



Designation: E748 – 19

## Standard Guide for Thermal Neutron Radiography of Materials<sup>1</sup>

This standard is issued under the fixed designation E748; 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 reappraisal. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reappraisal.

### 1. Scope\*

1.1 *Purpose*—Practices to be employed for the radiographic examination of materials and components with thermal neutrons are outlined herein. They are intended as a guide for the production of neutron radiographs that possess consistent quality characteristics, as well as aiding the user to consider the applicability of thermal neutron radiology. Statements concerning preferred practice are provided without a discussion of the technical background for the preference. The necessary technical background can be found in Refs (1-16).<sup>2</sup>

1.2 *Limitations*—Acceptance standards have not been established for any material or production process (see Section 5 on Basis of Application). Adherence to the guide will, however, produce reproducible results. Neutron radiography, whether performed by means of a reactor, an accelerator, subcritical assembly, or radioactive source, will be consistent in sensitivity and resolution only if the consistency of all details of the technique, such as neutron source, collimation, geometry, film, etc., are maintained. This guide is limited to the use of photographic or radiographic film in combination with conversion screens for image recording; other imaging systems are available. Emphasis is placed on the use of nuclear reactor neutron sources.

1.3 *Interpretation and Acceptance Standards*—Interpretation and acceptance standards are not covered by this guide. Designation of accept-reject standards is recognized to be within the cognizance of product specifications.

1.4 *Safety Practices*—General practices for personnel protection against neutron and associated radiation peculiar to the neutron radiologic process are discussed in Section 18. Jurisdictional nuclear regulations will also apply.

1.5 *Other Aspects of the Neutron Radiographic Process*—For many important aspects of neutron radiography such as technique, files, viewing of radiographs, storage of

radiographs, film processing, and record keeping, refer to Guide E94, which covers these aspects for X-ray radiography. (See Section 2.)

1.6 The values stated in either SI or inch-pound units are to be regarded as the standard.

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

1.8 *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*:<sup>3</sup>

E94 Guide for Radiographic Examination Using Industrial Radiographic Film

E543 Specification for Agencies Performing Nondestructive Testing

E545 Test Method for Determining Image Quality in Direct Thermal Neutron Radiographic Examination

E803 Test Method for Determining the *L/D* Ratio of Neutron Radiography Beams

E1316 Terminology for Nondestructive Examinations

2.2 *ASNT Standard*:<sup>4</sup>

Recommended Practice SNT-TC-1A for Personnel Qualification and Certification

2.3 *ANSI Standard*:<sup>5</sup>

ANSI/ASNT-CP-189 Standard for Qualification and Certification of Nondestructive Testing Personnel

<sup>1</sup> This guide is under the jurisdiction of ASTM Committee E07 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.05 on Radiology (Neutron) Method.

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<sup>2</sup> The boldface numbers in parentheses refer to the list of references at the end of this standard.

<sup>3</sup> 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.

<sup>4</sup> Available from American Society for Nondestructive Testing (ASNT), P.O. Box 28518, 1711 Arlington Ln., Columbus, OH 43228-0518, http://www.asnt.org.

<sup>5</sup> Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

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

#### 2.4 AIA Document:<sup>6</sup>

**NAS-410 Nondestructive Testing Personnel Qualification and Certification**

#### 2.5 ISO Standard:<sup>7</sup>

**ISO 9712 Non-Destructive Testing—Qualification and Certification of NDT Personnel**

### 3. Terminology

3.1 *Definitions*—For definitions of terms used in these practices, see Terminology **E1316**, Section H.

### 4. Significance and Use

4.1 This guide covers types of materials to be examined, neutron radiographic examination techniques, neutron production and collimation methods, radiographic film, and converter screen selection. Within the present state of the neutron radiologic art, these practices are generally applicable to specific material combinations, processes, and techniques.

### 5. Basis of Application

5.1 *Personnel Qualification*—If specified in the contractual agreement, personnel performing examinations to this standard shall be qualified in accordance with a nationally or internationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT-CP-189, SNT-TC-1A, NAS-410, ISO 9712, or a similar document and certified by the employer or certifying agency, as applicable. The practice or standard used and its applicable revision shall be identified in the contractual agreement between the using parties.

5.2 *Qualification of Nondestructive Agencies*—If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in Specification **E543**. The applicable edition of Specification **E543** shall be specified in the contractual agreement.

5.3 *Procedures and Techniques*—The procedures and techniques to be used shall be as described in these practices unless otherwise specified. Specific techniques may be specified in the contractual agreement.

5.4 *Reporting Criteria/Acceptance Criteria*—Reporting criteria for the examination results shall be in accordance with **1.3** unless otherwise specified. Acceptance criteria (for example, for reference radiographs) shall be specified in the contractual agreement.

### 6. Neutron Radiography

6.1 *The Method*—Neutron radiography is basically similar to X-ray radiography in that both techniques employ radiation beam intensity modulation by an object to image macroscopic object details. X-rays or gamma rays are replaced by neutrons as the penetrating radiation in a through-transmission examination. Since the absorption characteristics of matter for X-rays

and neutrons differ drastically, the two techniques in general serve to complement one another.

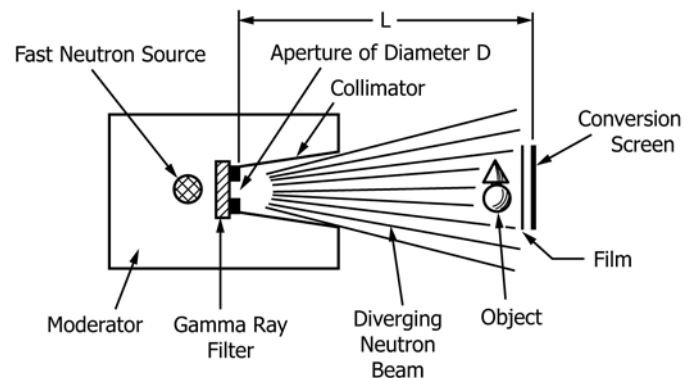
6.2 *Facilities*—The basic neutron radiography facility consists of a source of fast neutrons, a moderator, a gamma filter, a collimator, a conversion screen, a film image recorder or other imaging system, a cassette, and adequate biological shielding and interlock systems. A schematic diagram of a representative neutron radiography facility is illustrated in **Fig. 1**.

### 7. Neutron Sources

7.1 *General*—The thermal neutron beam may be obtained from a nuclear reactor, a subcritical assembly, a radioactive neutron source, or an accelerator. Neutron radiography has been achieved successfully with all four sources. In all cases the initial neutrons generated possess high energies and must be reduced in energy (moderated) to be useful for thermal neutron radiography. This may be achieved by surrounding the source with light materials such as water, oil, plastic, paraffin, beryllium, or graphite. The preferred moderator will be dependent on the constraints dictated by the energy of the primary neutrons, which will in turn be dictated by neutron beam parameters such as thermal neutron yield requirements, cadmium ratio, and beam gamma ray contamination. The characteristics of a particular system for a given application are left for the seller and the buyer of the service to decide. Characteristics and capabilities of each type of source are referenced in the References section. A general comparison of sources is shown in **Table 1**.

7.2 *Nuclear Reactors*—Nuclear reactors are the preferred thermal neutron source in general, since high neutron fluxes are available and exposures can be made in a relatively short time span. The high neutron intensity makes it possible to provide a tightly collimated beam; therefore, high-resolution radiographs can be produced.

7.3 *Subcritical Assembly*—A subcritical assembly is achieved by the addition of sufficient fissionable material surrounding a moderated source of neutrons, usually a radioisotope source. Although the total thermal neutron yield is smaller than that of a nuclear reactor, such a system offers the attractions of adequate image quality in a reasonable exposure



**FIG. 1 Typical Neutron Radiography Facility with Divergent Collimator**

<sup>6</sup> Available from Aerospace Industries Association (AIA), 1000 Wilson Blvd., Suite 1700, Arlington, VA 22209, <http://www.aia-aerospace.org>.

<sup>7</sup> Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, <http://www.ansi.org>.

**TABLE 1 Comparison of Thermal Neutron Sources**

| Type of Source       | Typical Radiographic Flux, n/cm <sup>2</sup> ·s | Radiographic Resolution | Characteristics                         |
|----------------------|---|-------------------------|---|
| Nuclear reactor      | 10 <sup>5</sup> to 10 <sup>8</sup>              | excellent               | stable operation, not portable          |
| Subcritical assembly | 10 <sup>4</sup> to 10 <sup>6</sup>              | good                    | stable operation, portability difficult |
| Accelerator          | 10 <sup>3</sup> to 10 <sup>6</sup>              | medium                  | on-off operation, transportable         |
| Radioisotope         | 10 <sup>1</sup> to 10 <sup>4</sup>              | poor to medium          | stable operation, portability possible  |

time, relative ease of licensing, adequate neutron yield for most industrial applications, and the possibility of transportable operation.

**7.4 Accelerator Sources**—Accelerators used for thermal neutron radiography have generally been of the low-voltage type which utilize the <sup>3</sup>H(d,n)<sup>4</sup>He reaction, high-energy X-ray machines in which the (x,n) reaction is applied and Van de Graaff and other high-energy accelerators which employ reactions such as <sup>9</sup>Be(d,n)<sup>10</sup>B. In all cases, the targets are surrounded by a moderator to reduce the neutrons to thermal energies. The total neutron yields of such machines can be on the order of 10<sup>12</sup>·n·s<sup>-1</sup>; the thermal neutron flux of such sources before collimation can be on the order of 10<sup>9</sup>·n·cm<sup>-2</sup>·s<sup>-1</sup>, for example, the yield from a Van de Graaff accelerator.

**7.5 Isotopic Sources**—Many isotopic sources have been employed for neutron radiologic applications. Those that have been most widely utilized are outlined in Table 2. Radioactive sources offer the best possibility for portable operation. However, because of the relatively low neutron yield, the exposure times are usually long for a given image quality. The isotopic source <sup>252</sup>Cf offers a number of advantages for thermal neutron radiology, namely, low neutron energy and small physical size, both of which lead to efficient neutron moderation, and the possibility for high total neutron yields.

## 8. Imaging Methods and Conversion Screens

**8.1 General**—Neutrons are indirectly ionizing particulate radiation that have little direct effect on radiographic film. To obtain a neutron radiographic image on film, a conversion screen is normally employed; upon neutron capture, screens emit prompt and delayed decay products in the form of nuclear radiation or light. In all cases the screen should be placed in intimate contact with the radiographic film in order to obtain sharp images.

**8.2 Direct Method**—In the direct method, a film is placed on the source side of the conversion screen (front film) and exposed to the neutron beam together with the conversion screen. Electron emission upon neutron capture is the mechanism by which the film is primarily exposed in the case of gadolinium conversion screens. The screen is generally one of

the following types: (1) a free-standing gadolinium metal screen accessible to film on both sides; (2) a sapphire-coated, vapor-deposited gadolinium screen on a substrate such as aluminum; or (3) a light-emitting fluorescent screen such as gadolinium oxysulfide or <sup>6</sup>LiF/ZnS. Exposure of an additional film (without object) is often useful to resolve artifacts that may appear in radiographs. Such artifacts could result from screen marks, excess pressure, light leaks, development, or non-uniform film. In the case of light-emitting conversion screens, it is recommended that the spectral response of the light emission be matched as closely as possible to that of the film used for optimum results. The direct method should be employed whenever high-resolution radiographs are required, and high beam contamination of low-energy gamma rays or highly radioactive objects do not preclude its use.

**8.3 Indirect Method**—This method makes use of conversion screens that can be made temporarily radioactive by neutron capture. The conversion screen is exposed alone to the neutron-imaging beam; the film is not present. Candidate conversion materials include rhodium, gold, indium, and dysprosium. Indium and dysprosium are recommended with dysprosium yielding the greater speed and emitting less energetic gamma radiation. It is recommended that the conversion screens be activated in the neutron beam for a maximum of three half-lives. Further neutron irradiation will result in a negligible amount of additional induced activity. After irradiation, the conversion screens should be placed in intimate contact with a radiographic film in a vacuum cassette, or other light-tight assembly in which good contact can be maintained between the radiographic film and radioactive screen. X-ray intensification screens may be used to increase the speed of the autoradiographic process if desired. For the indirect type of exposure, the material from which the cassette is fabricated is immaterial as there are no neutrons to be scattered in the exposure process. In this case, as in the activation process, there is little to be gained for conversion screen-film exposures extending beyond three half-lives. It is recommended that this method be employed whenever the neutron beam is highly contaminated with gamma rays, which in turn cause film fogging and reduced contrast sensitivity, or when highly

**TABLE 2 Radioactive Sources Employed for Thermal Neutron Radiography**

| Source                                  | Type                | Half-Life  | Comments <sup>A</sup>  |
|---|---------------------|------------|--|
| <sup>124</sup> Sb-Be                    | (γ,n)               | 60 days    | short half-life and high γ-background, low neutron energy is advantage for moderation, high yield source |
| <sup>210</sup> Po-Be                    | (α,n)               | 138 days   | short half-life, low γ-background  |
| <sup>241</sup> Am-Be                    | (α,n)               | 458 years  | long half-life, easily shielded γ-background   |
| <sup>241</sup> Am- <sup>242</sup> Cm-Be | (α,n)               | 163 days   | short half-life, high neutron yield  |
| <sup>252</sup> Cf                       | spontaneous fission | 2.65 years | long half-life, high neutron yield, small size and low energy offer advantages in moderation             |

<sup>A</sup> These comments compare sources in the table.