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Standard Guide for Digital Neutron Radiography[1]

This standard is issued under the fixed designation E3398; 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 guide covers the evaluation, qualification, and quantification of digital neutron images. These images can be acquired by many methods, including: neutron sensitive imaging plates (Computed Radiography – CR), Digital Detector Arrays – DDA's (amorphous silicon, CMOS, CCD, etc.), micro-channel plates, neutron sensitive fluoroscopes, neutron sensitive scintillators coupled to optical cameras, digitized radiographic films, and linear diode arrays.

1.2 This guide does not purport to establish what is considered an acceptable image but is intended to only give guidance on digital neutron imaging, as well as image quality metrics of importance, and how they can be measured and reported.

1.3 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

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

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E94 Guide for Radiographic Examination Using Industrial Radiographic Film
E545 Test Method for Determining Image Quality in Direct Thermal Neutron Radiographic Examination
E748 Guide for Thermal Neutron Radiography of Materials
E803 Test Method for Determining the *L/D* Ratio of Neutron Radiography Beams
E1316 Terminology for Nondestructive Examinations
E1647 Practice for Determining Contrast Sensitivity in Radiology
E2007 Guide for Computed Radiography
E2597 Practice for Manufacturing Characterization of Digital Detector Arrays
E2736 Guide for Digital Detector Array Radiography
E2861 Test Method for Measurement of Beam Divergence and Alignment in Neutron Radiologic Beams

3. Terminology

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

4. Significance and Use

4.1 *Purpose*—Practices to be employed for the radiographic examination of materials and components with neutrons using digital neutron detectors are outlined herein. They are intended as a guide for the assessment of a digital neutron radiograph's characteristics. For information on neutron beam lines for imaging and film neutron radiography, refer to Guide E748.

4.2 *Limitations*—Acceptance standards have not been established for any material or production process. Neutron radiography, whether performed by means of a reactor, an accelerator, subcritical assembly, or radioactive source, will be consistent in sensitivity and spatial resolution only if the consistency of all details of the technique, such as neutron source, collimation, geometry, imaging system, etc., are maintained. This guide is limited to the use of digital neutron detectors in combination with neutron conversion materials for image recording. This guide is intended for use with thermal and cold neutron spectrums. The production of thermal neutron radiographs by employing the use of film and appropriate conversion screens is covered in Guide E748.

4.3 *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.

4.4 *Other Aspects of the Neutron Radiographic Process*—For many important aspects of neutron radiography such as

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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.

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.)

TEST METHODS

5. Background

5.1 Neutron radiography in industry has been performed predominately using single emulsion X-ray film and gadolinium conversion screens using the direct method. The development of standards may allow applications to move to digital neutron imaging methods. There are some drawbacks to using digital neutron imaging, such as the typically smaller field of view, high cost per detector, and the difficulty to simultaneously achieve a high spatial resolution and a large field of view. However, digital neutron imaging offers many advantages over film methods. These include:

5.1.1 Shorter exposure times,

5.1.2 Expanded bit-depth (increased contrast and latitude),

5.1.3 Post processing (artifact correction, normalization, and filtering),

5.1.4 Digital files (transport, duplication, and storage),

5.1.5 Possibility for higher spatial resolution (neutron microscopes, single-event imaging),

5.1.6 Dynamic (time-resolved) imaging,

5.1.7 Ability to obtain 3D information via tomography, and

5.1.8 Advanced techniques such as phase contrast imaging, spin-polarized imaging, time-of-flight imaging, and Bragg-edge imaging.

5.2 Neutrons are neutral particles that are challenging to detect. As a result, to image with thermal neutrons, the neutrons are absorbed (or scattered) to produce some other form of radiation that is more easily detected. With film imaging, a thin layer of a strong neutron absorber (such as gadolinium, boron, or indium) is generally employed to convert neutrons into radiation that can expose the film (such as electrons and photons). Similarly, most approaches used for digital X-ray imaging can be used to produce images from neutrons with the use of a suitable material to convert neutrons into a more detectable radiation. After this neutron conversion process, the image recording, advantages, and disadvantages for producing images will be similar to those of X-ray imaging with the same method. However, the neutron conversion process and the presence of multiple types of radiation add other factors that will affect the image.

5.3 Neutron imaging setups always have some gamma content as a result of neutron production and subsequent neutron interactions, as is discussed in Guide E748. The effect of this gamma radiation should be considered specifically with relation to the image acquisition method. In some cases, it may be possible for a digital imaging system to establish which detections are the result of gamma radiation and which are from neutrons, and so ignore the gamma detections. These systems, however, have too slow of count rates for practical imaging applications currently.

5.4 Though there are numerous methods that can be used to produce digital neutron images, two methods are used commonly; these are Computed Radiography and Camera-Based systems.

5.5 *Computed Radiography (CR) Systems:*

5.5.1 For general information on CR systems, refer to Guide E2007. Only elements unique to neutron CR (nCR) are discussed here.

5.5.2 X-ray CR (XCR) and nCR are fundamentally the same process, except that nCR includes the use of a neutron converter. Neutrons are not directly detectable by any reaction, and therefore must be converted to some other particle that is detectable, such as ionizing radiation (for example, beta particles, gamma-rays). The storage phosphor and scanner are the same for both XCR and nCR.

5.5.3 X-ray CR imaging plates (IP) are not efficient at detecting neutrons since they do not usually contain a significant amount of a strong neutron absorber. To overcome this, two approaches are utilized: (*1*) embedding a neutron converter in an imaging plate built specifically for neutron imaging, and (*2*) pressing a neutron converter against the surface of an X-ray imaging plate.

5.5.4 A strong neutron absorber (for example, gadolinium oxide, Gd_2O_3) can be mixed into the imaging plate's storage phosphor. By mixing the neutron absorber into the phosphor layer, radiation emitted in any direction from the conversion material can be recorded in the phosphor layer, which can improve efficiency, shorten exposure times, and potentially increase spatial resolution. The disadvantage of using imaging plates with embedded conversion materials is they are not widely available, have high cost, and generally lack durability compared to standard high-resolution X-ray imaging plates. Since the imaging plate is flexible, a flexible cassette can be used to allow imaging on a curved surface with reduced geometric unsharpness.

5.5.5 The second approach that can be utilized is to press a thin layer of a neutron converter (often 25 µm of gadolinium on an aluminum back plate) to the surface of an X-ray imaging plate, just like film neutron radiography. This approach allows the use of X-ray imaging plates and potentially the conversion screens and cassettes utilized for film neutron radiography. This approach has several limitations. Firstly, with the conversion screen on the surface, not more than half of the emissions from the conversion screen will be traveling towards the IP, limiting conversion efficiency. Secondly, the conversion screen is normally placed behind the CR IP. As a result, the neutrons pass through the IP before reaching the conversion screen. Since the IP is reasonably thick and hydrogenous this results in some neutron scattering.

5.5.6 Spatial resolution of nCR is limited by several factors, including:

(1) The laser spot size, laser power, pixel pitch, and raster rate of the scanner,

(2) Light diffusion in the imaging plate phosphor layer, and

(3) Thickness of the phosphor layer, and other factors that affect spatial resolution in all CR systems. If a neutron absorber is added to the phosphor layer it may affect the light spread.