Designation: E 1935 – 97 (Reapproved 2003)

Standard Test Method for Calibrating and Measuring CT Density[1]

This standard is issued under the fixed designation E 1935; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers instruction for determining the density calibration of X- and γ-ray computed tomography (CT) systems and for using this information to measure material densities from CT images. The calibration is based on an examination of the CT image of a disk of material with embedded specimens of known composition and density. The measured mean CT values of the known standards are determined from an analysis of the image, and their linear attenuation coefficients are determined by multiplying their measured physical density by their published mass attenuation coefficient. The density calibration is performed by applying a linear regression to the data. Once calibrated, the linear attenuation coefficient of an unknown feature in an image can be measured from a determination of its mean CT value. Its density can then be extracted from a knowledge of its mass attenuation coefficient, or one representative of the feature.

1.2 CT provides an excellent method of nondestructively measuring density variations, which would be very difficult to quantify otherwise. Density is inherently a volumetric property of matter. As the measurement volume shrinks, local material inhomogeneities become more important; and measured values will begin to vary about the bulk density value of the material.

1.3 All values are stated in SI units.

1.4 *This standard does not purport to address 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 1316 Terminology for Nondestructive Examinations[2]
E 1441 Guide for Computed Tomography (CT) Imaging[2]
E 1570 Practice for Computed Tomographic (CT) Examination[2]

3. Terminology

3.1 *Definitions*:

3.1.1 The definitions of terms relating to CT, that appear in Terminology E 1316 and Guide E 1441, shall apply to the terms used in this test method.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *density calibration*—calibration of a CT system for accurate representation of material densities in examination objects.

3.2.2 *effective energy*—the equivalent monoenergetic energy for a polyenergetic CT system. Thus, the actual, polyenergetic CT system yields the same measured attenuation coefficient for an examination object as a theoretical, monoenergetic CT system at the effective energy.

3.2.3 *phantom*—a part or item being used to calibrate CT density.

3.2.4 *examination object*—a part or specimen being subjected to CT examination.

4. Basis of Application

4.1 The procedure is generic and requires mutual agreement between purchaser and supplier on many points.

5. Significance and Use

5.1 This test method allows specification of the density calibration procedures to be used to calibrate and perform material density measurements using CT image data. Such measurements can be used to evaluate parts, characterize a particular system, or compare different systems, provided that observed variations are dominated by true changes in object density rather than by image artifacts. The specified procedure may also be used to determine the effective X-ray energy of a CT system.

5.2 The recommended test method is more accurate and less susceptible to errors than alternative CT-based approaches, because it takes into account the effective energy of the CT system and the energy-dependent effects of the X-ray attenuation process.

5.3 This (or any) test method for measuring density is valid only to the extent that observed CT-number variations are reflective of true changes in object density rather than image artifacts. Artifacts are always present at some level and can masquerade as density variations. Beam hardening artifacts are

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[1] This test method 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] *Annual Book of ASTM Standards*, Vol 03.03.

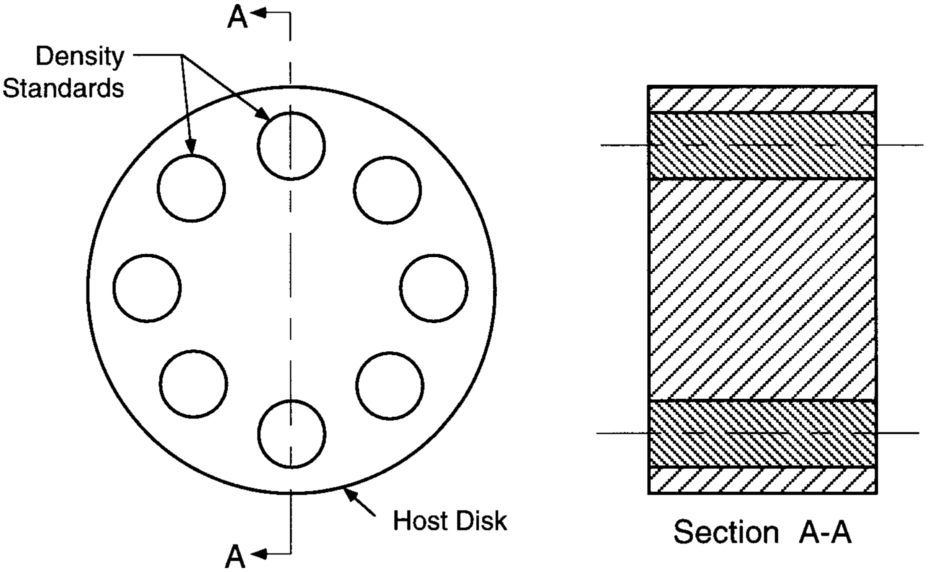

FIG. 1 Density Calibration Phantom

particularly detrimental. It is the responsibility of the user to determine or establish, or both, the validity of the density measurements; that is, they are performed in regions of the image which are not overly influenced by artifacts.

5.4 Linear attenuation and mass attenuation may be measured in various ways. For a discussion of attenuation and attenuation measurement, see Guide E 1441 and Practice E 1570.

6. Apparatus

6.1 Unless otherwise agreed upon between the purchaser and supplier, the density calibration phantom shall be constructed as follows (see Fig. 1):

6.1.1 A selection of density standards bracketing the range of densities of interest shall be chosen. For best results, the materials should have known composition and should be physically homogeneous on a scale comparable to the spatial resolution of the CT system. It is a good idea to radiographically verify homogeneity and to independently verify chemical composition. All materials should be manufactured to reproducible standards. Solids should be readily machinable and not susceptible to surface damage.

6.1.2 One or more cylinders of each density standard shall be machined or prepared, or both. Selecting cylinders over rectangles reduces the uncertainties and streaks that sharp corners have on volumetric determination and verification methods. The cylinders should be large enough that the mean CT number corresponding to each standard can be computed over a hundred or more uncorrupted (see 8.1.3) pixels but small enough relative to the dimensions of the host disk that radial effects are minimal.

6.1.3 The physical density of each density standard shall be determined empirically by weighing and measuring the specimens as accurately as possible. It is a good idea to independently verify the measured densities using volumetric displacement methods.

6.1.4 The mass attenuation coefficient, μ/ρ, at the effective energy of the system (see 8.3) shall be determined from a reference table. For compounds, μ/ρ can be obtained by taking the weighted sum of its constituents, in accordance with the following equation:

$$\mu_m = \mu/\rho = \sum_i w_i (\mu/\rho)_i \tag{1}$$

where:

w_i = the weight fraction of the ith elemental component.

6.1.5 For each density standard, the measured density, ρ, shall be multiplied by its corresponding mass attenuation coefficient, μ/ρ, as determined in 6.1.4. The linear attenuation coefficient, μ, thus obtained shall be permanently recorded for each density calibration standard.

6.1.6 A host disk to hold the density standards shall be fabricated. The opacity of the disk should approximate the attenuation range of the examination objects. If possible, the host disk should be of the same material as the examination objects, but other requirements take precedence and may dictate the selection of another material.

6.2 In general, it is very difficult to find acceptable materials for density standards. Published density data are generally not reliable enough for calibration purposes. Homogeneity often varies on a local scale and negatively influences the calibration procedure. Machine damage can increase the density at the surface of a sample, making it difficult to determine the density of the interior material crucial to the calibration process. Lot-to-lot variations in composition or alloy fraction can make it difficult to compute mass attenuation coefficients. For these and other reasons, development of a good density calibration phantom takes effort, resources and a willingness to iterate the selection and production of standards until acceptable results are obtained.

6.2.1 Liquids make the best standards, because they can be precisely controlled and measured. However, liquids require special handling considerations, are sensitive to temperature variations, and often tend to precipitate, especially high-concentration aqueous solutions. It is hard to find organic