

American National Standard for Evaluating the Image Quality of X-ray Computed Tomography (CT) Security-Screening Systems

Accredited by the American National Standards Institute

Sponsored by the
National Committee on Radiation Instrumentation, N42

IEEE
3 Park Avenue
New York, NY 10016-5997
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ANSI N42.45-2011

23 May 2011

American National Standard for Evaluating the Image Quality of X-ray Computed Tomography (CT) Security-Screening Systems

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Secretariat

Institute of Electrical and Electronics Engineers, Inc.

Approved 26 January 2011

American National Standards Institute

Abstract: Test methods and test articles for the evaluation of the image quality of CT security-screening systems are provided. The quality of data for automated analysis is the primary concern. This standard does not address the system's ability to use its image data to automatically detect explosives or other threat materials, which is typically verified by an appropriate regulatory body.

Keywords: ANSI N42.25, computed tomography, contraband, detection, explosives, image quality, luggage, screening, security

The Institute of Electrical and Electronics Engineers, Inc.
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PDF: ISBN 978-0-7381-6651-3 STD97144
Print: ISBN 978-0-7381-6652-0 STDPD97144

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Contents

1. Overview	1
1.1 Scope	1
1.2 Purpose	1
2. Normative references.....	2
3. Definitions	3
4. General test-performance requirements.....	3
5. Description of the test articles	4
6. Test procedures for image quality	6
6.1 General	6
6.2 Manually recorded data	7
6.3 Object length accuracy	10
6.4 Path length CT value and Z_{eff}	14
6.5 Noise equivalent quanta (NEQ).....	16
6.6 CT value consistency	18
6.7 Z_{eff} and CT value uniformity	19
6.8 Streak artifacts	22
6.9 Slice sensitivity profile (SSP).....	24
6.10 Image registration.....	26
Annex A (informative) Bibliography	31
Annex B (normative) Detailed test article drawings	32
B.1 General.....	32
B.2 Commercial parts	32
B.3 Outer case modifications.....	32
B.4 Detailed drawings of custom components	34
Annex C (informative) Sample report	44
C.1 General.....	44

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1. Overview

1.1 Scope

This standard provides test methods for the evaluation of image quality of computed tomography (CT) security-screening systems. The quality of data for automated analysis is the primary concern. This standard does not address the system’s ability to use this image data to automatically detect explosives or other threat materials, which is typically verified by an appropriate regulatory body.

1.2 Purpose

Security screening systems are generally used to scan parcels, including luggage, for the presence of illicit items such as explosives, drugs, or other contraband. Many of the screening systems currently used, particularly in transportation security applications, are based on CT imaging technology. Generally, as the parcel is transported through the system, the system collects a CT image of the parcel. These data are then subjected to automated analysis to determine whether a threat may be present or the parcel is considered clear. If the automated analysis determines a threat may be present, the image is often presented to a system operator who can override the automated decision, clearing the parcel, or referring it for further processing such as opening it and manually searching for threats.

Historically, government regulators have established evaluation procedures to determine whether a system’s automated detection performance is adequate for use in applications within their borders. Typically, a vendor submits a copy of their product, including their software to the regulator’s facility. The regulator runs a wide variety of parcels with threats inside through the system as well as parcels without threats that represent the typical stream of commerce. Detection and false alarm rates are determined and compared against performance criteria. If the criteria are met, the system is approved for use. This testing

assures that the system is capable of meeting the required criteria, but how does one assure that all copies of the system meet the criteria? Normal manufacturing variability, quality control issues, or aging of the equipment may degrade performance versus what was observed on the article tested by the regulator. Replicating the original test on each machine in question is impractical. Transporting the regulator's threat set to a factory site or to locations where the machines are in use, presents significant security and in some cases safety concerns. This standard seeks to address this issue by specifying a suite of test methods that can be carried out on site without need for hazardous materials.

The performance testing carried out by the regulators essentially evaluates the combination of the system's ability to produce an image of the parcel along with its automatic analysis of that image data to reach a decision of threat or clear. The second part of this sequence, the analysis, is implemented through software. It should be noted that the regulators generally require that this software be designed so as to NOT evolve through use. The software used at all locations in the field must perform the same as the software did at the time of evaluation by the regulator. Configuration management of such software is a well known and straightforward art. Therefore, the real opportunity for performance variation comes from the imaging system that provides the data to the analysis software. If one can quantitatively validate that the quality of the image produced by the system in question is statistically equivalent to the image produced by the article evaluated by the regulator, one can be highly confident that the performance of the system in question is the same as what was approved by the regulator.

Purchasers of CT systems for security screening applications are generally not CT experts. Inconsistencies in methods for measuring seemingly standard image quality values (resolution, signal-to-noise, etc.) can confuse the potential user of such CT systems. Other standards exist for testing aspects of CT image quality, particularly in the medical field. This standard specifies a set of methods to apply in assessing CT image quality geared towards security screening. An application of this standard would be in the factory acceptance testing of equipment. The standard could be used to indicate whether the unit offered for sale produces the equivalent image quality as the unit that was tested by the cognizant regulatory agency. Since various image quality metrics can be traded off against one another and achieve similar levels of threat detection, it is generally not valid, in contrast to medical CT, to make model-to-model or manufacturer-to-manufacturer comparisons of individual test results for CT systems used for security-screening.

This standard does not address image quality presented to the operator. The image quality provided to the operator is not necessarily at the same level as that used by the automated analysis. The data may be degraded before presenting to the operator to decrease resources required for rendering the image on the screen. Conversely, the data used in the automated analysis may be intentionally degraded to control the computational loading of the analysis computer. The user of this standard may want to separately assess the quality of the images presented to the system's operator. A wide range of methods is available for this purpose including the use of visual line pair gauges and ASTM F792-08 [B1].¹

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in the text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ASTM E1695-95 (2006), Standard Test Method for Measurement of Computed Tomography (CT) System Performance.²

ASTM D6100-05, Standard Specification for Extruded, Compression Molded and Injection Molded Acetal Shapes (POM).

¹ The numbers in brackets correspond to those of the bibliography in Annex A.

² ASTM publications are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA (<http://www.astm.org/>).

3. Definitions

For the purposes of this standard, the following terms and definitions apply. *The IEEE Standards Dictionary: Glossary of Terms & Definitions* should be referenced for terms not defined in this clause.³

computed tomography (CT): The process of making a three-dimensional image of a volume based on two-dimensional projection data.

CT value: Value reported by CT systems on a per voxel basis that is a function of the material's density and atomic number.

coronal image: An image produced by summing a volume along the y-axis.

NOTE— As defined in Figure 1.⁴

effective atomic number (Z_{eff}): A material property that represents the atomic number of a theoretical element that, if the material were replaced by the element, would produce the same x-ray attenuation characteristics.

multi-energy: An x-ray imaging system that collects image data at more than one x-ray energy spectrum. This can be accomplished, for example, by varying the x-ray tube voltage, using an energy discriminating detector, or using multiple sets of detectors with differing energy response.

projection image: An x-ray image created by detecting the x-ray intensity transmitted through the subject, resulting in an image in which all the subject's components appear to be projected onto a single image plane.

registration: The spatial relationship between the coordinate systems of multiple imaging subsystems. It determines the ability to accurately correlate observations from one image to the others.

slice: A cross sectional image of the inspected object. The normal of the plane of the image is in the direction of the z-axis (direction of belt motion).

standard mode of operation: A mode of operation normally recommended by the manufacturer for inspection of parcels. Some systems have special modes for collecting extra data for training. This would not be considered a standard mode of operation.

test article: An item, to be imaged by the system, containing multiple test objects in a specific geometric layout.

NOTE—As used in this standard, test article refers to the specific items defined in Clause 5.

test object: An individual object having specific properties (size, shape, materials, etc.) that when imaged by the system allows a certain image quality evaluation to be carried out.

voxel: A volume element representing a rectangular prism-shaped region in space within a volumetric image.

4. General test-performance requirements

These tests shall be conducted under ambient temperature and humidity conditions defined as $23^{\circ}\text{C} \pm 5^{\circ}\text{C}$ ($73.4^{\circ}\text{F} \pm 9^{\circ}\text{F}$) and non-condensing humidity. The temperature and relative humidity should be reported with the testing results.

If performance is required outside of the above specified environmental conditions, the user should not assume that reported image quality performance metrics are equivalent to those reported under ambient conditions. The user may wish to require testing outside of ambient conditions or request engineering analysis to gauge performance in the field.

³ *The IEEE Standards Dictionary: Glossary of Terms & Definitions* is available at <http://shop.ieee.org/>.

⁴ Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

System components and adjustments should be as for the standard commercial product in normal security screening operation mode; any deviations shall be noted by the evaluators in the manually recorded data. If the system is approved to operate under more than one configuration, the user may want to request the test be carried out at all appropriate settings. Evaluation is to be based on images or other data normally used in standard mode of operation. The exposure time and level shall be chosen as that used when the CT system is operated for the intended use in the security screening application. A calibration of the CT system shall be carried out prior to any testing. Any recalibration of the CT system shall be allowed according to the standard operation of the system. In order to assure that the system is using a configuration approved by the appropriate regulatory agency, the user may wish to request that the vendor provide the specific settings used during the evaluation such as: tube voltage(s), amperage, voxel size, belt speed, etc.

The test articles (see Clause 5) shall be presented to the system in a controlled position and orientation. The main axis of each test article should be parallel to the conveyor belt motion direction and the front of the article shall enter the system first (front designated via labeling). The test method described in 6.3 determines the angle of rotation and side to side offset of the test articles relative to the center line of the system conveyor. Results for rotations more than 2 degrees off parallel from conveyor center line shall be rejected. This standard requires that the test articles be measured at the center of the belt, directly on the belt, within ± 2 cm of the conveyor center line. If the user decides to also run the test articles off center line, the parallel requirement shall still be met, and the data shall be segregated and treated separately.

For reference, Figure 1 shows the coordinate system that shall be used for all procedure descriptions. The z axis is aligned along the direction of the conveyor motion. The y axis is in the vertical direction and the x axis is across the belt. The positive/negative direction of the axis system is immaterial as used in this standard.

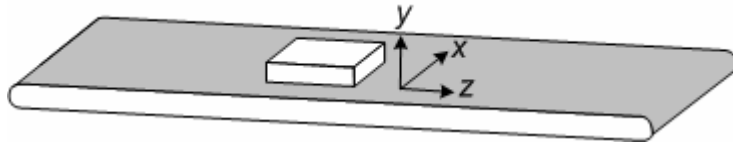


Figure 1—Reference axes for procedures

Not all the methods stated are applicable to all CT systems. Each method shall identify whether it is applicable to all CT types or only a subset.

Each of the test methods specified in this standard can include required procedures and examples of optional techniques for achieving the required results. This is necessary because of the range of implementations used in security CT equipment. Each test method identifies where latitude for deviation from the analysis techniques exists. Any deviation from provided example techniques shall be documented including rationale for deviating from the suggested standard method of analysis. Such documentation shall be provided to the end user of the image quality evaluation.

5. Description of the test articles

Execution of this standard requires two test articles. They are designated “test article A” and “test article B,” and are represented in Figure 2 and Figure 3. The articles consist of several test objects supported in a machined frame within a commercial carrying case. The placement of the test objects has been selected to minimize artifacts from one test object interfering with the image of another test object. Additionally, the commercial cases have been modified to eliminate unnecessary artifacts (steel hinge pins replaced with plastic, some reinforcing structures have been machined off, etc.)

When fabricating test articles for use in this standard, the test objects and the supporting structural frame shall be built in accordance with the detailed drawing package included in Annex B. The outer case may be

selected for durability. It shall be large enough to contain the specified support structure. The case shall be modified to remove any metal structures (hinges, handles, fasteners, etc.) from the sides, top and bottom. (Removing structures on the front and back surfaces is optional.) Also, the case shall be modified to remove any significant plastic structure along the sides, top, and bottom that might interfere with the imaging of the test object.

The outer case shall be outfitted with appropriate low-density foam inserts to hold the test article support structure firmly in place, parallel to the bottom plane of the case and aligned with its centerline.

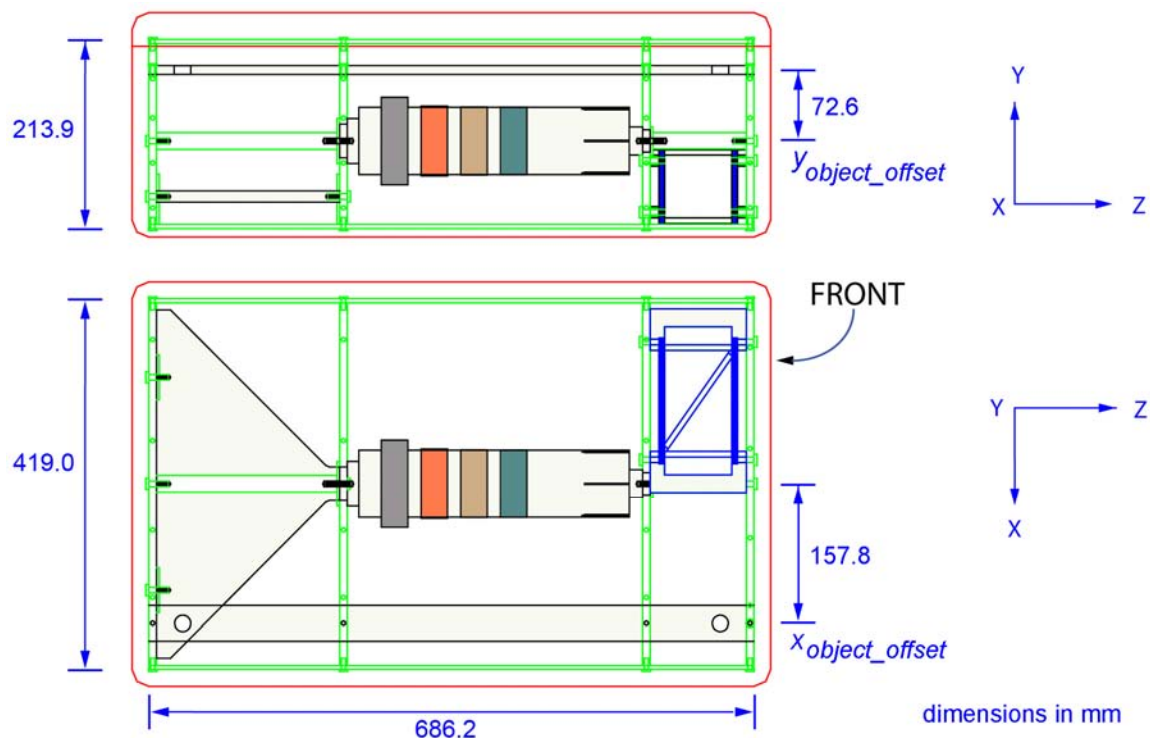


Figure 2—Test article A

Test article A contains the test objects for the methods covered in the following subclauses:

- 6.3 Object length accuracy
- 6.4 Path length CT value and Z_{eff}
- 6.7 Z_{eff} and CT value uniformity
- 6.8 Streak artifacts
- 6.10 Image

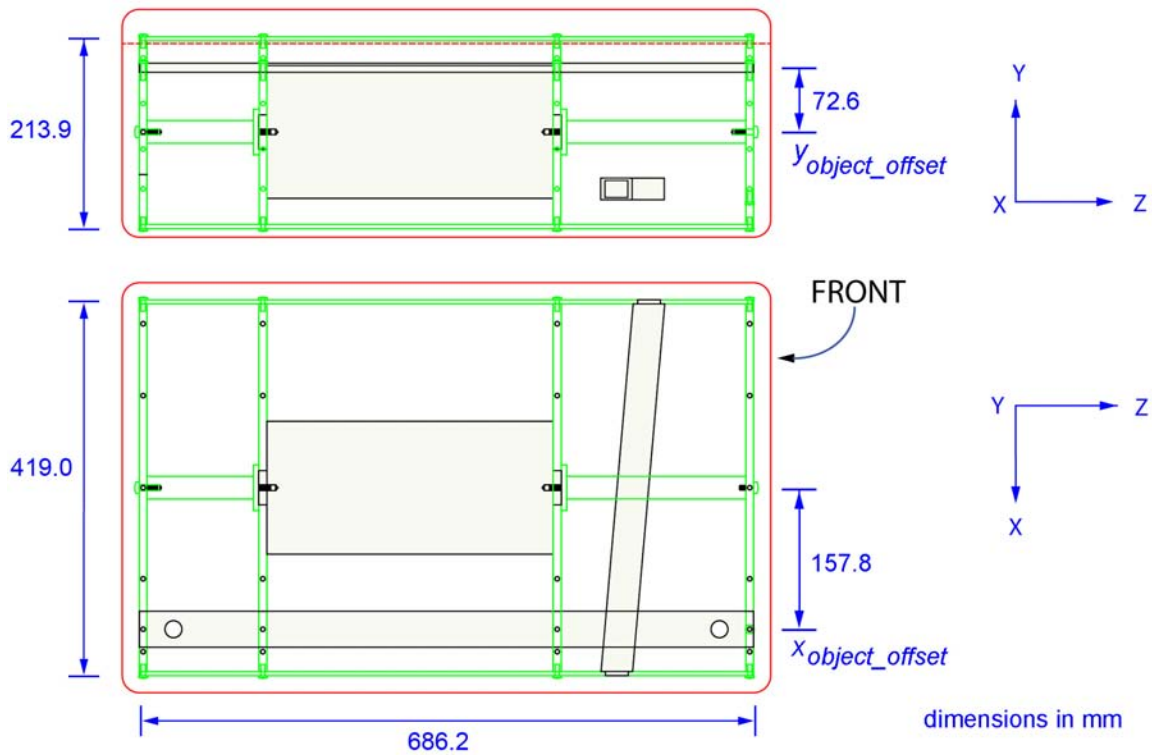


Figure 3—Test article B

Test article B contains the test objects for the methods covered in the following subclauses:

- 6.3 Object length accuracy
- 6.5 Noise equivalent quanta (NEQ)
- 6.6 CT value consistency
- 6.9 Slice sensitivity profile (SSP)

6. Test procedures for image quality

6.1 General

This standard specifies procedures for measuring a wide range of image quality indicators. Table 1 provides a list of the test procedures, the image quality indicators they measure, and the test object they use.

Table 1—List of test methods and indicators measured

Test procedure	Image quality indicator	Test object	Test article
Object length accuracy	Length of objects relative to their expected values	Acetal ^a plate with machined hole in each end	A & B
Path length CT value and Z _{eff}	Consistency of density and Z _{eff} measured along a variable x-ray path length	Acetal triangle	A
Noise equivalent quanta (NEQ)	In-plane spatial resolution of the system normalized by the system's noise	Acetal cylinder	B
CT value consistency	(a) Measurement of the average CT value for a reference object (b) Variance of CT values within reference object	Acetal cylinder	B
Z _{eff} and CT value uniformity	Measurement of Z _{eff} and CT value through different thicknesses of attenuating metals	Acetal cylinder wrapped with layers of aluminum, copper, tin, and lead	A
Streak artifacts	Level of variation in a nominal Z _{eff} material induced by the presence of a high Z _{eff} material in close proximity	Acetal cylinder with imbedded tungsten alloy pins	A
Slice sensitivity profile (SSP)	Resolution of the image along the direction of belt movement	Acetal rectangular bar presented at 5°	B
Image registration	Physical alignment between imaging subsystem frames of reference	Acetal and aluminum plates arranged to form a box with a diagonal acetal plate	A

^a FULL SPECIFICATION: Use acetal copolymer (also called acetal, polyoxymethylene or POM) designated as ASTM D6100-05 S-POM0211LP. This is a general-purpose grade thermoplastic, with a density near 1.4 g/cm³, and that does not include fillers, impact modifiers or other additives including colorant, fiber, chemical lubricant, or heavy metals. Before construction of the NEQ test object, the core of the delivered acetal rod should be verified for low centerline porosity using the procedure specified in ASTM D6100-05.

In addition to carrying out the cited image quality methods, it is important to manually record certain data about the system being tested and the environment of the test. The manual data to be collected is specified in 6.2. The following subclauses discuss each method, detailing how the measurements are to be made.

6.2 Manually recorded data

6.2.1 Purpose

Manufacturers may produce a number of models under the same general product name, and they may perform differently under different environmental conditions. When looking at results from this evaluation method, it is important to be sure you are comparing similar machines under similar conditions. This section specifies the minimum data that shall be manually recorded about the system and the evaluation conditions.

6.2.2 System data

The following data are available from the manufacturer of the system, or in some cases, provided by the system itself. It is not intended that the evaluation team actually measure any of the data to record for this section.

6.2.2.1 General information

- a) Test method: State that the evaluation was carried out in accordance with this standard.
- b) Manufacturer: Record the name of the company producing the system.
- c) Model: Record the full model name/number for the system.