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Standard Guide to Test Methods and Standards for Nondestructive Testing of Advanced Ceramics[1]

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1. Scope

1.1 This guide identifies and describes standard procedures and methods for nondestructive testing of advanced ceramics using radiology, ultrasonics, liquid penetrants, and acoustic emission.

1.2 This guide is to identify existing standards for nondestructive testing that have been determined to be (or have been modified to be) applicable to the examination of advanced ceramics. These standards have been generated by, and are under the jurisdiction of, ASTM Committee E-7 on Nondestructive Testing. Selection and application of these standards to be followed must be governed by experience and the specific requirements in each individual case, together with agreement between producer and user.

1.3 The values stated in SI units are to be regarded as the standard. The inch-pound units given in parentheses are for information only.

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

2. Referenced Documents

2.1 *ASTM Standards:*

E 94 Guide for Radiographic Testing[2]
E 114 Practice for Ultrasonic Pulse-Echo Straight-Beam Examination by the Contact Method[2]
E 165 Test Method for Liquid Penetrant Examination[2]
E 317 Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Testing Systems Without the Use of Electronic Measurement Instruments[2]
E 494 Practice for Measuring Ultrasonic Velocity in Materials[2]
E 569 Practice for Acoustic Emission Monitoring of Structures During Controlled Stimulation[2]
E 587 Practice for Ultrasonic Angle-Beam Examination by the Contact Method[2]
E 650 Guide for Mounting Piezoelectric Acoustic Emission Sensors[2]
E 664 Practice for Measurement of the Apparent Attenuation of Longitudinal Ultrasonic Waves by Immersion Method[2]
E 750 Practice for Characterizing Acoustic Emission Instrumentation[2]
E 797 Practice for Measuring Thickness by Manual Ultrasonic Pulse-Echo Contact Method[2]
E 976 Guide for Determining the Reproducibility of Acoustic Emission Sensor Response[2]
E 999 Guide for Controlling the Quality of Industrial Radiographic Film Processing[2]
E 1000 Guide for Radioscopy[2]
E 1065 Guide for Evaluating Characteristics of Ultrasonic Search Units[2]
E 1079 Practice for Calibration of Transmission Densitometers[2]
E 1106 Method for Primary Calibration of Acoustic Emission Sensors[2]
E 1165 Test Method for Measurement of Focal Spots of Industrial X-Ray Tubes by Pinhole Imaging[2]
E 1208 Test Method for Fluorescent Liquid Penetrant Examination Using the Lipophilic Post-Emulsification Process[2]
E 1209 Test Method for Fluorescent Liquid Penetrant Examination Using the Water-Washable Process[2]
E 1210 Test Method for Fluorescent Liquid Penetrant Examination Using the Hydrophilic Post-Emulsification Process[2]
E 1219 Test Method for Fluorescent Liquid Penetrant Examination Using the Solvent-Removable Process[2]
E 1220 Test Method for Visible Penetrant Examination Using the Solvent-Removable Process[2]
E 1254 Guide for Storage of Radiographs and Unexposed Industrial Radiographic Films[2]
E 1255 Practice for Radioscopy[2]
E 1316 Terminology for Nondestructive Examinations[2]
E 1324 Guide for Measuring Some Electronic Characteristics of Ultrasonic Examination Instruments[2]
E 1390 Guide for Illuminators Used for Viewing Industrial Radiographs[2]
E 1411 Practice for Qualification of Radioscopic Systems[2]
E 1441 Guide for Computed Tomography (CT) Imaging[2]

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

E 1453 Guide for Storage of Media That Contains Analog or Digital Radioscopic Data[2]

E 1570 Practice for Computed Tomographic (CT) Examination[2]

E 1647 Practice for Determining Contrast Sensitivity in Radioscopy[2]

E 1672 Guide to Computed Tomography (CT) System Selection[2]

E 1695 Test Method for Measurement of Computed Tomography (CT) System Performance[2]

E 1781 Practice for Secondary Calibration of Acoustic Emission Transducers[2]

E 1817 Practice for Controlling Quality of Radiological Examination by Using Representative Quality Indicators (RQIs)[2]

3. Terminology

3.1 *Definitions*—For definitions of terms used in this guide, refer to Terminology E 1316, Section F for liquid penetrants, Section I for ultrasonics, Section D for radiology, and Section B for acoustic emission.

4. Significance and Use

4.1 This guide is a compilation of standards intended to provide assistance in selecting appropriate nondestructive examination for advanced ceramics, and in turn, to provide guidance for performing the examination, as well as ensuring the proper performance of the equipment.

5. Apparatus

5.1 Use the equipment as specified in each standard.

6. Radiology

6.1 *Terminology*:

6.1.1 Terminology E 1316, Section D, covers the consensus definitions used to describe the various aspects of radiology of materials.

6.1.2 *Significance and Use*—The identification and use of common terms and definitions are necessary to ensure proper communication between producers, examiners, and users of both nondestructive examination equipment and techniques and advanced ceramics.

6.2 Practice E 1079 covers the calibration of transmission densitometers used to perform radiographic film density measurements.

6.2.1 *Summary of Practice*—Practice E 1079 describes the necessary apparatus (film strips and instrument), measurement procedure, recording requirements, and periods of verification for calibrating transmission densitometers.

6.2.2 *Significance and Use*—Attaining proper film density is important to the establishment of valid radiographic film. Practice E 1079 provides a means of evaluating the reliability of transmission densitometers used for the measurement of radiographic film density. The test is not intended to qualify the radiographs measured by transmission densitometers calibrated in accordance with this practice.

6.3 Guide E 1000 is a guide for tutorial purposes only and outlines the general principles of radioscopic imaging. This guide describes practices and image quality measuring systems for real-time and near real-time non-film detection, display, and recording of radioscopic images. These images, used in materials inspection, are generated by penetrating radiation passing through the subject material and producing an image on the detecting medium. The image detection and display techniques are nonfilm, but the use of photographic film as a means for permanent recording of the image is not precluded.

6.3.1 *Summary of Guide*—Guide E 1000 outlines the practices for the use of radioscopic methods and techniques for materials examinations. It is intended to provide a basic understanding of the method and the techniques involved. The selection of an imaging device, radiation source, and radiological and optical techniques to achieve a specified quality in radioscopic images is described.

6.3.2 *Significance and Use*—Radioscopy is a versatile nondestructive means for examining an object. It provides immediate information regarding the nature, size, location, and distribution of imperfections, both internal and external. It also provides a rapid check of the dimensions, mechanical configuration, and the presence and positioning of components in a mechanism. It indicates in real-time the presence of structural or component imperfections anywhere in a mechanism or an assembly. Through manipulation, it may provide three-dimensional information regarding the nature, sizes, and relative positioning of items of interest within an object, and can be further employed to check the functioning of internal mechanisms. Radioscopy permits timely assessments of product integrity, and allows prompt disposition of the product based on acceptance standards. Although closely related to the radiographic method, it has much lower operating costs in terms of time, manpower, and material. Long-term records of the radioscopic image may be obtained through motion-picture recording (cinefluorography), video recording, or "still" photographs using conventional cameras. The radioscopic image may be electronically enhanced, digitized, or otherwise processed for improved visual image analysis or automatic, computer-aided analysis, or both.

6.4 Practice E 1255 provides application details for radioscopic examination using penetrating radiation. This includes real-time radioscopy and, for the purposes of this standard, radioscopy where the motion of the test object must be limited (commonly referred to as near-real-time radioscopy). Since the techniques involved and the applications for radioscopic examination are diverse, this practice is not intended to be limiting or restrictive, but rather to address the general applications of the technology and thereby facilitate its use.

6.4.1 The general principles discussed in Practice E 1255 apply broadly to penetrating radiation radioscopic systems. However, this document is written specifically for use with X-ray and gamma-ray systems.

6.4.2 *Summary of Practice*—Manual evaluation as well as computer-aided automated radioscopic examination systems are used in a wide variety of penetrating radiation examination applications. A simple manual evaluation radioscopic examination system might consist of a radiation source and a directly viewed fluorescent screen, suitably enclosed in a radiation-protective enclosure. At the other extreme, a complex automated radioscopic examination system might consist of an

X-ray source, a robotic test part manipulator, a radiation-protective enclosure, an electronic image detection system, a closed circuit television image transmission system, a digital image processor, a video display, and a digital image archiving system. All system components are supervised by the host computer, that incorporates the software necessary to not only operate the system components, but to make accept/reject decisions as well. Systems having a wide range of capabilities between these extremes can be assembled using available components. Guide E 1000 lists many different system configurations.

6.4.3 While Practice E 1255 outlines the approach to be taken in applying radioscopic real-time examination techniques, a supplemental document is required covering those areas where agreement between the provider[3] and user[4] of radioscopic examination services is required. Generally, those areas are application-specific and performance-related, covering such areas as system configuration, equipment qualification, performance measurement, and interpretation of results.

6.4.4 *Significance and Use*—As with conventional radiography, radioscopic examination is broadly applicable to any material or test object through which a beam of penetrating radiation may be passed and detected, including metals, plastics, ceramics, composites, and other nonmetallic materials. In addition to the benefits normally associated with radiography, radioscopic examination is a dynamic, filmless technique, allowing the test part to be manipulated and imaging parameters optimized while the test object is undergoing examination. Recent technological advances in the area of projection imaging, detectors, and digital image processing provide acceptable sensitivity for a wide range of applications.

6.5 Test Method E 1165 provides instructions for determining the length and width dimensions of line focal spots in industrial X-ray tubes (see Note 1). This determination is based on the measurement of an image of a focal spot that has been radiographically recorded with a "pinhole" projection/imaging technique.

NOTE 1—Line focal spots are associated with vacuum X-ray tubes whose maximum voltage rating does not generally exceed 500 kV.

6.5.1 Test Method E 1165 may not yield meaningful results on focal spots whose nominal size is less than 0.3 mm (0.011 in. (see Note 2)). This test method may also be used to determine the presence or extent of focal spot damage or deterioration that may have occurred due to tube age, tube overloading, and the like. This would entail the production of a focal spot radiograph (with the pinhole method) and an evaluation of the resultant image for pitting, cracking, and the like.

NOTE 2—The X-ray tube manufacturer may be contacted for nominal focal spot dimensions.

6.5.2 *Significance and Use*—One of the factors affecting the quality of a radiographic image is geometric unsharpness. The degree of geometric unsharpness is dependent upon the focal size of the radiation source, the distance between the source and the object to be radiographed, and the distance between the object to be radiographed and the film. This test method allows the user to determine the focal size of the X-ray source and to use this result to establish source-to-object and object-to-film distances appropriate for maintaining the desired degree of geometric unsharpness.

6.6 Guide E 999 establishes guidelines that may be used for the control and maintenance of industrial radiographic film processing equipment and materials. The provisions in this guide are intended to control the reliability of the chemical process only and are not intended for controlling the acceptability or quality of industrial radiographic films or of the materials or products radiographed.

6.6.1 *Summary of Guide*—Guide E 999 provides instructions for the mixing of radiographic processing chemicals for both manual and automatic processes and for their storage, replenishment, and cautions about temperature, deterioration, and contamination. Recommendations are provided for both manual and automated processing of film. Instructions are given for the activity testing of processing solutions and for maintenance of records.

6.6.2 *Significance and Use*—Effective use of these guidelines aids in controlling the consistency and quality of industrial radiographic film processing. Improper processing can obscure the desired radiographic detail even though the proper radiographic procedure may have been used. The necessity of applying specific control procedures such as those described in this guide is dependent, to a certain extent, on the degree to which a facility adheres to good processing practices as a matter of routine procedure.

6.7 Guide E 1254 covers the control and maintenance of industrial radiographs and unexposed films used for industrial radiography.

6.7.1 *Summary of Guide*—Guide E 1254 provides recommendations for storage of unexposed film including temperature and humidity for both opened and unopened containers. For completed radiographs, recommendations are relative to testing for proper processing to minimize aging stain, to enclosure (interleaving) materials, and to storage area conditions including air impurities, temperature, humidity, and fire resistance.

6.7.2 *Significance and Use*—Poor storage practice can render unexposed film unusable for radiography and exposed radiographs can become so degraded as to be uninterpretable for later reference. The provisions of Guide E 1254 are intended to control the quality of industrial radiographs and unexposed films only and are not intended for controlling the acceptability of the materials or products radiographed. The necessity for applying specific control procedures such as those described in this guide is dependent to a certain extent, on the degree to which a user adheres to good processing and storage practices as matter of routine procedure.

6.8 Guide E 1390 provides the recommended requirements for illuminators used for viewing film radiographs using transmitted light.

6.8.1 *Significance and Use*—The function of the illuminator

[3] As used within this guide, the provider of radioscopic services refers to the entity that physically provides the radioscopic services. The provider may be a part of the same organization as the user, or an outside organization.

[4] As used within this guide, the user of radioscopic services refers to the entity that requires the radioscopic services. The user may be a part of the same organization as the provider or an outside organization.

is to provide sufficient illumination and viewing capabilities to visually review industrial film radiographs by light transmitted through them for the purpose of identification and interpretation of images.

6.9 Practice E 1411 provides test and measurement details for measuring the performance of X-ray and Gamma ray radioscopic systems. Radioscopic examination applications are diverse. Therefore, system configurations are also diverse and constantly changing as the technology advances.

6.9.1 Practice E 1411 is intended as a means of initially qualifying and requalifying a radioscopic system for a specified application by determining its performance level when operated in a static mode. System architecture including the means of radioscopic examination record archiving and the method for making the accept/reject decision are also unique system features and their effect upon system performance must be evaluated.

6.9.2 The general principles, as stated in Practice E 1411, apply broadly to transmitted-beam penetrating radiation radioscopy systems. Other radioscopic systems, such as those employing neutrons and Compton back-scattered X-ray imaging techniques, are not covered as they may involve equipment and application details unique to such systems.

6.9.3 *Summary of Practice*:

6.9.3.1 Practice E 1411 provides a standardization procedure for the initial qualification and requalification of a radioscopic system to establish radioscopic examination capabilities for a specified range of applications.

6.9.3.2 Practice E 1411 is intended for use in association with a standard practice governing the use of radioscopic examination, such as Practice E 1255. (See 6.4.)

6.9.3.3 Practice E 1411 specifies the procedures to be used in determining the performance level of the radioscopic system. Unique system features, including component selection, system architecture, programmability and image archiving capabilities are important factors and are taken into account in this practice. The overall system performance level, as well as key system features, are to be recorded in a qualification document which shall qualify the performance level of the total radioscopic system.

6.9.4 *Significance and Use*:

6.9.4.1 As with conventional radiography, radioscopic examination is broadly applicable to the many materials and test object configurations which may be penetrated with X-rays or gamma rays. The high degree of variation in architecture and performance among radioscopic systems due to component selection, physical arrangement and test object variables, makes it necessary to establish the level of performance which the selected radioscopic system is capable of achieving in specific applications. The manufacturer of the radioscopic system, as well as the user, require a common basis for determining the performance level of the radioscopic system.

6.9.4.2 Practice E 1411 does not purport to provide a method to measure the performance of individual radioscopic system components which are manufactured according to a variety of industry standards. Practice E 1411 covers measurement of the combined performance of the radioscopic system elements when operated together as a functional radioscopic system.

6.9.4.3 Practice E 1411 addresses the performance of radioscopic systems in the static mode only. Radioscopy can also be a dynamic, real-time or near real-time examination technique which can allow test-part motion as well as parameter changes during the radioscopic examination process. The use of Practice E 1411 is not intended to be limiting concerning the use of the dynamic properties of radioscopy. Users of radioscopy are cautioned that the dynamic aspects of radioscopy can have beneficial as well as detrimental effects upon system performance and must be evaluated on a case-by-case basis.

6.9.4.4 The qualification procedures are intended to benchmark radioscopic system performance under selected operating conditions to provide a measure of system performance. Qualification shall not restrict operation of the radioscopic system at other radioscopic examination parameter settings which may provide improved performance on actual test objects.

6.9.4.5 Radioscopic system performance measured pursuant to Practice E 1411 does not guarantee the level of performance which may be realized in actual operation. The effects of test part-geometry and test part-generated scattered radiation cannot be reliably predicted by a standardized test. All radioscopic systems age and degrade in performance as a function of time. Maintenance and operator adjustments, if not correctly made, can adversely affect the performance of radioscopic systems.

6.9.4.6 The performance of the radioscopic system operator in manual and semi-automatic radioscopic systems is not taken into account in Practice E 1411 and can have a major effect upon radioscopic system performance. Operator qualifications are an important aspect of system operation and should be covered in a separate written procedure.

6.10 Guide E 1441 provides a tutorial introduction to the technology and terminology of CT. It deals extensively with the physical and mathematical basis of CT, discusses the basic hardware configuration of all CT systems, defines a comprehensive set of fundamental CT performance parameters, and presents a useful method of characterizing and predicting system performance. Also, extensive descriptions of terms and references to publications relevant to the subject are provided.

6.10.1 *Summary of Guide*—Computed tomography (CT) is a radiographic method that provides an ideal examination technique whenever the primary goal is to locate and size planar and volumetric detail in three dimensions. Because of the relatively good penetrability of X rays, as well as the sensitivity of absorption cross sections to atomic chemistry, CT permits the nondestructive physical and, to a limited extent, chemical characterization of the internal structure of materials. Also, since the method is X-ray based, it applies equally well to metallic and non-metallic specimens, solid and fibrous materials, and smooth and irregularly surfaced objects. When used in conjunction with other nondestructive evaluation (NDE) methods, such as ultrasound, CT data can provide evaluations of material integrity that cannot currently be provided nondestructively by any other means.

6.10.2 *Significance and Use*:

6.10.2.1 Guide E 1441 provides a tutorial introduction to the theory and use of computed tomography. Guide E 1441 begins with an overview intended for the interested reader with a general technical background. Subsequent, more technical sections describe the physical and mathematical basis of CT technology, the hardware and software requirements of CT equipment, and the fundamental measures of CT performance. Guide E 1441 includes an extensive glossary (with discussion) of CT terminology and an extensive list of references to more technical publications on the subject. Most importantly, Guide E 1441 establishes consensus definitions for basic measures of CT performance, enabling purchasers and suppliers of CT systems and services to communicate unambiguously with reference to a recognized standard. Guide E 1441 also provides a few carefully selected equations relating measures of CT performance to key system parameters.

6.10.2.2 Guide E 1441 is intended to satisfy two general needs for users of industrial CT equipment: (*1*) the need for a tutorial guide addressing the general principles of X-ray CT as they apply to industrial imaging; and (*2*) the need for a consistent set of CT performance parameter definitions, including how these performance parameters relate to CT system specifications. Potential users and buyers, as well as experienced CT inspectors, will find Guide E 1441 a useful source of information for determining the suitability of CT for particular examination problems, for predicting CT system performance in new situations, and for developing and prescribing new scan procedures.

6.11 Guide E 1453 provides for the control and maintenance of recorded and unrecorded media of analog or digital electronic data from industrial radioscopy.

6.11.1 *Significance and Use*:

6.11.1.1 The provisions of Guide E 1453 intended to control and maintain the quality of industrial electronic data from radioscopy and unrecorded media only and are not intended for controlling the acceptability of the materials or products examined. It is further intended that Guide E 1453 be used as an adjunct to Guide E 1000, Practice E 1255, and Terminology E 1316. (See 6.1, 6.3, and 6.4, respectively.)

6.11.1.2 The necessity for applying specific control procedures such as those described in Guide E 1453 is dependent to a certain extent on the degree to which the user adheres to good recording and storage practices as a matter of routine procedure.

6.12 Guide E-94 provides information for X-ray and gamma-ray radiographic examination as applied to industrial radiographic film recording.

6.12.1 *Summary of Guide*—The guide discusses preferred practice and incorporates a bibliography for additional information. It covers types of materials to be examined; radiographic examination techniques and production methods; radiographic film selection, processing, viewing and storage; and maintenance of inspection records.

6.12.2 *Significance and Use*—Guide E-94 is generally applicable to available materials, processes, and techniques where industrial X-ray films are used as the recording media. Radiography will be consistent in sensitivity and resolution only if the effects of all details of techniques such as geometry, film, filtration, viewing, etc., are properly established and maintained.

6.13 Practice E-1570 provides procedural information for performing computed tomographic examinations.

6.13.1 The CT systems addressed in this practice utilize a set of X-ray transmission measurements made along a set of paths through the test object for many different directions. Each of the transmission measurements is digitized and stored in a computer, where they are subsequently normalized, corrected, and reconstructed by one of a variety of techniques.

6.13.2 *Summary of Practice*

6.13.2.1 Practice E-1570 describes CT that can be used to establish procedures for nondestructive testing and evaluation. Requirements in this practice are intended to control the reliability and quality of the CT images.

6.13.2.2 CT systems are composed of a number of subsystems. The function served by each subsystem is common in almost all CT scanners. The practice describes the following subsystems: sources of penetrating radiation detector(s), mechanical scanning system, and computer system. The computer system includes image reconstruction software/hardware, image display/analysis system, data storage system, and operator interface.

6.13.2.3 The practice describes and defines the procedures for establishing and maintaining quality control of CT examination services.

6.13.2.4 The extent to which a CT image faithfully 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 are discussed in this practice. Also, provided are methods for the measurement of CT system performance.

6.13.3 *Significance and Use*—Practice E-1570 is applicable for the systematic assessment of the internal structure of a material or assembly. It may be used to prescribe CT operating procedures. It provides a basis for the formation of a program for quality control and its continuation through calibration, standardization, reference samples, inspection plans and procedures. Typical applications of this practice are expected to be for final acceptance examinations required by purchase order or specification.

6.14 Practice E–1647 covers the design and materials selection of a contrast sensitivity measuring gage used to determine the minimum change in material thickness of density that may be imaged without regard to spatial resolution limitations when using a radioscopic imaging system.

6.14.1 *Summary of Practice*—E-1647 provides fabrication details for the construction of contrast sensitivity measuring gages and a method for calculation of the resultant contrast sensitivity.

6.14.2 *Significance ad Use*—It is often useful to evaluate the contrast sensitivity of a penetrating radiation imaging system separately from spatial resolution measurements. Conventional image quality indicators (IQIs) combine the contrast sensitivity and resolution measurements into an overall performance figure of merit that is often inadequate to detect subtle changes in imaging system and performance. For example, in a high-contrast image, spatial resolution can degrade with almost no noticeable effect upon overall image quality. Similarly, in a application in which the imaging system provides a very sharp image, contrast can fade with little noticeable effect upon the overall image quality. These situations may develop and go unnoticed until the system performance deteriorates below acceptable image quality limits. The contrast sensitivity gage measures contrast sensitivity independent of the imaging system spatial resolution limitations. The thickness recess dimensions are large with respect to the spatial resolution limitations of most imaging systems. The measurements cited in E-1647 are appropriate of the qualification and performance monitoring of radiographic and radioscopic imaging systems. For ceramics or other nonmetallic materials, it will be necessary to establish equivalence to the selected material used for the gage.

6.15 E-1672 covers guidelines for translating application requirements into computed tomography (CT) system requirements/specifications and establishes a common terminology to guide both purchaser and supplier in the CT system selection process.

6.15.1 *Summary of Guide*—E-1672 describes the capabilities and limitations of the various CT subsystems and identifies the typical purchaser's examination requirements that must be met. These requirements factor into the system design. Some of the requirements identified are the ability to support the size and weight of the object to be examined; detection capability for size of flaws (both spatial resolution and contrast discrimination); dimensioning precision; artifact level; throughput; ease of use; and archival procedures. The guide also describes the tradeoff between the CT performance as required by the purchaser and the choice of system components and subsystems.

The guide also covers some management cost considerations as well as other recommendations related to the procurement of CT systems.

6.15.2 *Significance and Use*—Guide E-1672 will aid the purchaser in generating a CT system specification through the conversion of purchaser's requirements (for specific or general examination application) to system components for preparation of a useful specification for a CT system.

The guide is applicable to purchasers seeking CT scan services.

6.16 E-1695 provides instructions for determining the spatial and contrast sensitivity in X-ray and gamma-ray computed tomography (CT) images.

6.16.1 *Summary of Test Method*—The determination of spatial resolution and contrast sensitivity is based on examination of the CT image of a uniform disk of material. The spatial resolution measurement is derived from an image analysis of the sharpness at the edge of the disk. The contrast sensitivity measurement is derived from an image analysis of the statistical noise at the center of the disk.

6.16.2 *Significance and Use*

6.16.2.1 Two factors affecting the quality of a CT image are geometrical unsharpness and random noise. Geometrical unsharpness limits the spatial resolution of a CT system, i.e., its ability to image fine structural detail in an object. Random noise limits the contrast sensitivity of a CT system, i.e., its ability to detect the presence or absence of features in an object. E-1695 allows the purchaser or the provider of CT systems or services to measure and specify spatial resolution and contrast sensitivity.

6.16.2.2 E-1695 provides a method that is more quantitative and less susceptible to interpretation than alternative approaches because the required disk is easy to fabricate and the analysis is immune to cupping artifacts. The method may not yield meaningful results if the disk image occupies less than a significant fraction of the field of view.

6.17 Practice E 1817 describes methods of assessing the image quality for radiological examination of unique materials or processes, or both, for which conventional image quality indicators (IQIs), such as thin plaques containing holes or small-diameter wires, may be inadequate for controlling the quality and repeatability of radiological images. Where appropriate, representative quality indicators (RQIs) also may represent criteria levels for the acceptance or rejection of discontinuities whose images are displayed.

6.17.1 *Summary of Practice*—Practice E 1817 provides rationale for the use of RQIs as well as details for the design and use of RQIs.

6.17.2 *Significance and Use*:

6.17.2.1 The use of RQIs is a significant departure from standard practice in industrial radiology because the RQI is a custom design rather than a standard design and is dependent on the application, material, and process, and therefore, cannot be a simple plaque or wire. The use of an RQI provides documented evidence that radiological images have the level of quality necessary to reveal those nonconformances for which the parts are being examined by assuring adequate spatial resolution and contrast sensitivity in the areas of interest.

6.17.2.2 The designer also may use the RQI, when in compliance with the requirements of E 1817, to set accept or reject criteria, as applicable to the part designed.

7. Ultrasonics

7.1 *Terminology*:

7.1.1 See Terminology E 1316, Section I.

7.1.2 *Significance and Use*—The identification and use of common terms and definitions are necessary to ensure proper communication between producers, examiners, and users of both nondestructive examination equipment and techniques and advanced ceramics.

7.2 Guide E 1065 describes measurement procedures for evaluating certain characteristics of ultrasonic search units (also known as "transducers") that are used with ultrasonic examination instrumentation. This guide describes means for obtaining performance data that may be used to define the acoustic and electric responses of ultrasonic search units.

7.2.1 The procedures are designed to measure search units as individual components (separate from the ultrasonic test instrument) using commercial search unit characterization systems or using laboratory signal generators, oscilloscopes, and analyzers.

7.2.2 The procedures are applicable to manufacturing acceptance and incoming inspection of new search units or to periodic performance evaluation of search units throughout their service life.

7.2.3 The procedures in Annexes A1 through A6 of Guide E 1065 are generally applicable to ultrasonic search units operating within the 0.4 to 10 MHz range. Annex A7 is applicable to higher frequency immersion search unit evaluation. Annexes under development will be added to Guide E 1065 when approved and will apply to measurement of the sound field patterns from angle-beam and contact straight beam search units, alternative means for making measurements of characteristics, and the like.

7.2.4 *Summary of Guide*—Guide E 1065 defines equipment and procedures for measuring the acoustical and electrical characteristics of ultrasonic search units. Frequency response and bandwidth characteristics may be determined by one of two procedures for shock excitation and sinusoidal burst. Procedures for other acoustical properties include relative pulse-echo sensitivity, time response, and generated sound field. Electrical characteristics include complex electrical impedance and d-c resistance.

7.2.5 *Significance and Use*:

7.2.5.1 Guide E 1065 is intended to provide standardized procedures evaluating ultrasonic search units. It is not intended to define performance and acceptance criteria, but rather to provide data from which such criteria may be established.

7.2.5.2 These procedures are intended to evaluate the characteristics of single element piezoelectric search units designed for immersion, contact straight-beam, or contact angle-beam examinations.

7.2.5.3 Implementation may require more detailed procedural instructions in a format of the using facility.

7.2.5.4 The measurement data obtained may be employed by users of Guide E 1065 to specify, describe, or provide a performance criteria for procurement and quality assurance, or service evaluation of the operating characteristics of ultrasonic search units. All or portions of the guide may be used as determined by the user.

7.2.5.5 The measurements are made primarily under pulse-echo conditions. To determine the relative performance of a search unit as either a transmitter or a receiver may require additional tests.

7.2.5.6 While these procedures relate to many of the significant parameters, others that may be important in specific applications may not be treated. These might include power handling capability, breakdown voltage, wear properties of contact units, radio-frequency interference, and the like.

7.2.5.7 Care must be taken to ensure that comparative measurements are made and that users follow like procedures. These conditions specified or selected (if optional) may affect the test results and lead to apparent differences.

7.2.5.8 Interpretation of some test results, such as the shape of the frequency response curve, may be subjective. Small irregularities may be significant. Interpretation of the test results is beyond the scope of Guide E 1065.

7.2.5.9 Certain results obtained using the procedures outlined in Guide E 1065 may differ from measurements made with ultrasonic test instruments. These differences may be attributed to differences in the nature of the experiment or the electrical characteristics of the instrumentation.

7.2.5.10 The pulse generator used to obtain the frequency response and time response of the search unit must have a rise time, duration, and spectral content sufficient to excite the search unit over its full bandwidth, otherwise time distortion and erroneous results may result.

7.3 Practice E 317 describes procedures for evaluating the following performance characteristics of ultrasonic pulse-echo testing systems: horizontal limit and linearity; vertical limit and linearity; resolution-entry surface and far surface; sensitivity and noise; and accuracy of calibrated gain controls.

7.3.1 Ultrasonic test systems using pulsed-wave trains and A-scan presentation (radio frequency (rf or video)) may be evaluated. The procedures are applicable to shop or field conditions; additional electronic measurement instrumentation is not required.

7.3.2 Practice E 317 establishes no performance limits for test systems; if such acceptance criteria are required, these must be specified by the using parties.

7.3.3 The specific parameters to be evaluated, conditions and frequency of test, and report data required, must also be determined by the user.

7.3.4 This practice is intended primarily for the evaluation of a complete testing system, including search unit, instrument, interconnections, and fixtures. However, certain characteristics of the instrument alone can be determined within the limitations discussed.

7.3.5 Required test apparatus includes selected test blocks and a precision external attenuator (where specified) in addition to the system to be evaluated.

7.3.6 Precautions relating to the applicability of the procedures and interpretation of the results are included.

7.3.7 *Summary of Practice*:

7.3.7.1 A testing system to be evaluated comprises an ultrasonic pulse-echo instrument, search unit, interconnecting cables, and couplant; for immersion testing systems suitable fixturing is required.

7.3.7.2 Test conditions are selected that are consistent with the intended end-use of the inspection system, as determined by the user.

7.3.7.3 The ultrasonic response from appropriate test blocks is obtained, and presented in numerical or graphical form.

7.3.7.4 The test data can be used to characterize the related system parameters in accordance with user requirements.

7.3.8 *Significance and Use*:

7.3.8.1 Practice E 317 describes procedures applicable to both shop and field conditions. More comprehensive or precise measurements of the characteristics of complete systems and their components will generally require laboratory techniques and electronic equipment such as oscilloscopes and signal generators. Substitution of these methods is not precluded where appropriate; however, their usage is not within the scope of this practice.

7.3.8.2 Practice E 317 does not establish system acceptance limits, nor is it intended as a comprehensive equipment specification.

7.3.8.3 While several important characteristics are included, others of possible significance in some applications are not covered.

7.3.8.4 Since the parameters to be evaluated and the applicable test conditions must be specified, Practice E 317 should be prescribed only by those familiar with ultrasonic NDT technology and the required tests should be performed either by such a qualified person or under his supervision.

7.3.8.5 Implementation may require more detailed procedural instructions in the format of the using facility.

7.3.8.6 Selection of the specific tests to be made should be done cautiously; if the related parameters are not critical in the intended application, then their inclusion may be unjustified. For example, vertical linearity may be irrelevant for a "go/no-go" test with a flaw gate alarm, while horizontal linearity might be required only for accurate flaw-depth or thickness measurement from the CRT display.

7.3.8.7 No frequency of system evaluation or calibration is recommended or implied. This is the prerogative of the using parties and is dependent on application, environment, and stability of equipment.

7.3.8.8 Certain sections are applicable only to instruments having receiver gain controls calibrated in decibels (dB). While these may sometimes be designated "gain," "attenuator," or" sensitivity" on various instruments, the term "gain controls" is used in Practice E 317 in referring to those that specifically control instrument receiver gain but not including reject, electronic distance-amplitude compensation, or automatic gain control.

7.3.8.9 These procedures can generally be applied to any combination of instrument and search unit of the commonly used types and frequencies, and to most straight-beam testing, either contact or immersed. Certain sections are also compatible with angle-beam, wheel, delay-line, and dual-search unit techniques. Their use, however, should be mutually agreed upon and so identified in the test report.

7.3.8.10 The validity of the results obtained will depend on the precision of the CRT readings. This is assumed to be ±0.04 in. (±1 mm), yielding between 1 and 2 % of full scale (fs) readability for available instrumentation having suitable screen graticules and display sharpness.

7.4 Practice E 664 describes a procedure for measuring the apparent attenuation of ultrasound in materials or components with flat, parallel surfaces using conventional pulse-echo ultrasonic flaw detection equipment in which reflected indications are displayed on a cathode-ray tube in an A-scan presentation.

7.4.1 The measurement procedure in Practice E 664 is readily adaptable for the determination of relative attenuation between materials. For absolute (true) attenuation measurements, indicative of the intrinsic nature of the material, it is necessary to correct for specimen geometry, sound beam divergence, instrumentation, and procedural effects. These results can be obtained with more specialized ultrasonic equipment and techniques.

7.4.2 *Summary of Practice*—Practice E 664 describes a procedure for determining apparent attenuation by measuring the decay of multiple back reflections of longitudinal ultrasonic waves introduced into specimens with flat, parallel surfaces by the immersion technique.

7.4.3 *Significance and Use*:

7.4.3.1 The measurement of apparent attenuation in materials is useful in applications such as the comparison of heat treatments of different lots of material or the assessment of the degradation of materials due to environment.

7.4.3.2 Several different modes of wave vibration can be propagated in solids. Practice E 664 is concerned with the attenuation associated with longitudinal waves introduced into the specimen by the immersion method.

7.4.3.3 Practice E 664 allows for the comparison of the apparent attenuations of geometrically similar specimens.

7.4.3.4 For the determination of apparent attenuation, the procedures described herein are valid only for measurements in the far field of the ultrasonic beam.

7.5 Practice E 494 covers a test procedure for measuring ultrasonic velocities in materials with conventional ultrasonic pulse echo flaw detection equipment in which results are displayed on an A-scan cathode ray tube. This practice describes a method whereby unknown ultrasonic velocities in a material sample are determined by comparative measurements using a reference material whose ultrasonic velocities are accurately known.

7.5.1 *Summary of Practice*—Several possible modes of vibration can propagate in solids. The procedure in Practice E 494 is concerned with two velocities of propagation, namely those associated with longitudinal (v_1) and transverse (v_t) waves. The longitudinal velocity is independent of sample geometry when the dimensions at right angles to the beam are very large compared with beam area and wave length. The transverse velocity is little affected by physical dimensions of the sample.

7.5.2 *Significance and Use*:

7.5.2.1 Ultrasonic velocity measurements are useful for determining several important material properties. Young's modulus of elasticity, Poisson's ratio, acoustic impedance, and several other useful properties and coefficients can be calculated for solid materials with the ultrasonic velocities if the density is known as shown in Appendix X2 of Practice E 494.

NOTE 3—Factors including techniques, equipment, types of material, and operator variables will result in variations in absolute velocity readings, sometimes by as much as 5 %. Relative results with a single combination of the above factors can be expected to be much more accurate (probably within a 1 % tolerance).

7.5.2.2 More accurate results can be obtained with more specialized ultrasonic equipment, auxiliary equipment, and specialized techniques. Some of the supplemental techniques are described in Appendix X2 of Practice E 494.

7.6 Practice E 797 provides guidelines for measuring the thickness of materials using the contact pulse-echo method at temperatures not to exceed 200°F (94°C).

7.6.1 Practice E 797 is applicable to any material in which ultrasonic waves will propagate at a constant velocity throughout the part, and from which back reflections can be obtained and resolved.

7.6.2 *Summary of Practice*:

7.6.2.1 Thickness (*T*) when measured by the pulse-echo ultrasonic method is a product of the velocity of sound in the material and one-half of the transit time (round trip) through the material:

$$T = \frac{Vt}{2}$$

where:

T = thickness,
V = velocity, and
t = transit time.

7.6.2.2 The pulse-echo ultrasonic instrument measures the transit time of the ultrasonic pulse through the part.

7.6.2.3 The velocity in the material under test is a function of the physical properties of the material. It is usually assumed to be a constant for a given class of materials.

7.6.2.4 One or more reference blocks are required having known velocity, or of the same material to be tested and having thicknesses accurately measured and in the range of thicknesses to be measured. It is generally desirable that the thicknesses be "round numbers" rather than miscellaneous odd values. One block should have a thickness value near the maximum of the range of interest and another block near the minimum thickness.

7.6.2.5 The display element (CRT (cathode ray tube), meter, or digital display) of the instrument must be adjusted to present convenient values of thickness dependent on the range being used. The control for this function may have different names on different instruments, including range, sweep, material calibrate, or velocity.

7.6.2.6 The timing circuits in different instruments use various conversion schemes. A common method is the so-called time/analog conversion in which the time measured by the instrument is converted into a proportional d-c voltage which is then applied to the readout device. Another technique uses a very high-frequency oscillator that is modulated or gated by the appropriate echo indications, the output being used either directly to suitable digital readouts, or converted to a voltage for other presentation.

7.6.3 *Significance and Use*:

7.6.3.1 The techniques described in Practice E 797 provide indirect measurement of thickness of sections of materials not exceeding temperatures of 200°F (94°C). Measurements are made from one side of the object, without requiring access to the rear surface.

7.6.3.2 Ultrasonic thickness measurements are used extensively on basic shapes and products of many materials, on precision machined parts, and to determine wall thinning in process equipment caused by corrosion and erosion.

7.7 Practice E 114 covers ultrasonic examination of materials by the pulse-echo method using straight-beam longitudinal waves introduced by direct contact of the search unit with the material being examined and is applicable for the development of an examination procedure agreed upon by the users of this practice.

7.7.1 *Summary of Practice*:

7.7.1.1 A series of electrical pulses is applied to a piezoelectric element (transducer) that converts these pulses to mechanical energy in the form of pulsed waves at a nominal frequency. This transducer is mounted in a holder so it can transmit the waves into the material through a suitable wear surface and couplant. The assembly of transducer, holder, wearface, and electrical connector comprise the search unit.

7.7.1.2 Pulsed energy is transmitted into materials, travels in a direction normal to the contacted surface, and is reflected back to the search unit by discontinuity or boundary interfaces that are parallel or nearly parallel to the contacted surface. These echoes return to the search unit, where they are converted from mechanical to electrical energy and are amplified by a receiver. The amplified echoes (signals) are usually presented in an A-scan display on a cathode ray tube (CRT), such that the entire round trip of pulsed energy within the resolution of the system may be indicated along the horizontal base line of a CRT by vertical deflections corresponding to echo amplitudes from each interface, including those from intervening discontinuities. By adjustment of the sweep (range) controls, this display can be expanded or contracted to obtain a designated relation between the CRT signals and the material reflectors from which the signal originates. Thus, a scaled distance to a discontinuity and its displayed signal becomes a true relationship. By comparison of the displayed discontinuity signal amplitudes to those from a reference standard, both location and estimated discontinuity size may be determined. Discontinuities having dimensions exceeding the size of the sound beam can also be estimated by determining the amount of movement of a search unit over the examination surface where a discontinuity signal is maintained.

7.7.2 *Significance and Use*—Types of information that may be obtained from the pulsed-echo straight-beam practice are as follows:

7.7.2.1 Apparent discontinuity size (see Note 4) by comparison of the signal amplitudes from the test piece to the amplitudes obtained from a reference standard.

NOTE 4—The term "apparent" is emphasized since true size depends on orientation, composition, and geometry of the discontinuity and equipment limitations.

7.7.2.2 Depth location of discontinuities by calibrating the horizontal scale of the CRT screen.

7.7.2.3 Material properties as indicated by the relative sound attenuation or velocity changes of compared items.

7.7.2.4 The extent of bond and unbond (or fusion and lack of fusion) between two ultrasonic conducting materials if geometry and materials permit.

7.8 Practice E 587 covers ultrasonic examination of materials by the pulse-echo technique, using continuous coupling of angular incident ultrasonic vibrations.

7.8.1 *Summary of Practice*:

7.8.1.1 An electrical pulse is applied to a piezoelectric transducer that converts electrical to mechanical energy. In the angle-beam search unit, the transducer is generally a thickness expander that creates compressions and rarefactions. This longitudinal (compressional) wave travels through a wedge (generally a plastic). The angle between the transducer face and the examination face of the wedge is equal to the angle between the normal (perpendicular) to the examination surface and the incident beam.

7.8.1.2 When the examination face of the angle-beam search unit is coupled to a material, ultrasonic waves may travel in the material. The angle in the material (measured from the normal to the examination surface) and mode of vibration are dependent on the wedge angle, the ultrasonic velocity in the wedge, and the velocity of the wave in the examined material. When the material is thicker than a few wavelengths, the waves traveling in the material may be longitudinal and shear, shear alone, shear and Rayleigh, or Rayleigh alone. Total reflection may occur at the interface. In thin materials (up to a few wavelengths thick), the waves from the angle-beam search unit traveling in the material may propagate in different Lamb wave modes.

7.8.1.3 Practice E 587 describes the apparatus, calibration techniques, and examination techniques for generating and applying angle-beam longitudinal waves, angle-beam shear waves (transverse waves), surface waves, and Lamb waves.

7.8.2 *Significance and Use*:

7.8.2.1 All ultrasonic modes of vibration may be used for angle-beam examination of material. The material forms and the probable flaw locations and orientations determine selection of beam directions and modes of vibration. The use of angle beams and the selection of the proper wave mode presuppose a knowledge of the geometry of the object, the probable location, size, orientation, and reflectivity of the expected flaws; and the laws of physics governing the propagation of ultrasonic waves. Characteristics of the examination system used and the ultrasonic properties of the material being examined must be known or determined.

7.9 Guide E 1324 covers procedures for electronically measuring the following performance-related characteristics of some sections of ultrasonic instruments:

7.9.1 *Power Supply Section*:

7.9.1.1 Line regulation,

7.9.1.2 Battery discharge time, and

7.9.1.3 Battery charge time.

7.9.2 *Pulser Section*:

7.9.2.1 Pulse shape,

7.9.2.2 Pulse amplitude,

7.9.2.3 Pulse rise time, pulse length, and

7.9.2.4 Pulse frequency spectrum.

7.9.3 *Receiver Section*:

7.9.3.1 Vertical linearity,

7.9.3.2 Frequency response,

7.9.3.3 Noise and sensitivity, and

7.9.3.4 dB controls.

7.9.4 *Time Base Section*:

7.9.4.1 Horizontal linearity, and

7.9.4.2 Clock (pulse repetition rate).

7.9.5 *Gate/Alarm Section*:

7.9.5.1 Delay and width,

7.9.5.2 Resolution,

7.9.5.3 Alarm level,

7.9.5.4 Gain uniformity,

7.9.5.5 Analog output, and

7.9.5.6 Back echo gate.

7.9.6 Practice E 1324 complements Practice E 317 (see 7.3), and is not intended for evaluating the performance characteristics of ultrasonic examination instruments on the inspection/production line. No access to internal circuitry is required.

7.9.7 *Summary of Guide*—The electronic performance of each section is measured by identifying that portion of the electrical circuit of the instrument which comprises the section, applying the recommended stimulus or load, or both, and performing the required measurements using commercially available electronic test equipment. These data are then summarized in tabular or graphical form as performance-related values which can be compared with corresponding values of other ultrasonic examination instruments or of values for the same instrument obtained earlier.

7.9.8 *Significance and Use*:

7.9.8.1 The recommended measurement procedures described in Guide E 1324 are intended to provide performance-related measurements that can be reproduced under the specified test conditions using commercially available test instrumentation. These measurements indicate capabilities of sections of the ultrasonic examination instrument independent of specific transducers or examination conditions. Measurements are made from normally available connectors or test points so that no access to internal circuitry is required. Further, Guide E 1324 is not intended for service, calibration, or maintenance of circuitry for which the manufacturer's instructions are available. It is intended primarily for pulse echo flaw detection instruments operating in the nominal frequency range of 100 kHz to 25 MHz. Measurements on instruments utilizing significantly higher frequency components may require alternate techniques and instrumentation.

7.9.8.2 These procedures can be applied to the evaluation of any pulse-echo ultrasonic examination instrument which can be described as a combination of the electronic sections discussed in Guide E 1324.

7.9.8.3 An ultrasonic examination instrument that cannot be completely described as a combination of the electronic sections discussed in Guide E 1324 can be partially evaluated. Each portion of the ultrasonic examination instrument that is evaluated must fit the description for the corresponding section.

7.9.8.4 Guide E 1324 is meant to be used by electronic personnel to evaluate the electronic system components and not the ultrasonic system characteristics.

8. Liquid Penetrants

8.1 *Terminology*:

8.1.1 See Terminology E 1316, Section F.

8.1.2 *Significance and Use*—The identification and use of common terms and definitions are necessary to ensure proper communication between producers, examiners, and users of both nondestructive examination equipment and techniques and advanced ceramics.

8.2 Practice E 165 covers procedures for liquid penetrant inspection of materials.

8.2.1 *Summary of Practice*:

8.2.1.1 Liquid penetrant inspection methods provide a means for the detection of discontinuities that are open to the surface. In general, a liquid penetrant is applied evenly over the surface of the part being tested and allowed to enter discontinuities. After a suitable dwell time, the excess surface penetrant is removed and the part dried. A developer is then applied that draws the entrapped penetrant out of the discontinuity, staining the developer. The test part is then inspected visually to determine the presence or absence of indications.

8.2.1.2 The selection of a particular method and type of penetrant inspection procedure depends upon the nature of the application, conditions under which the inspection is to be performed, availability of processing equipment, and type of materials to perform the inspection.

8.2.1.3 Processing parameters, such as precleaning, penetration time, etc., are determined by the specific materials used, the nature of the part under inspection (that is, size, shape, surface condition, alloy), type of discontinuities expected, etc. Liquid penetrant inspection methods indicate the presence, location, and, to some extent, the nature and magnitude of the detected discontinuities.

8.2.2 *Significance and Use*—Liquid penetrant processes are nondestructive testing methods for detecting discontinuities that are open to the surface. They are applicable to in-process, final, and maintenance inspection. They can be effectively used in the inspection of nonporous metallic materials, both ferrous and nonferrous, and of nonporous, nonmetallic materials such as ceramics, plastics, and glass. Discontinuities open to the surface such as cracks, seams, laps, cold shuts, laminations, through leaks, or lack of fusion are indicated by these methods.

8.2.3 Practice E 165 also provides a reference for the following:

8.2.3.1 A reference by which the liquid penetrant inspection processes recommended or required by individual organizations can be reviewed to ascertain their applicability and completeness.

8.2.3.2 A reference for use in the preparation of process specifications dealing with the liquid penetrant inspection of materials and parts. Agreement by the purchaser and the manufacturer regarding specific techniques is strongly recommended.

8.2.3.3 A reference for use in the organization of the facilities and personnel concerned in the liquid penetrant inspection.

8.2.3.4 Practice E 165 does not indicate or suggest standards for evaluation of the indications obtained. It should be pointed out, however, that after indications have been produced, they must be interpreted or classified and then evaluated. For this purpose there must be a separate code or specification or a specific agreement to define the type, size, location, and direction of indications considered acceptable, and those considered unacceptable.

8.3 Five separate test methods for liquid penetrant examination have been recognized and documented to provide specific instructions for procedures. Review of the individual test methods should provide guidance for the selection and performance of a test method for application to a given advanced ceramic. The test methods also provide a reference by which specific processes recommended or required by individual organizations can be reviewed to ascertain applicability and completeness and for use in preparation of process specifications.

NOTE 5—Fluorescent penetrant examination should not follow a visible penetrant examination unless the procedure has been demonstrated and qualified, because visible dyes may cause deterioration or quenching of fluorescent dyes.

NOTE 6—Requirements for the developer step in the various test methods may be omitted by agreement between purchaser and supplier.

8.3.1 Test Method E 1208 covers procedures for fluorescent liquid penetrant examination using the lipophilic post-emulsification process.

8.3.1.1 *Summary of Test Method*—A post-emulsifiable, liquid fluorescent penetrant is applied evenly over the surface being tested and allowed to enter open discontinuities. After a suitable dwell time, the excess surface penetrant is removed by applying the lipophilic emulsifier and the part is water rinsed and dried. If an aqueous developer is to be employed, the developer is applied prior to the drying step. A developer is applied to draw the entrapped penetrant out of the discontinuity and stain the developer. The test surface is then examined visually using a black light in a darkened area to determine the presence or absence of indications.

8.3.1.2 *Significance and Use*—Liquid penetrant examination methods indicate the presence, location, and, to a limited extent, the nature and magnitudes of the detected discontinuities. This test method is normally used for production examination of critical components or structures when removal of excessive amounts of penetrant from discontinuities using a water-washable process can be a problem and when the use of a hydrophilic remover is impractical.

8.3.2 Test Method E 1209 covers procedures for water-washable fluorescent penetrant examination of materials.

8.3.2.1 *Summary of Test Method*—A liquid penetrant is applied evenly over the surface being tested and allowed to enter open discontinuities. After a suitable dwell time, the excess surface penetrant is removed with water and the surface is dried prior to the application of a dry or nonaqueous developer. A developer is then applied, drawing the entrapped penetrant out of the discontinuity and staining the developer. If an aqueous developer is to be employed, the developer is applied prior to the drying step. The test surface is then examined visually under black light in a darkened area to determine the presence or absence of indications.

8.3.2.2 *Significance and Use*—Liquid penetrant examination methods indicate the presence, location, and, to a limited extent, the nature and magnitude of the detected discontinuities. This test method is normally used for production inspection of large volumes of parts or structures, where emphasis is on productivity. This test method has a wide latitude in applicability when extensive and controlled conditions are available. Multiple levels of sensitivity can be achieved by proper selection of materials and variations in process.

8.3.3 Test Method E 1210 covers procedures for fluorescent penetrant examination using the hydrophilic post-emulsification process.

8.3.3.1 *Summary of Test Method*—A post-emulsifiable, liquid fluorescent penetrant is applied evenly over the surface being tested and allowed to enter open discontinuities. After a suitable dwell time and prerinse, the excess surface penetrant is removed by applying a hydrophilic emulsifier, and the surface is rinsed and dried. A developer is then applied, drawing the entrapped penetrant out of the discontinuity and staining the developer. If an aqueous developer is to be employed, the developer is applied prior to the drying step. The test surface is then examined visually under black light in a darkened area to determine the presence or absence of indications.

8.3.3.2 Processing parameters such as precleaning, penetration time, prerinsing, hydrophilic emulsifier concentration, etc., are determined by the specific materials used, the nature of the part under examination (that is, size, shape, surface condition), type of discontinuities expected, etc.

8.3.3.3 *Significance and Use*—Liquid penetrant examination methods indicate the presence, location, and, to a limited extent, the nature and magnitude of the detected discontinuities. This test method is normally used for production examination of critical components, where reproducibility is essential. More procedural controls and processing steps are required than with other processes.

8.3.4 Test Method E 1219 covers procedures for fluorescent penetrant examination using the solvent-removable process.

8.3.4.1 *Summary of Test Method*—A liquid fluorescent penetrant is applied evenly over the surface being tested and allowed to enter open discontinuities. After a suitable dwell time, the excess surface penetrant is removed with a solvent and the surface is dried prior to the application of a nonaqueous, wet, or liquid film developer. If an aqueous developer is to be employed, the developer is applied prior to the drying step. The developer draws the entrapped penetrant out of the discontinuity, staining the developer. The surface is then examined visually under black light to determine presence or absence of indications.

8.3.4.2 *Significance and Use*—Liquid penetrant examination methods indicate the presence, location, and, to a limited extent, the nature and magnitude of the detected discontinuities. This test method is intended primarily for portability and for localized areas of examination, utilizing minimal equipment, when a higher level of sensitivity than can be achieved using visible penetrants is required. Surface roughness may be a limiting factor. If so, an alternative process such as post-emulsified penetrant should be considered when grinding or machining is not practical.

8.3.5 Test Method E 1220 covers procedures for visible penetrant examination using the solvent-removable process.

8.3.5.1 *Summary of Test Method*—A liquid visible-dye penetrant is applied evenly over the surface being tested and allowed to enter open discontinuities. After a suitable dwell time, the excess surface penetrant is removed by wiping with a solvent and the surface is dried. If an aqueous developer is to be employed, the developer is applied prior to the drying step. A developer is then applied, drawing the entrapped penetrant out of the discontinuity, staining the developer. The test surface is then examined visually to determine the presence or absence of indications.

8.3.5.2 Processing parameters, such as precleaning, penetration time, etc., are determined by the specific materials used, the nature of the part under examination (that is, size, shape, surface condition), and type of discontinuities expected.

8.3.5.3 *Significance and Use*—Liquid penetrant examination methods indicate the presence, location, and, to a limited extent, the nature and magnitude of the detected discontinuities. This test method is intended primarily for portability and for localized areas of examination using minimal equipment. Surface roughness may be a limiting factor. If so, an alternate process, such as water-wash visible or post-emulsified penetrant, should be considered when grinding or machining is not practical.

9. Acoustic Emission (AE)

9.1 *Terminology*:

9.1.1 See Terminology E 1316, Section B.

9.1.2 *Significance and Use*—The identification and use of common terms and definitions are necessary to ensure proper communication between producers, examiners, and users of both advanced ceramics and nondestructive examination equipment and techniques.

9.2 Practice E 569 provides guidelines for acoustic emission examination or monitoring of structures that can be stressed by mechanical or thermal methods.

9.2.1 *Summary of Practice*—Acoustic emission examination of a structure usually requires application of a mechanical or thermal stimulus. Such stimulation produces changes in the stresses in the structure. During stimulation of a structure, AE from discontinuities (such as cracks and inclusions) and from other areas of stress concentration, or from other acoustic sources (such as leaks, loose parts, and structural motion) can be detected by an instrumentation system, using sensors which, when stimulated by stress waves, generate electrical signals.

9.2.2 *Significance and Use*—The basic functions of an AE monitoring system are to detect, locate, and classify emission sources. In addition to immediate evaluation of the emissions detected during the application of the stimulus, a permanent record of the number and location of emitting sources and the relative amount of AE detected from each source provides a basis for comparison with sources detected during the test and during subsequent stimulation.

9.3 Guide E 650 provides guidelines for mounting piezoelectric acoustic emission (AE) sensors.

9.3.1 *Summary of Guide*—This guide provides guidance on sensor selection, surface preparation, mounting fixtures, methods of ensuring adequate contact of the sensor with the interrogated surfaces (with pressure or coupling agents), and verification of response after mounting and activation of the sensor.

9.3.2 *Significance and Use*—The methods and procedures used in mounting AE sensors can have significant effects upon the performance of those sensors. Optimum and reproducible detection of AE requires both appropriate sensor-mounting fixtures and consistent sensor-mounting procedures.

9.4 Practice E 750 is used for testing and measuring operating characteristics of acoustic emission electronic components or units.

9.4.1 *Summary of Practice*—This practice identifies the electronic instruments and describes the procedures for determining instrumentation bandwidth, frequency response, gain, noise level, threshold level, dynamic range, signal overload, dead time, and counter accuracy of AE equipment.

9.4.2 *Significance and Use*—This practice is intended for application to periodic calibration or usage in the event of a malfunction of AE instrumentation. It is not intended for frequent, routine checks of the instrumentation.

9.5 Guide E 976 is used for determining the reproducibility of response of acoustic emission sensors.

9.5.1 *Summary of Guide*—This guide defines simple economical procedures for testing or comparing the performance of acoustic emission sensors. The procedures allow the user to check for degradation of a sensor or to select sets of sensors with nearly identical performances.

9.5.2 *Significance and Use*—Acoustic emission data is affected by several characteristics of the instrumentation. The most obvious of these is the system sensitivity. Of all the parameters and components contributing to the sensitivity, the acoustic emission sensor is the one most subject to variation. This variation can be a result of damage or aging, or there can be variations between nominally identical sensors. To detect such variations, it is desirable to have a method for measuring the response of a sensor to an acoustic wave. Specific purposes for checking sensors include: (*1*) checking the stability of its response with time; (*2*) checking the sensor for possible damage after accident or abuse; (*3*) comparing a number of sensors for use in a multichannel system to ensure that their responses are adequately matched; and (*4*) checking the response after thermal cycling or exposure to a hostile environment. It is very important that the sensor characteristics be always measured with the same sensor cable length and impedance as well as the same preamplifier or equivalent. This guide presents several procedures for measuring sensor response. Some of these procedures require a minimum of special equipment. The procedures are not capable of providing an absolute calibration of the sensor nor do they ensure transferability of data sets between organizations.

9.6 Method E 1106 covers the requirements for the absolute calibration of AE sensors.

9.6.1 *Summary of Method*—This method describes apparatus and procedures for measuring the frequency response of a sensor to waves, at a surface, of the type normally encountered in AE work. The transducer voltage response is determined at discrete frequency intervals of approximately 10 kHz up to 1 MHz. The input is a given, well–established displacement normal to the mounting surface.

9.6.2 *Significance and Use*:

9.6.2.1 *Transfer Standards*—One purpose of this method is for the direct calibration of displacement transducers for use as secondary standards for the calibration of AE sensors for use in nondestructive evaluation. For this purpose, the transfer standard should be high fidelity and very well-behaved and understood. If this can be established, the stated accuracy should apply over the full frequency range up to 1 MHz.

9.6.2.2 *Application Sensors*—This method may also be used for the calibration of AE sensors for use in nondestructive evaluation. Some of these sensors are less well-behaved than devices suitable for a transfer standard. The stated accuracy for such devices applies in the range from 100 kHz to 1 MHz and with less accuracy below 100 kHz.

9.7 Practice E 1781 covers requirements for the secondary calibration of AE sensors.

9.7.1 *Summary of Test Method*—The procedures in this practice for secondary calibration yield the frequency response of a sensor to waves of the type normally encountered in acoustic emission work. The source producing the signal used for the calibration is mounted on the same surface of the test block as the sensor under testing (SUT). Rayleigh waves are dominant under these conditions; the calibration results represent primarily the sensor's sensitivity to Rayleigh waves. The sensitivity of the sensor is determined for excitation within the range from 100 kHz to 1MHz. Sensitivity values are usually determined at frequencies approximately 10 kHz apart. The units of the calibration are volts per unit of mechanical input (displacement, velocity, or acceleration).

9.7.2 *Significance and Use*—The purpose of this practice is to enable the transfer of calibration from sensors that have been calibrated by primary calibration to other sensors.

10. Keywords

10.1 acoustic emission; advanced ceramics; equipment calibration; flaw detection; liquid penetrants; measurement of properties; nondestructive testing; radiography; radiology; ultrasonics