Designation: E3375 – 23

Standard Practice for Cone Beam Computed Tomographic (CT) Examination[1]

This standard is issued under the fixed designation E3375; 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 computed tomography (CT) examination of components using cone beam systems. The purpose of this practice is to establish instruction, procedures, and equipment qualification to inspect a component for specified discontinuities.

1.2 This practice applies to systems with a Digital Detector Array (DDA) and an X-ray source. It does not cover the use of isotope sources.

1.3 There are sections in this practice that may require agreement between the purchaser and the supplier, or specific direction from the cognizant engineering organization (CEO). These items should be addressed in the purchase order or the contract. Generally, the items are application-specific, performance related, or both.

1.4 Applications for cone-beam CT are diverse. This practice is not intended to be limiting or restrictive. Refer to Guide E1441 for guidance on CT fundamentals and Guide E1672 for tradeoffs in selection of a CT system.

1.5 *Units*—The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.6 *This standard does not purport to address all of the safety concerns 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.* NCRP 144 or NIST Handbook 114, or both, may be used as guides to ensure that radiographic procedures are performed so that personnel shall not receive a radiation dosage exceeding the maximum permitted by the city, state, or national codes.

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

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E543 Specification for Agencies Performing Nondestructive Testing

E1316 Terminology for Nondestructive Examinations

E1441 Guide for Computed Tomography (CT)

E1672 Guide for Computed Tomography (CT) System Selection

E1695 Test Method for Measurement of Computed Tomography (CT) System Performance

E1817 Practice for Controlling Quality of Radiological Examination by Using Representative Quality Indicators (RQIs)

E2002 Practice for Determining Image Unsharpness and Basic Spatial Resolution in Radiography and Radioscopy

E2339 Practice for Digital Imaging and Communication in Nondestructive Evaluation (DICONDE)

E2597/E2597M Practice for Manufacturing Characterization of Digital Detector Arrays

E2698 Practice for Radiographic Examination Using Digital Detector Arrays

E2767 Practice for Digital Imaging and Communication in Nondestructive Evaluation (DICONDE) for X-ray Computed Tomography (CT) Test Methods

E3147 Practice for Evaluating DICONDE Interoperability of Nondestructive Testing and Inspection Systems

2.2 *ANSI Standards:*[3]

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

SNT-TC-1A Recommended Practice - Personnel Qualification and Certification in Nondestructive Testing

2.3 *ISO Standards:*[4]

ISO 9712 Non-destructive Testing - Qualification and Certification of NDT Personnel

[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 National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

[4] Available from International Organization for Standardization (ISO), ISO Central Secretariat, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, https://www.iso.org.

ISO/CIE 19476 Characterization of the Performance of Illuminance Meters and Luminance Meters

2.4 *AIA Standard:*[5]

NAS 410 National Aerospace Standard Certification and Qualification of Nondestructive Testing Personnel

2.5 *CEN Standard:*[6]

EN 4179 Aerospace Series - Qualification and Approval of Personnel for Non-destructive Testing

2.6 *Government Standards:*

NCRP 144 Radiation Protection for Particle Accelerator Facilities[7]

NIST Handbook 114 General Safety Standard for Installations Using Non-Medical X-ray and Sealed Gamma Ray Sources, Energies up to 10 MeV[8]

3. Terminology

3.1 *Definitions*—For definitions of terms related to CT used in this practice, refer to Terminology E1316.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *cone beam, n*—a beam of radiation that is restricted to two dimensions in an areal extent with the area covering the detector array.

3.2.2 *contrast-detail-diagram (CDD), n*—describes the minimum relative contrast (in %) of a circular indication, required for the perception by human operators as a function of the indication diameter in voxels in a 2D CT slice on a monitor (see Guide E1441 and Test Method E1695).

3.2.3 *contrast discrimination function (CDF), n*—describes the influence of image noise on the detectability of a feature in an elsewhere homogeneous material neighborhood as a function of the size of this feature in voxels.

3.2.4 *modulation transfer function (MTF), n*—describes the transfer of a spatial modulation in an image signal (relative intensity variation, here by a CT system) as a function of the modulation's spatial frequency

3.2.4.1 *Discussion*—SR_b^{image} in volume CT is corresponding MTF 10 % established as per Test Method E1695. If calculated value is given in *LP/mm*, conversion in $\mu m = ½ \times [(1 / (MTF\ value\ LP/mm)]$

3.2.5 *purchaser, n—as used within this document*, the purchaser of computed tomographic services refers to the entity that requires the computed tomographic services; the purchaser may be a part of the same organization as the supplier, or an outside organization.

3.2.6 *supplier, n—as used within this document*, the supplier of computed tomographic service refers to the entity that physically provides the computed tomographic services; the supplier may be a part of the same organization as the purchaser, or an outside organization.

[5] Available from Aerospace Industries Association (AIA), 1000 Wilson Blvd., Suite 1700, Arlington, VA 22209, http://www.aia-aerospace.org.

[6] Available from European Committee for Standardization (CEN), Avenue Marnix 17, B-1000, Brussels, Belgium, http://www.cen.eu.

[7] Available from National Council on Radiation Protection and Measurements (NCRP), https://ncrponline.org.

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

4. Significance and Use

4.1 The purpose of this practice is to establish instruction, procedures, and equipment qualification to inspect a component for specified discontinuities. This practice is written so it can be specified on the engineering drawing, specification, or contract. This practice requires a detailed procedure delineating the technique or procedure requirements and shall be approved by the Cognizant Engineering Organization (CEO).

4.2 The requirements in this practice shall be used when placing a CT system into NDT service and establishing a baseline of system performance measures. Monitoring the system performance over time shall be performed, including detector correction procedures, performance measurements, and system maintenance.

4.3 For CT examinations where specified discontinuities are not known/identified/requested/available (that is, engineering analysis, engineering information only), portions of Section 7 – 9 requirements do not necessarily apply. For these types of examinations, the purchase order or contract shall specify the development of a specific procedure, approved by purchaser and supplier, to specify the requirements of this practice to be incorporated into the examination.

5. Basis of Application

5.1 The following items are subject to contractual agreement between the parties using or referencing this practice.

5.1.1 *Personnel Qualification*—Personnel performing examinations to this practice shall be qualified in accordance with NAS410, EN 4179, ANSI/ASNT CP 189, ISO 9712, or SNT-TC-1A and certified by the employer or certifying agency as applicable. Other equivalent qualification documents may be used when specified on the contract or purchase order. The applicable revision shall be the latest unless otherwise specified in the contractual agreement between parties.

5.1.2 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 contract.

5.1.3 *Procedures and Techniques*—The procedures and techniques to be utilized shall be as specified in the contractual agreement.

5.1.4 *Reporting Criteria*—Reporting criteria for the examination results shall be in accordance with this standard practice unless otherwise specified.

5.1.5 *Acceptance Criteria*—Any acceptance criteria shall be specified in the contractual agreement.

6. Equipment

6.1 Many different CT system configurations are possible, and it is important that the user understands the advantages and limitations of each (see Guide E1441 and Test Method E1695).

6.2 All CT systems have four major subsystems: radiation source, radiation detectors, mechanical handling system, and computer system. The following represents considerations for each subsystem for a CT examination.

6.2.1 *Source Setup*—The radiation source shall be selected to provide the maximum signal-to-noise ratio (SNR) and

contrast to noise ratio (CNR) while maintaining the necessary spatial resolution. See Guide E1441 for a detailed discussion.

6.2.2 *Radiation Detection Systems*—The detection system shall consist of a two-dimensional array in an area detector. The more detectors used, the faster the required scan data can be collected; but there are important tradeoffs to be considered such as increased noise, increased data size, and decreased collimation abilities to reduce scatter radiation capture.

6.2.2.1 The detector cannot be operated without computing hardware and software for image acquisition.

6.2.2.2 The acquisition software shall be capable of acquiring images projection-by-projection from the detector and integrating or averaging frames, or both.

6.2.2.3 The acquisition software shall perform a detector correction to correct any inhomogeneities of the detector.

6.2.2.4 Users shall comply with the detector manufacturer's requirements of temperatures and humidity conditions for both operation and shipping.

6.2.2.5 The detector shall be corrected using the manufacturer's recommendation both for frequency of detector correction and the method used. Other detector correction methods are allowed as long as they are approved by the CEO.

6.2.2.6 The user shall ensure that all exposures are within the linear operating range of the detector, using either information obtained from the manufacturer or data obtained by the user/CEO.

6.2.3 *Manipulation System*—The manipulation system has the function of holding the test object to provide the necessary range of motions to position the test object between the radiation source and detector. This practice applies to scan motion geometries that are rotate-only motion or rotate-translate (helical). Other types of scan motion geometries may be used as agreed upon between user and CEO.

6.2.3.1 Users shall comply with the handling system manufacturer's requirements of weight, size, temperatures, and humidity conditions for both operation and shipping.

6.2.3.2 The handling system shall be calibrated using the manufacturer's recommendation both for frequency of calibration and the method used. Other calibration methods are allowed as long as they are approved by the CEO.

6.2.3.3 The geometric accuracy of the system shall be checked to ensure the source to detector distance (SDD) and the source to object distance (SOD) relation is within tolerance. A ball bar or other device with a known distance between at least two points may be used to calibrate the geometric accuracy. The resulting image measurement shall be within an established tolerance of the nominal geometry of the ball bar and approved by the CEO.

6.2.3.4 The user shall ensure that all exposures are within the X-ray cone beam envelope of the source-handling system, using either information obtained from the manufacturer or data obtained by the user/CEO. Source-handling systems that allow for offset scanning large components outside of the X-ray cone beam may be used as agreed upon by the user and CEO.

6.2.4 *Computer System(s)*—The computer system provides the operator interface and performs the tasks of acquisition, reconstruction, visualization, and storage. The system shall have the necessary storage and device interfaces to work with the system provided.

6.2.4.1 *Data Acquisition System*—Very large data sets are possible from high density pixel architectures with thousands of views. Therefore, the computer system shall have enough random-access memory (RAM) and hard drive space to accommodate and process this amount of data.

6.2.4.2 *Data Reconstruction System*—The acquired scan data may or may not be reconstructed on the same computer as described in 6.2.4.1. It is preferred to also have Graphical Processing Units (GPUs) to accelerate the compute intensive mathematical operations of CT reconstruction.

6.2.4.3 *Visualization System*—The reconstructed data may or may not be viewed on the same computer(s) as described in 6.2.4.1 and 6.2.4.2. This computer system shall be capable of displaying the CT data as described by the written procedure.

6.3 *System Software*—Acquisition and reconstruction software shall be established such that the scan data that is collected, can be readily reconstructed either while the scan is being collected, or very shortly after the scan is completed. If these two software modules are located on two separate computer systems, there shall be a high-speed link between the two.

6.3.1 *Acquisition Software*—Acquisition software shall be capable of modifying the projection data such as normalizing pixel gain and offset levels, and bad pixel correction.

6.3.2 *Reconstruction Software*—Reconstruction software shall include the reconstruction kernel, beam hardening corrections, reconstruction filters.

6.4 *Image Display*—The function of the image display is to convey derived information (that is, an image) of the test object to the system operator. For manual evaluation systems, the displayed image is used as the basis for accepting or rejecting the test object, subject to the operator's interpretation of the CT data.

6.4.1 Dust and dirt need to be kept to a minimum and the image display face needs to be cleaned often to prevent interference with interpretation.

6.5 *Data Storage Medium and Data Transfer*—A separate data storage system may be required to manage the massive amount of data that is collected over time. This storage system architecture is dependent on the amount of data and time that the data, be it the projection views or the reconstructed volumes, or both, and associated technique data need to be stored. This storage system is also dependent on whether the purchaser will manage the archival of data. If this is the case, there shall be an agreement between parties on how the data is transmitted to the purchaser. The reproduction quality of the archival method shall be sufficient to demonstrate the same image quality as was used to qualify the CT technique. For systems that are intended to be DICONDE compliant, the software shall be capable of storing and transferring data in accordance with Practices E2339, E3147, and E2767.

6.6 *Image Quality Indicators (IQIs) and Representative Quality Indicators (RQIs)*—IQIs or RQIs shall be used to

demonstrate the CT system's ability to detect discontinuities, indications, or flaws and to monitor the performance of a CT system over time.

6.6.1 *RQIs*—RQIs are used to validate the performance of a system to detect indications. RQIs shall be used as specified by the purchaser in the contractual agreement between purchaser and supplier in accordance with Practice E1817. A discussion on the use of RQIs is found in 8.3.

6.6.2 *Volumetric IQIs*—In some cases, it is impossible to fabricate the appropriate RQIs. Alternatively, additional phantoms may be needed to determine the quality of the CT system to detect the features of interest in each component. In these cases, a volumetric IQI may be fabricated representing the thickness of the component and the indications to be detected in that component. The RQI indication requirements of 8.3 shall be met in developing the Volumetric IQI. The placement of the IQI shall be as agreed upon between the user and the CEO.

6.6.3 *E1695 Rods*—Rod-like hardware is defined in Test Method E1695 and referred to as cylinders to measure the Modulation Transfer Function (MTF) and Contrast Discrimination Function (CDF) which depend on the voxel size and the cylinder diameter and other important attributes of a CT scan. Guide E1441 describes the determination of the Contrast Detail Diagram (CDD) as a combination of the MTF and CDF. The intersection point of the CDD and MTF informs on the minimum visible hole diameter in a slice for human interpreters (using the typical physiological factor, c, in the range of 2-5). The selection of the size, material, and quality of the phantom is discussed in Test Method E1695. It is not necessary to obtain a size of rod that matches the diameter of the component under test. As stated in Test Method E1695, a rod that is on the order of a 2 half-value layer (HVL) thickness of the planned inspection is adequate, and the rod shall be long enough to project the greater of 80 % of the detector height, or equal to the component's ROI height as projected onto the detector at its highest rotational magnification.

6.6.4 *Duplex Wire Gage (DWG) for $SR_b^{detector}$*—The duplex wire quality indicator is specified in Practice E2002 for the measurement of $SR_b^{detector}$.

6.7 *System Maintenance*—Periodic maintenance shall be performed in accordance with the manufacturer's requirements. Other maintenance routines may be used as agreed upon between the user and the CEO.

7. Equipment Qualification and Long-term Stability Tests

7.1 Documentation of the initial equipment qualification shall be kept on file for the life of the system as well as all subsequent re-qualifications.

7.1.1 Initial system qualification (or detector replacement) shall include: a $SR_b^{detector}$ measurement (see Practice E2597/E2597M).

7.1.2 An overall system requalification shall be required when:

(1) The DDA, X-ray generator, X-ray tube, or other component(s) affecting image quality is repaired or replaced.

(2) Changes are made to image acquisition software, reconstruction software, or processing software where any of these has an impact on image or measurement quality.

(3) Image display monitors are repaired or replaced.

(4) The system is moved.

7.2 For initial equipment qualification, long-term stability tests (as defined in Table 1) and a baseline shall be established.

7.2.1 The data for qualification shall be acquired at a frequency defined by contracting parties to assure consistent results are achieved over the span of a series of thirty (30) stability tests conducted over a minimum of thirty (30) days of data.

7.2.2 Tolerances for long-term stability tests requiring the use of statistical process control (SPC) shall be established when the system is considered stable and in control. To facilitate setting tolerances on these metrics, it is recommended to scan the baseline using the image quality metrics and scan-to-scan variability to establish baseline metrics as agreed upon between the user and the CEO. The system may be used during the initial SPC data collection period with the approval of the CEO.

7.3 Documentation of the long-term stability tests shall be made available upon request.

7.4 Upon system requalification, the system shall be verified that it is within established SPC limits. If new baseline or limits are required, the relevant changes and the impact they have to any previous techniques shall be understood and approved by the Radiographic Level III.

7.5 See Table 1 for the list of long-term stability tests. Alternate tests or frequencies may be used with CEO approval.

7.5.1 *Spatial Resolution*—The spatial resolution for the long-term stability tests shall be measured according to Test

TABLE 1 Long-term Stability Tests for CT – Minimum Frequency

Type	Frequency		
	Weekly (or before use)	Monthly	Semi-Annually
MTF_{10} (SR_b^{image})	x		
CDF	x		
Offset Level (mean)	x		
Offset Variation (STDev)	x		
Corrected Image Level (mean)	x		
Corrected Image Variation (STDev)	x		
Image Display[A]	x	x	
Ambient Light[A]			x

[A] See Practice E2698.