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

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This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This practice is for computed tomography (CT), which may be used to nondestructively disclose physical features or anomalies within a test object by providing radiological density and geometric measurements. This practice implicitly assumes the use of penetrating radiation, specifically X-ray and γ-ray.

1.2 CT systems utilize a set of transmission measurements made along paths through the test object from many different directions. Each of the transmission measurements is digitized and stored in a computer, where they are subsequently reconstructed by one of a variety of techniques. A treatment of CT principles is given in Guide E1441.

1.3 CT is broadly applicable to any material or test object through which a beam of penetrating radiation passes. The principal advantage of CT is that it provides densitometric (that is, radiological density and geometry) images of thin cross sections through an object without the structural superposition in projection radiography.

1.4 This practice describes procedures for performing CT examinations. This practice is to address the general use of CT technology and thereby facilitate its use.

1.5 *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.* For specific safety statements, see Section 8, NBS Handbook 114, and Federal Standards 21 CFR 1020.40 and 29 CFR 1910.96.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E1316 Terminology for Nondestructive Examinations

E1441 Guide for Computed Tomography (CT) Imaging

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

2.2 *NIST Standard:*

ANSI N43.3 General Radiation Safety Installations Using Non-Medical X-Ray and Sealed Gamma Sources up to 10 MeV[3]

2.3 *Federal Standards:*[4]

21 CFR 1020.40 Safety Requirements of Cabinet X Ray Systems

29 CFR 1910.96 Ionizing Radiation

2.4 *ASNT Documents:*[5]

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

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

2.5 *Military Standard:*

MIL-STD-410 Nondestructive Testing Personnel Qualification and Certification[4]

2.6 *AIA Standard:*

NAS-410 Certification and Qualification of Nondestructive Testing Personnel[6]

3. Terminology

3.1 *Definitions*—For definitions of terms used in this guide, refer to Terminology E1316 and Annex A1 in Guide E1441.

4. Summary of Practice

4.1 Requirements in this practice are intended to control the reliability and quality of the CT images.

4.2 CT systems are made up of a number of subsystems; the function served by each subsystem is common in almost all CT scanners. Section 7 describes the following subsystems:

4.2.1 Source of penetrating radiation,

4.2.2 Radiation detector or an array of detectors,

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

[4] Available from Standardization Documents Order Desk, DODSSP, Bldg. 4, Section D, 700 Robbins Ave., Philadelphia, PA 19111-5098, http://dodssp.daps.dla.mil.

[5] Available from American Society for Nondestructive Testing (ASNT), P.O. Box 28518, 1711 Arlingate Ln., Columbus, OH 43228-0518, http://www.asnt.org.

[6] Available from Aerospace Industries Association of America, Inc. (AIA), 1000 Wilson Blvd., Suite 1700, Arlington, VA 22209-3928, http://www.aia-aerospace.org.

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

4.2.3 Mechanical scanning assembly, and

4.2.4 Computer system including:

4.2.4.1 Image reconstruction software/hardware,

4.2.4.2 Image display/analysis system,

4.2.4.3 Data storage system, and

4.2.4.4 Operator interface.

4.3 Section 8 describes and defines the procedures for establishing and maintaining quality control of CT services.

4.4 The extent to which a CT image reproduces an object or a feature within an object is influenced by spatial resolution, statistical noise, slice plane thickness, and artifacts of the imaging system. Operating parameters should strike an overall balance between image quality, inspection time, and cost. These parameters should be considered for CT system configurations, components, and procedures. The setting and optimization of CT system parameters is discussed in Section 9.

4.5 Methods for the measurement of CT system performance are provided in Section 10 of this practice.

5. Significance and Use

5.1 This practice is applicable for the systematic assessment of the internal structure of a material or assembly using CT technology. This practice may be used for review by system operators, or to prescribe operating procedures for new or routine test objects.

5.2 This practice provides the basis for the formation of a program for quality control and its continuation through calibration, standardization, reference samples, inspection plans, and procedures.

6. Basis of Application

6.1 This practice provides the approach for performing CT examinations. Supplemental information covering specific items where agreement between supplier[7] and purchaser[8] are necessary is required. Generally the items are application specific or performance related, or both. Examples include: system configuration, equipment qualification, performance measurement, and interpretation of results.

7. System Configuration

7.1 Many different CT system configurations are possible and it is important to understand the advantages and limitations of each. It is important that the optimum system parameters be selected for each examination requirement, through a careful analysis of the benefits and limitations of the available system components and the chosen system configuration.

7.2 *Radiation Sources*—While the CT systems may utilize either gamma-ray or X-ray generators, the latter is used for most applications. For a given focal spot size, X-ray generators (that is, X-ray tubes and linear accelerators) are several orders of magnitude more intense than isotope sources. Most X-ray generators are adjustable in peak energy and intensity and have the added safety feature of discontinued radiation production when switched off; however, the polychromaticity of the energy spectrum from an X-ray source causes artifacts such as beam hardening (the anomalous decreasing attenuation toward the center of a homogeneous object) in the image if uncorrected.

7.2.1 X-rays produced from electrical radiation generators have focal spot sizes ranging from a few millimetres down to a few micrometres. Reducing the focal spot size reduces geometric unsharpness, thereby enhancing detail sensitivity. Smaller focal spots permit higher spatial resolution, but at the expense of reduced X-ray beam intensity.

7.2.2 A radioisotope source can have the advantages of small physical size, portability, low power requirements, simplicity, and stability of output. The disadvantages are limited intensity and limited peak energy.

7.2.3 Synchrotron Radiation (SR) sources produce very intense, naturally collimated, narrow bandwidth, tunable radiation. Thus, CT systems using SR sources can employ essentially monochromatic radiation. With present technology, however, practical SR energies are restricted to less than approximately 20 to 30 keV. Since any CT system is limited to the inspection of samples with radio-opacities consistent with the penetrating power of the X-ray employed, SR systems can in general image only small (about 1 mm) objects.

7.3 *Radiation Detection Systems*—The detection system is a transducer that converts the transmitted radiation containing information about the test object into an electronic signal suitable for processing. The detection system may consist of a single sensing element, a linear array of sensing elements, or an area array of sensing elements. The more detectors used, the faster the required scan data can be collected; but there are important tradeoffs to be considered.

7.3.1 A single detector provides the least efficient method of collecting data but entails minimal complexity, eliminates detector cross talk and detector matching, and allows an arbitrary degree of collimation and shielding to be implemented.

7.3.2 Linear arrays have reasonable scan times at moderate complexity, acceptable cross talk and detector matching, and a flexible architecture that typically accommodates good collimation and shielding. Most commercially available CT systems employ a linear array of detectors.

7.3.3 An area detector provides a fast method of collecting data but entails the transfer and storage of large amounts of information, forces tradeoffs between cross talk and detector efficiency, and creates serious collimation and shielding challenges.

7.4 *Manipulation System*—The manipulation system has the function of holding the test object and providing the necessary range of motions to position the test object between the radiation source and detector. Two types of scan motion geometries are most common: translate-rotate motion and rotate-only motion.

7.4.1 With translate-rotate motion, the object is translated in a direction perpendicular to the direction and in the plane of the X-ray beam. Full data sets are obtained by rotating the test

[7] 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.

[8] As used within this document, the purchaser of computed tomographic services refer 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.

object between translations by the fan angle of the beam and again translating the object until a minimum of 180 degrees of data have been acquired. The advantage of this design is simplicity, good view-to-view detector matching, flexibility in the choice of scan parameters, and ability to accommodate a wide range of different object sizes including objects too big to be subtended by the X-ray fan. The disadvantage is longer scan time.

7.4.2 With rotate-only motion, a complete view is collected by the detector array during each sampling interval. A rotate-only scan has lower motion penalty than a translate-rotate scan and is attractive for industrial applications where the part to be examined fits within the fan beam and scan speed is important.

7.4.3 In volume CT, a complete data set for the entire part is acquired in at least one rotation. This allows for much faster data acquisition, as the data required for multiple slices can be acquired in one rotation.

7.5 *Computer System*—CT requires substantial computational resources, such as a large capacity for image storage and archival and the ability to efficiently perform numerous mathematical computations, especially for the back-projection operation. Computational speed can be augmented by either generalized array processors or specialized back-projection hardware. The particular implementations will change as computer hardware evolves, but high computational power will remain a fundamental requirement for efficient CT examination. A separate workstation for image analysis and display often is appropriate.

7.6 *Image Reconstruction Software*— The aim of CT is to obtain information regarding the nature of material occupying exact positions inside a test object. In current CT scanners, this information is obtained by "reconstructing" individual cross-sections of the test object from the measured intensity of X-ray beams transmitted through that cross section. An exact mathematical theory of image reconstruction exists for idealized data. This theory is applied although the physical measurements do not fully meet the requirements of the theory. When applied to actual measurements, algorithms based on this theory produce images with blurring and noise, the extent of which depends on the quantity and quality of the measurements.

7.6.1 The simplifying assumptions made in setting up the theory of reconstruction algorithms are: (*1*) cross sections are infinitely thin (that is, they are planes), (*2*) both the source focal spot and the detector elements are infinitely small (that is, they are points), (*3*) the physical measurements correspond to total attenuation along the line between the source and detector, and (*4*) the radiation is, or can be treated as, effectively monoenergetic. A reconstruction algorithm is a collection of step-by-step instructions that define how to convert the measurements of total attenuation to a map of linear attenuation coefficients over the field of view.

7.6.2 A number of methods for recovering an estimate of the cross section of an object have evolved. They can be broadly grouped into three classes of algorithms: matrix inversion methods, finite series-expansion methods, and transform methods. See Guide E1441 for treatment of reconstruction algorithms.

7.6.3 If the test object is larger than the prescribed field of view (FOV), either by necessity or by accident, unexpected and unpredictable artifacts or a measurable degradation of image quality can result.

7.7 *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.

7.7.1 Generally, CT image display requires a special graphics monitor; television image presentation is of lower quality but may be acceptable. Most industrial systems utilize color displays. These units can be switched between color and gray-scale presentation to suit the preference of the viewer, but it should be noted that gray-scale images presented on a color monitor are not as sharp as those on a gray-scale monitor. The use of color permits the viewer to distinguish a greater range of variations in an image than gray-scale does. Depending on the application, this may be an advantage or a disadvantage. Sharply contrasting colors may introduce false, distinct definition between boundaries. While at times advantageous, unwanted instances can be corrected through the choice of color (or monochrome) scale.

7.8 *Data Storage Medium*—Many CT applications require an archival-quality record of the CT examination. This could be in the form of raw data or reconstructed data. Therefore, formats and headers of digital data need to be specified so information can be retrieved at a later date. Each archiving system has its own specifics as to image quality, archival storage properties, equipment, and media cost. Computer systems are designed to interface to a wide variety of peripherals. As technology advances or needs change, or both, equipment can be easily and affordably upgraded. The examination record archiving system should be chosen on the basis of these and other pertinent parameters, as agreed upon by the supplier and purchaser of CT services. The reproduction quality of the archival method should be sufficient to demonstrate the same image quality as was used to qualify the CT system.

7.9 *Operator Interface*—The operator interface determines much of the function of the rest of the CT system. The control panel and image display system are the two significant subsystems affected. The control software, hardware mechanisms, and interface to a remote data workstation if applicable, are among those controlled by this interface. Override logic, emergency shutdown, and safety interlocks are also controlled at this point. There are three types of operator interfaces.

7.9.1 A simple programming console interface, where the operator types in commands on a keyboard. While being less "user friendly," this type can offer the greatest range of flexibility and versatility.

7.9.2 The dedicated console with specific function buttons and relatively rigid data and processing features. These systems are usually developed explicitly for standardized, non-varying examination tasks. They are designed to be "functionally hardwired" for efficient throughput for that program. Medical CT equipment is often of this type.