Practice E 2023.

CVatlueg ory				f *NCH GS*γP Gap			
			I[A]		65T		
			1		65T		
	6	6		U			
	2	6		U			
5			3	3			
5			3	V			
		II[A]			606 6 6	4	4
		II[A]			606 6 6	4	W
		III[A]			55 5 575		5
		III[A]			55 5 575		5X
		IV			504 5 8	6	6
		IV			504 5 8	6	Y
		V			453 5 9	7	7
		V			453 5 9	7	Z

[A] For Categories I, II, and III, the 0.25-mm hole must be visible at all lead thicknesses.

TABLE 4 Neutron Radiographic Categories

NOTE 1—It should be recognized that these categories favor contrast factors because the sensitivity indicators do not permit accurate determination of sharpness alone. It may, therefore, be advantageous to use a lower number category when sharpness is a more important factor than contrast.

Category	*NC*	*H*	*G*	*S*	γ	*P*
I	65	6	6	5	3	3
II	60	6	6	6	4	4
III	55	5	5	7	5	5
IV	50	4	5	8	6	6
V	45	3	5	9	7	7

determined by visually analyzing the image of the sensitivity indicator and subsequently calculating the value as detailed in Section 8.

7.2 ASTM

8.1 The ASTM designation of quality level shall include thermal neutron content and sensitivity level. The designation shall be is NC-H-G (see 8.1 9.1 and 8.5). 7.13). Values for scattered neutron content, gamma content, and pair production content may be specified at the option of the user. (When no designation of NC-H-G is specified by the customer, radiographs shall be Category II.)

78.32 Visual analysis of the beam purity indicator BPI requires inspection of two areas— – the image of the cadmium rods wires and the image of the areas containing the lead disks. If either of the cadmium rod images wire appears significantly less sharp than the other image, the *L/D* ratio is lower than normally required. If the lead disks noticeably appear either darker or lighter than the surrounding polytetrafluoroethylene, there is either a high gamma content (lighter image) or a high pair production content (darker image). Any of these observations indicates the need for further image analysis and subsequent determination of the usefulness of the radiograph for that particular examination.

89. Determination of Exposure Contributors and Sensitivity Level

8.1 Calculate Contributors

9.1 Calculate the effective thermal neutron content, *NC*, as follows:

$$NC = \frac{D_H - (\text{highest } D_B + \Delta D_L)}{D_H} \times 100 \quad (1)$$

$$NC = \frac{D_H - (\text{higher } D_B + \Delta D_L)}{D_H} \times 100 \quad (1)$$

where definitions of *D* parameters are given in Table 1.

89.2 Calculate the effective scattered neutron content, *S*,, as follows:

$$S = (\Delta D_B/D_H) \times 100 \quad (2)$$

$$S = (\Delta D_B/D_H) \times 100 \quad (2)$$

89.3 Calculate the effective gamma content, γ, as follows:

$$\gamma = (D_T - \text{lowest } D_L)/(D_H) \times 100 \quad (3)$$

$$\gamma = (D_T - \text{lower } D_L)/D_H \times 100 \quad (3)$$

89.4 Calculate the effective pair production content, P,: as follows:

$$P = (\Delta D_L/D_H) \times 100 \quad (4)$$

$$P = (\Delta D_L/D_H) \times 100 \quad (4)$$

8.5 Determine the radiographic category from Table 4.

9. Rejection and Retesting

9.1 A process control radiograph may be prepared for verification of exposure and sensitivity requirements when:

9.1.1 The size or setup of parts is such that the object scattered neutron level relative to background density, sensitivity, or facility scattered neutron exposure requirements is cause for nonconformance.

9.1.2 The part configuration necessitates a film to beam orientation that does not permit satisfactory density measurements for calculation of exposure by collimated thermal neutrons.

9.1.3 The part setup does not permit the location of image quality indicators to give adequate readings.

9.1.4 The radiograph background density does not meet the requirements of 6.8.

9.2 The process control radiograph shall be prepared with the same image quality indicators and exposure conditions as the suspect nonconforming exposure except for 9.1.4; however, the test parts are not required in the image and the film may be normal to the beam axis. To verify facility and process quality in the event of very high or low density, a normal density film may be used.

10. Certification

10.1 Upon requestProcess Control Radiographs

10.1 A process control radiograph (as defined in Terminology E 1316, Section H) may be prepared for verification of exposure and sensitivity requirements when the purchaser by contract following occur:

10.1.1 The size or purchase order, the radiographing facility shall certify setup of objects is such that the radiograph was prepared and examined in accordance with this standard method.

10.2 Any fabricator object-scattered neutron level relative to background density, sensitivity, or facility-scattered neutrons' exposure requirements is cause for nonconformance.

10.1.2 The object configuration necessitates a film-to-beam orientation that does not permit satisfactory density measurements for calculation of exposure by collimated thermal neutrons.

10.1.3 The object setup or size does not permit the location of image quality indicators described in this document should be prepared to provide documentation of give adequate readings.

10.1.4 The radiograph background density does not meet the materials and the details requirements of construction. Suggested methods to verify the details 7.10.

10.2 The process control radiograph shall be prepared with a background film optical density of construction include: 1. Photographs of individual components of the IQI 2.0 to assure 3.0 and the presence, correct location same image quality indicators and correct size of exposure conditions as the holes, or 2. A comparison thermal neutron radiograph of suspect nonconforming exposure. Similar test objects may be in the assembled IQI with that of a known, accepted IQI (preferably on a single neutron radiograph). image.

10.3 The film shall be normal to the beam axis.

11. Records

11.1 Complete recordsCertification

11.1 Upon request of the technique details shall be maintained purchaser by contract or purchase order, the examining radiographing facility for three years or as specified in shall certify that the basis of purchase. radiograph was prepared and examined in accordance with this test method.

12. Records

12.1 Complete records of the technique details shall be maintained by the examining facility for three years or as specified in the basis of purchase.

13. Keywords

123.1 beam purity indicator; direct method; image quality indicator; neutron radiography; sensitivity indicator