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American National Standard for the Performance of Checkpoint Cabinet X-Ray Imaging Security Systems

N42.44

Accredited by the American National Standards Institute

Sponsored by the
National Committee on Radiation Instrumentation, N42

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Secretariat
Institute of Electrical and Electronics Engineers, Inc.

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Abstract: This document establishes standards for the technical performance of cabinet x-ray imaging systems used for screening at security checkpoints and other inspection venues.
Keywords: cabinet x-ray, checkpoint, minimum performance

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Contents

American National Standard for the Performance of Checkpoint Cabinet X-Ray Imaging Security Systems

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1. Overview

Numerous measures of imaging performance for x-ray screening systems have been defined over the past several years. For example, penetration, spatial resolution, and wire gauge diameter are well-known and frequently used measures for defining an x-ray system's imaging performance. ASTM F792-01[1] establishes nine tests to determine the performance levels of an x-ray system. These tests have been widely accepted by the x-ray screening community, both manufacturers and users, and are adopted in this standard.

This document establishes minimum performance requirements for the nine tests of the ASTM F792-01 test method as applied to checkpoint cabinet x-ray systems. A well-defined test method and a set of minimum acceptable image-quality standards will provide value to both users and manufacturers of these x-ray imaging security systems. Manufacturers will have a better understanding of the needs, wants, and expectations of the user community and a clearer understanding of the minimum set of imaging goals. It is understood that some users will require image-quality standards higher than the minimum performance required in this standard.

Additionally, this standard provides a number of safety requirements, derived from a variety of standards documents and federal regulations, that are essential to the responsible operation of checkpoint cabinet x-ray systems. These include: radiological safety, electrical and mechanical safety, electromagnetic compatibility, and limitation of x-ray exposure to scanned objects (e.g., photographic film).

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[1] Information on references can be found in Clause 2.

Sample test reports are given in Annex A (informative). Selected human-factors engineering considerations are included in Annex B (informative).

1.1 Scope

This document establishes standards for the technical performance of cabinet x-ray imaging systems used for screening at security checkpoints and other inspection venues. Included are all x-ray systems designed primarily for the inspection of baggage at airline, railroad, and bus terminals, and in similar facilities. An x-ray tube used within a shielded part of a building, or x-ray equipment that may temporarily or occasionally incorporate portable shielding, is not considered to be a cabinet x-ray system.

Hereinafter, systems covered by the scope of this standard are referred to as the system.

This standard applies to x-ray imaging equipment with all of the following characteristics:

— Meet the definition of cabinet x-ray systems as given in 21 CFR 1020.40

— Operate at or above 120 kV

— Have tunnel nominal dimensions of up to 1.1 m × 1.1 m

— Provide a single-view direct-projection image as the primary image

— Are used to examine items to detect prohibited and illicit materials at security-checkpoint locations (e.g., airports, seaports, land border crossings, office buildings, court houses, correctional institutions, nuclear power facilities, military facilities, commercial shipping and receiving stations, stations used for manifest verification)

For further clarification, systems included in this standard can be those with or without organic/inorganic differentiation, with or without active or passive threat alerts, and those incorporating multi-view and computed-tomography (CT) imaging (if the primary image presented is a single-view projection image), if they have all of the characteristics found in the list above.

This standard therefore is not intended for x-ray imaging systems with any of the following characteristics:

— Operate at potentials that are less than 120 kV

— Are not cabinet systems (e.g., open bomb-squad systems)

— Do not present a direct-projection image

— Can provide a projection image only through image reconstruction from multiple views

— Are based primarily on the use of CT

— Are used for medical diagnostic imaging

— Are used for non-destructive evaluation (NDE) or non-destructive testing (NDT), industrial quality control (e.g., food inspection), industrial sortation of recyclables or natural resource extraction, systems used for scientific research purposes

— Are based only on backscattered or coherently scattered x-rays

This standard specifies minimum requirements and test procedures for x-ray imaging performance, radiation-limitation requirements, and electrical, mechanical, and environmental requirements. This standard addresses technical image-quality performance, not threat-detection performance.

1.2 Purpose

Screeners frequently use the images provided by checkpoint x-ray systems to detect weapons and contraband materials, as well as to verify manifests (to determine that the contents of a package are what they are purported to be). For these applications, this standard is intended to provide procurers and/or prospective users of checkpoint x-ray systems with: test methods that facilitate performance comparisons among systems, and the minimum acceptable imaging-performance requirements. These values are achievable in the current state of the art of production checkpoint x-ray systems. Additionally, a variety of factors essential for the safe operation of checkpoint x-ray systems are assembled and standardized in this document.

While it appears logical that better imaging performance will result in better screening performance, the user is cautioned that the correlation between specific imaging-performance metrics and detection performance has not been established on a strict scientific basis. In addition, there may be trade-offs among imaging-performance parameters. For example, higher penetration may result in decreased contrast sensitivity. Consequently, users are encouraged to evaluate candidate checkpoint x-ray systems against their specific requirements whenever possible, and especially in cases in which the application is atypical.

The tests specified in this standard may be used for type testing. Type tests are intended to demonstrate that production systems made according to a specific design meet defined performance criteria.

2. Normative references

The following normative documents contain provisions which, through reference in the text of this standard, also constitute provisions of ANSI N42.44. For dated references or those with specified editions, subsequent amendments to, or revisions of, any of these publications do not apply. For undated references, the latest edition of the normative document referred to applies. Users of this standard should note that alternative referenced standards specified in this standard may not fulfill the legal requirements and practices in all countries. Care should be taken to ensure regulatory compliance.

ASME B20.1, Safety Standard for Conveyors and Related Equipment.[2]

ASTM F792-01e2, Standard Practice for Evaluating the Imaging Performance of Security X-Ray Systems.[3]

ASTM F1039, Standard Test Method for Measurement of Low Level X-Radiation Used in X-Ray Security Screening Systems.

CISPR 11, Industrial, Scientific and Medical (ISM) Radio-Frequency Equipment—Electromagnetic Disturbance Characteristics—Limits and Methods of Measurement.[4]

FDA Rules, Code of Federal Regulations, Title 21, Part 1020, Performance Standards for Ionizing Radiation Emitting Products, Section 1020.40—Cabinet x-ray systems (hereinafter referred to as 21 CFR 1020.40).[5]

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[2] ASME publications are available from the American Society of Mechanical Engineers, 3 Park Avenue, New York, NY 10016-5990, USA (http://www.asme.org/).

[3] 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/).

[4] CISPR documents are available from the International Electrotechnical Commission, 3, rue de Varembé, Case Postale 131, CH 1211, Genève 20, Switzerland/Suisse (http://www.iec.ch/). They are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

[5] Title 21 of the CFR is reserved for rules of the US Food and Drug Administration. Title 21 publications are available from the US Food and Drug Administration online at http://www.fda.gov.

FCC Rules, Code of Federal Regulations, Title 47—Telecommunications, Part 15—Radio Frequency Devices (hereinafter referred to as 47 CFR 15).[6]

FCC Rules, Code of Federal Regulations, Title 47—Telecommunications, Part 18—Industrial, Scientific, and Medical Equipment (hereinafter referred to as 47 CFR 18).

IEC 60204-1, Safety of machinery—Electrical equipment of machines—Part 1: General requirements.[7]

IEC 60601-2-28 (1993), Medical electrical equipment—Part 2: Particular requirements for the safety of X-ray source assemblies and X-ray tube assemblies for medical diagnosis.

IEC 61000-4-2, Electromagnetic Compatibility (EMC)—Part 4-2: Testing and measurement techniques—Electrostatic discharge immunity test.

IEC 61000-4-3, Electromagnetic Compatibility (EMC)—Part 4-3: Testing and measurement techniques—Radiated, radio-frequency, electromagnetic field immunity test.

IEC 61000-4-4, Electromagnetic Compatibility (EMC)—Part 4-4: Testing and measurement techniques—Electrical fast transient/burst immunity test.

IEC 61000-4-5, Electromagnetic Compatibility (EMC)—Part 4-5: Testing and measurement techniques—Surge immunity test.

IEC 61000-4-6, Electromagnetic Compatibility (EMC)—Part 4-6: Testing and measurement techniques—Immunity to conducted disturbances, induced by radio-frequency fields.

IEC 61000-4-11, Electromagnetic Compatibility (EMC)—Part 4-11: Testing and measurement techniques—Voltage dips, short interruptions and voltage variations immunity tests.

IEC 61010-1, Safety requirements for electrical equipment for measurement, control, and laboratory use—Part 1: General requirements.[8]

3. Definitions

The following definitions apply to ANSI/IEEE standards that have been developed at the request of the Department of Homeland Security (DHS) for instruments to be used by DHS and emergency responders.

3.1 air kerma: The sum of the initial kinetic energies of all the charged particles liberated by uncharged particles (e.g., photons) in a mass of air, divided by that mass, in the limit as the mass goes to zero. The special name for the unit of kerma is gray (Gy), with 1 Gy = 1 joule per kilogram.

3.2 backscattered x-rays: X-rays that are scattered at backward angles, roughly toward the x-ray source.

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[6] CFR publications are available from the Superintendent of Documents, U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20013-7082, USA.

[7] IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3 rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse (http://www.iec.ch/). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

[8] This standard is also known as UL 61010-1, Standard for Safety Electrical Equipment for Measurement, Control, and Laboratory Use; Part 1: General Requirements and is available from Underwriters Laboratories via COMM 2000 at http://www.comm-2000.com/default.aspx.

3.3 cabinet x-ray system: An x-ray system with the x-ray tube installed in an enclosure that, independent of existing architectural structures except the floor on which it may be placed, is intended to contain at least that portion of a material being irradiated, provide radiation attenuation, and exclude personnel from its interior during generation of x radiation.

3.4 checkpoint: For the purposes of this standard, an area where x-ray equipment is used to examine items to identify security threat material or other illicit or prohibited materials, which may be placed in baggage or parcels and/or is concealed within an item.

3.5 coherently scattered x-rays: X-rays that are elastically scattered with no loss in energy.

3.6 degradation (of performance): An undesired departure in the operational performance of the system from its intended performance.

3.7 exposure: The absolute value of the total charge of the ions of one sign produced in a mass of (dry) air when all the electrons and positrons liberated or created by photons in the air are completely stopped in air, divided by that mass of air, in the limit as the mass goes to zero. The special name for the unit of exposure was roentgen (R), with $1\ \text{R} = 2.58 \times 10^{-4}\ \text{C kg}^{-1}$ (exactly). Note that the roentgen is no longer recognized in the International System of Units (SI) and exposure has been largely replaced by air kerma. At the x-ray energies of interest here, the relation between air kerma (K_{air}) and exposure (X) is $K_{\text{air}} = 0.00876\ \text{Gy R}^{-1}\ X$.

3.8 projection (or transmission) image: Pertains to conventional x-ray technology in which x-rays pass through an object and create a shadowgram, which is the result of the differential attenuation due to variations of composition, density and thickness of every portion of the object in the path of the x-ray beam.

3.9 type test: For the purpose of this standard, a test that can be performed by manufacturers or other parties on one or more samples of the system, representative of production systems, with the objective of determining if the system, as designed and manufactured, meets the requirements of this standard.

4. General considerations

All tests in this standard may be considered as type tests.

4.1 Special word usage

The following word usage applies:

- The word "shall" signifies a mandatory requirement (except where an appropriate qualifying statement is included to indicate that there may be an allowable exception).
- The word "should" signifies a recommended specification or method.
- The word "may" signifies an acceptable method or an example of good practice.

4.2 Environmental factors

It is recognized that checkpoint x-ray systems are used predominantly in controlled environments. To insure uniformity of test results, all tests in this standard shall be performed under standard environmental test conditions. The ranges of acceptable test conditions are shown in Table 1 under "Standard test conditions."

If the system is intended for operation in environmental conditions significantly outside the ranges specified in Table 1, additional testing should be done to demonstrate that the imaging performance reported for standard test conditions remains unchanged at the low-temperature/low-humidity limit and at the high-temperature/high-humidity limit of the intended range.

Table 1—Standard test environmental conditions

Influence quantity (ambient)	Standard test conditions
Air temperature	22 °C ± 5 °C (71.6 °F ± 9.0 °F)
Relative humidity	30% to 75%, non-condensing
Atmospheric pressure	86 kPa to 106 kPa (645 mm Hg to 795 mm Hg)

The value of ambient air temperature, relative humidity, and atmospheric pressure at the time of the test shall be recorded (see, e.g., Annex A). The environmental conditions stated in this standard take priority over other environmental conditions stated in the referenced standards.

4.3 Radiological safety

Checkpoint x-ray systems shall comply with the requirements of 21 CFR 1020.40.

4.4 Fire, electrical, and mechanical safety

Checkpoint x-ray systems shall meet the existing fire, electrical, and mechanical safety requirements of the following indicated standards:

a) IEC 61010-1 and/or UL 61010-1

b) IEC 60601-2-28:1993 for:

   1) Products having a high-voltage cable external to the high-voltage assembly. These products shall comply with Clause 16 of IEC 60601-2-28:1993.

   2) Products having field-replaceable x-ray tubes. These products shall comply with subclauses 45.2 and 45.7 of IEC 60601-2-28:1993.

c) ASME B20.1 and/or IEC 60204-1 for requirements for safety of machinery

4.5 Electromagnetic compatibility

Checkpoint x-ray systems shall meet the electromagnetic-compatibility requirements of the indicated regulations or standards. Subclauses 4.5.3 to 4.5.8 specify testing parameters to be used in conjunction with the indicated IEC 61000 testing standards. Performance criteria (classifications) pertaining to the requirements listed in 4.5.3 to 4.5.8 are detailed in Table 2.

Table 2—Performance criteria for electromagnetic-compatibility requirements

Performance criteria	Description
A	The apparatus shall continue to operate as intended during and after the disturbance. No degradation of imaging performance (see Clause 5) or loss of function is allowed.
B	Temporary loss of function or degradation of performance that ceases after the disturbance ceases, and from which the equipment under test recovers its normal performance, without operator intervention. No change of actual operating state or stored data is allowed. No degradation of performance or loss of function is allowed below a performance level specified by the manufacturer, when the apparatus is used as intended.
C	Temporary loss of function or degradation of performance, the correction of which requires operator intervention. No degradation of performance or loss of function is allowed below a performance level specified by the manufacturer, when the apparatus is used as intended.

4.5.1 Conducted emissions

47 CFR 15, 47 CFR 18, and/or IEC CISPR 11 (Class A)

4.5.2 Radiated emissions

47 CFR 15, 47 CFR 18, and/or IEC CISPR 11 (Class A)

4.5.3 Electrostatic discharge

IEC 61000-4-2, with the following settings and conditions:

a) Contact discharge mode at 2 kV, 4 kV, and 6 kV

b) Air discharge mode at 2 kV, 4 kV, 8 kV, and 15 kV

c) Ten equipment discharge test points plus both vertical and horizontal coupling planes, positive and negative discharge waveform polarities

d) Performance criterion, Class B

4.5.4 Radiated RF immunity

IEC 61000-4-3, with the following settings and conditions:

a) 80 MHz to 1.0 GHz, 10 V/m

b) 1.4 GHz to 2.0 GHz, 3 V/m

c) 2.0 GHz to 4.0 Ghz, 1 V/m

d) Four sides of EUT, 1% steps, 2.8 s dwell, AM, 80%, 1 kHz sine wave

e) Class A

4.5.5 Electrical fast transient/burst immunity test

IEC 61000-4-4, with the following settings and conditions:

a) AC and DC power ports at 0.5 kV, 1 kV, and 2 kV

b) Signal lines over 3 m at 0.25 kV, 0.5 kV, and 1 kV

c) Class B

4.5.6 Surge immunity test

IEC 61000-4-5, with the following settings and conditions:

a) AC power port at 2 kV line-to-earth, 1 kV line-to-line at 0°, 90°, 180°, and 270°

b) DC power ports at 0.5 kV line-to-earth, 0.5 kV line-to-line

c) Signal lines over 5 m at 1 kV line-to-earth

d) Positive and negative polarity, 5 surges per mode of appearance

e) For non-linear devices contained in the circuitry, lower voltage levels up to the limit are also to be tested

f) Class B

4.5.7 Immunity to conducted disturbances, induced by radio-frequency fields

IEC 61000-4-6, with the following settings and conditions:

a) 10 V rms, 150 kHz to 80 MHz

b) Power ports and signal lines over 3 m, 1% steps, 2.8 s dwell

c) Class B

4.5.8 Voltage dips, short interruptions, and voltage variations immunity tests

IEC 61000-4-11, with the following settings and conditions:

a) 30% reduction for 0.5 periods (10 ms), performance criterion, Class B

b) 60% for 5 periods (100 ms), performance criterion, Class C

c) 60% for 50 periods (1 s), performance criterion, Class C

d) 95% for 250 periods (5 s), performance criterion, Class C

4.6 Limitation of x-ray exposure to photographic film

In order to limit the effects of x-ray exposure on photographic film, the radiation exposure in a single screening, as measured using ASTM Test Method F1039, shall be less than 2.58×10^{-7} C/kg (i.e., an air kerma of less than 8.76 μGy or, equivalently, an exposure of less than 1 mR). Compliance with this limit assures what is generally regarded as film-safe inspection, at least for most unprocessed consumer films (i.e., speeds below ISO 800) undergoing a limited number of screenings. However, it is acknowledged that newer technologies, such as multi-view and CT checkpoint systems, might offer improved security performance but with increased exposure.

The radiation exposure in a single screening shall be reported for the technique (i.e., x-ray tube voltage and current, and conveyor belt speed) that produces the maximum exposure to scanned objects, and the technique parameter settings, if known, shall be recorded in test documentation (see, for example, Annex A). It is recommended that exposure be similarly reported for routine screening, and for any special techniques available to the operator.

5. Imaging-performance evaluation procedures

The test procedures in this standard are meant to add specificity to the test procedures of ASTM F792-01e2 for the system. This standard shall be used in conjunction with ASTM F792-01e2. Available ASTM F792-01e2 test objects (see ASTM ADJF0792) have an outer case similar to that of a briefcase. To more realistically simulate routine screening and to simplify and better facilitate reproducibility of image-performance test results, this standard has more restrictive requirements on test-object placement and orientation (see 5.2) than does ASTM F792-01e2. Thus, if the procedures of this standard are more restrictive than those of ASTM F792-01e2, this standard's procedures take precedence.

5.1 Imaging-performance test object

The test object used in this document is that specified in ASTM F792-01e2. It is composed of fixtures for the following nine tests:

Test 1—Wire display

Test 2—Useful penetration

Test 3—Spatial resolution

Test 4—Simple penetration

Test 5—Thin organic imaging

Test 6—Image-quality-indicator (IQI) sensitivity

Test 7—Organic/inorganic differentiation

Test 8—Organic differentiation

Test 9—Useful organic differentiation

Available ASTM F792-01e2 test objects have solid copper wires that are not tinned (see ASTM ADJF0792). The use of non-tinned, solid copper wires is required for Test 1, Test 2, and Test 3 in this standard. Note also that the indicated positions of the plastics in Test 9 of the test object in Figure 1 of ASTM F792-01e2 are reversed from the actual positions in the available test objects (see ASTM ADJF0792), so care should be taken in interpreting and reporting results for that test.

5.2 Imaging-performance test procedure

The test object shall be placed alone and in its case such that one surface of the case is in contact with the x-ray conveyor belt. The surface in contact with the conveyor belt should be chosen such that the test object is more nearly perpendicular to the x-ray beam axis. Thus, if the x-ray beam is primarily directed vertically upward ("up-shooter"), the case should lie flat; if the x-ray beam is primarily directed horizontally ("side-shooter"), the case should be positioned on edge. An exception is permitted for systems in which the x-ray beam is primarily directed vertically downward ("down-shooter"), for which the test object shall be positioned with the bottom surface of the case parallel to the conveyor surface but may be elevated to a height above the conveyor belt of up to one-fourth of the vertical tunnel dimension.

In all cases, the test object (in its case) shall be scanned with its long dimension parallel to the direction of the conveyor motion. The case may be positioned laterally (with respect to the direction of the conveyor motion) for optimal performance in any test.

In all cases, the placement and orientation of the test object shall be reported in the test procedure with the corresponding test results (see, for example, Annex A).

5.3 Imaging-performance evaluation considerations

a) If image-enhancement features are available to the operator in normal use, these may be used to achieve the best possible x-ray image. Examples are zoom, high penetration, edge enhancement, expanded density, black-and-white reverse, and pseudo-color. The use of these features shall be recorded in test documentation (see, for example, Annex A).

b) Any deviation from specified measurement procedures shall be described in test documentation.

6. Minimum acceptable imaging performance

Table 3 shows minimum acceptable performance for each of the imaging tests. Different minimum acceptable performance requirements are given for tunnels for which any dimension, width or height, is either <70 cm or ≥70 cm. This reflects the fact that tunnel dimension and the consequent size of bags or parcels being screened can influence imaging performance for certain of the tests. Therefore, a large tunnel system, with greater source-to-object distance, can degrade performance when compared to a smaller tunnel with a smaller source-to-object distance. This phenomenon is reflected in a relaxation of acceptable minimum performance for certain of the tests for the larger tunnel systems.

Note that for systems without organic/inorganic differentiation there is no requirement for meeting the minimum acceptable performance indicated for Test 7, Test 8, and Test 9.

Table 3—Minimum acceptable performance

Test #	Description	Largest tunnel dimension	
		<70 cm	≥70 cm
1	Wire display: Smallest wire noted under 0 mm Al	32 AWG	32 AWG
2	Useful penetration: Smallest wire noted under 9.5 mm Al Smallest wire noted under 15.9 mm Al Smallest wire noted under 22.2 mm Al	30 AWG 30 AWG 30 AWG	30 AWG 24 AWG 24 AWG
3	Vertical wire resolution: Horizontal wire resolution:	1.6 mm 1.6 mm	1.6 mm 1.6 mm
4	Simple penetration (steel):	22 mm	22 mm
5	Thin organic imaging (thicknesses of Delrin®)[a]: Distinguish 1 mm and 3 mm Distinguish 3 mm and 5 mm	Yes Yes	Yes Yes
6	IQI sensitivity (smallest hole discerned): Delrin® (plastic): 4T 2T 1T Steel: 4T 2T 1T	3 (9.6 mm) 4 (6.4 mm) No minimum No minimum No minimum No minimum	4 (12.8 mm) 4 (6.4 mm) No minimum No minimum No minimum No minimum
7[b]	Inorganic/organic differentiation:	Yes	Yes
8[b]	Organic differentiation: Behind 0 mm steel: PVC/XM®[c] XM®/nylon	Yes Yes	Yes Yes
9[b]	Useful organic differentiation: Behind 1.6 mm steel: PVC/XM® XM®/nylon Behind 3.2 mm steel: PVC/XM® XM®/nylon Behind 4.8 mm steel: PVC/XM® XM®/nylon	Yes Not required Not required Not required Not required Not required	Yes Not required Not required Not required Not required Not required

[a] Delrin® is a registered trademark of E.I. Du Pont de Nemours and Company Corporation. This information is given for the convenience of users and does not constitute an endorsement by the IEEE of these products. Equivalent products may be used if they can be shown to lead to similar results.

[b] Not required for systems without organic and inorganic differentiation.

[c] XM is a division of Van Aken International. For purposes of this table, XM represents the TNT stimulant XM-02-X manufactured by the XM Division of Van Aken International, Rancho Cucamomga, CA. This information is given for the convenience of users and does not constitute an endorsement by the IEEE of these products. Equivalent products may be used if they can be shown to lead to similar results.

Annex A

(informative)

Test reports

Sample test reports, covering measurements of imaging performance and of exposure to scanned objects, are given in this annex.

The imaging-performance check form is directly modeled after that used in ASTM F792-01e2, but with guidance on Test 9 to clarify an inconsistency in position of the plastic samples. The check form should greatly simplify the recording of distinguishable features according to ASTM F792-01e2 and facilitate the transfer of the test results to the summary table that follows.

The x-ray exposure test report includes only exposure to the scanned object (see sample report). Conformance with leakage-radiation requirements is covered in the FDA Code of Federal Regulations, Title 21, Part 1020. Most of the x-ray security-screening systems covered here have only one scanning mode, and the parameter settings (x-ray tube kV and mA; belt speed) might not be displayed. In that case, place an appropriate indication, such as "standard/routine," in the "Parameter settings" column.

ANSI N42.44 Cabinet X-Ray System Test Report

Doc. Ref. #:____________, Page 1 of 4

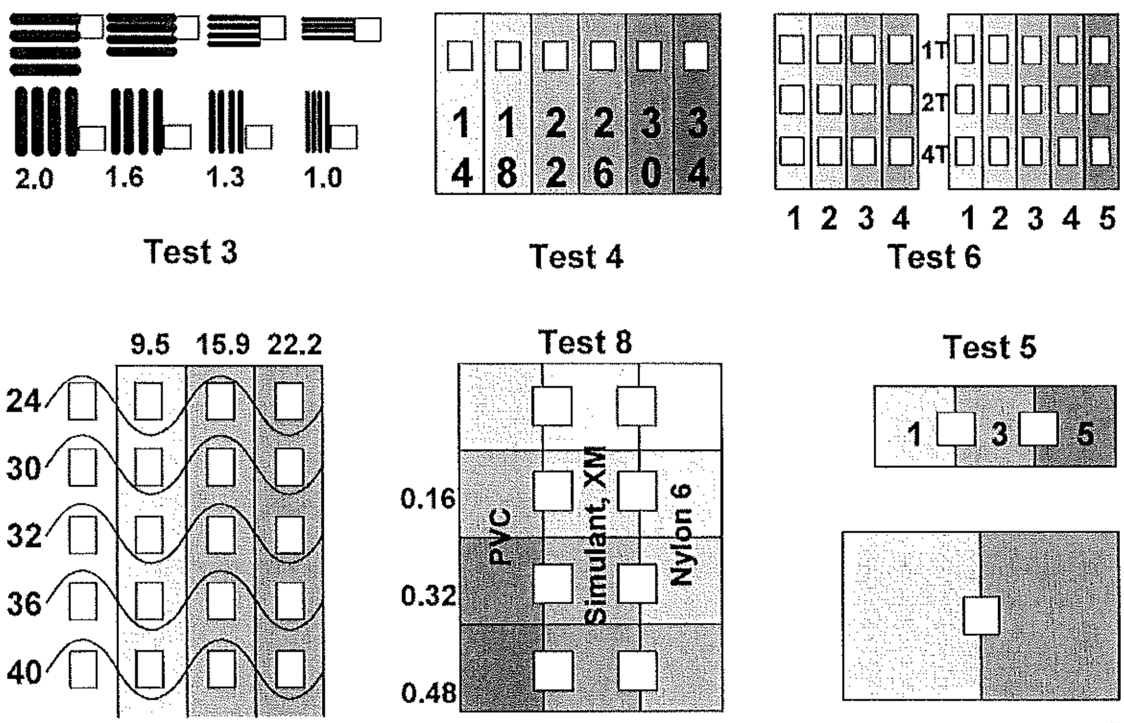
Tester:	Place:	Date/time:
X-ray system mfr:	Model:	Serial #:
Tunnel height, H (cm):	Tunnel width, W (cm):	Total H+W (cm):
Beam orientation (up-, down-, side-shooter):		Software version:
Monitor manufacturer:	Model:	Serial #:
Ambient temperature:	Relative humidity:	Pressure:
Test-Object Placement		
Lateral position on belt (left, middle, right, facing direction of motion):		
Orientation (horizontal/flat, vertical/upright):		
Height above belt (cm) (for down-shooters only):		

ANSI N42.44 Cabinet X-Ray System Test Report

Doc. Ref. #:_____________, Page 2 of 4

Test	Image enhancement features used
1. Wire display	
2. Useful penetration	
3. Wire resolution	
4. Simple penetration	
5. Thin organic imaging	
6. IQI sensitivity	
7. Inorganic/organic differentiation	
8. Organic differentiation	
9. Useful organic differentiation	

Test-Object Imaging-Performance Check Form



ANSI N42.44 Imaging-Test Results Summary

Doc. Ref. #:______________, Page 3 of 4

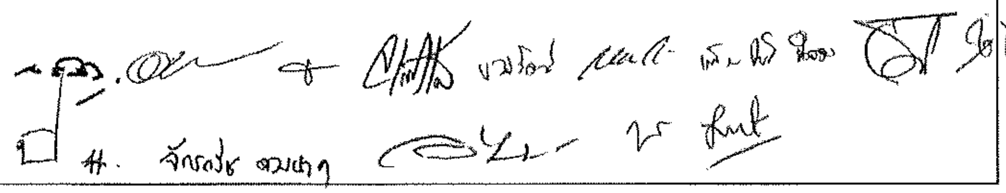
(If system does not claim organic differentiation, place NA in Test results and Pass columns)

Test	Description	Minimum requirement Largest tunnel dimension <70 cm	 ≥70 cm	Test results	Pass (✓)
1	Wire display: Smallest wire under 0 mm Al	32 AWG	32 AWG		
2	Useful penetration:				
	Smallest wire under 9.5 mm Al	30 AWG	30 AWG		
	Smallest wire under 15.9 mm Al	30 AWG	24 AWG		
	Smallest wire under 22.2 mm Al	30 AWG	24 AWG		
3	Vertical wire resolution:	1.6 mm	1.6 mm		
	Horizontal wire resolution:	1.6 mm	1.6 mm		
4	Simple penetration (steel):	22 mm	22 mm		
5	Thin organic imaging:				
	Distinguish 1 mm and 3 mm	Yes	Yes		
	Distinguish 3 mm and 5 mm	Yes	Yes		
6	IQI sensitivity (smallest discerned):				
	Delrin®[a] (plastic): 4T	3 (9.6 mm)	4 (12.8 mm)		
	2T	4 (6.4 mm)	4 (6.4 mm)		
	1T	No minimum	No minimum		
	Steel: 4T	No minimum	No minimum		
	2T	No minimum	No minimum		
	1T	No minimum	No minimum		
7[b]	Inorganic/organic differentiation:	Yes	Yes		
8[b]	Organic differentiation:				
	0 mm steel: PVC/XM®[c]	Yes	Yes		
	XM®/nylon	Yes	Yes		
9[b]	Useful organic differentiation:				
	1.6 mm steel: PVC/XM®	Yes	Yes		
	XM®/nylon	Not required	Not required		
	3.2 mm steel: PVC/XM®	Not required	Not required		
	XM®/nylon	Not required	Not required		
	4.8 mm steel: PVC/XM®	Not required	Not required		
	XM®/nylon	Not required	Not required		

[a] Delrin is a registered trademark of E.I. Du Pont de Nemours and Company Corporation. This information is given for the convenience of users and does not constitute an endorsement by the IEEE of these products. Equivalent products may be used if they can be shown to lead to similar results.

[b] Not required for systems without organic and inorganic differentiation.

[c] XM is a division of Van Aken International. For purposes of this table, XM represents the TNT stimulant XM-02-X manufactured by the XM Division of Van Aken International, Rancho Cucamonga, CA. This information is given for the convenience of users and does not constitute an endorsement by the IEEE of these products. Equivalent products may be used if they can be shown to lead to similar results.



ANSI N42.44 X-Ray Exposure Measurement Results

Doc. Ref. #:____________, Page 4 of 4

Tester:	Place:	Date/time:
X-Ray system manufacturer:	Model:	Serial #:

Instrument Used for Exposure-of-Contents Measurements

Manufacturer:	Model:	Serial #:
Calibration date:		

Requirement: < 8.76 μGy (< 1 mR) in a Single Scan

Test conditions	Parameter settings (x-ray tube kV and mA; belt speed)	Measurement result	Pass (✓)
Maximum exposure[a]			
Routine exposure[b]			
Optional scan			
Optional scan			

[a] Pertains to parameter settings that produce the maximum air kerma or exposure in a scan
[b] Pertains to parameter settings for routine screening

Annex B

(informative)

Human-factors engineering considerations

Screening performance is a function of both the system imaging performance and the operator performance. Operator performance can be enhanced by more optimal engineering of the controls and display of the system. Commonality of features can simplify operator training and help avoid confusion, particularly for large-scale screening applications involving multiple system manufacturers. Many important human-factors considerations can be identified for standardization. Some of the most important are included in this annex. Without question many of these have a direct, if unquantifiable, bearing on screening performance. Defined testing procedures are not proposed for the human-factors considerations in this document.

Human-factors issues considered to be most important for screening performance are indicated below.

Full functionality for operators meeting personnel requirements is specified in the TSA Code of Federal Regulations, Title 49, Part 1544.

The operator control panel (OCP) should provide x-ray image-analysis tools (e.g., organic/inorganic stripping, magnification, inverse imaging) for the screener/operator to enhance the displayed image. The displays should provide good resolution and color saturation to enable the operator to discern common and familiar objects. The system manufacturer should follow the human factors guidelines found in Chapter 7 and Chapter 8 of the Federal Aviation Administration Technical Report DOT/FAA/CT-96/1 and in the revision to Chapter 8 (DOT/FAA/CT-01/08). Specific considerations should address the following:

- Displays should indicate system status, threat resolution, bag jams, and faulty image events.
- System should respond to inputs by the operator in 1 s or less.
- OCP and display icons, symbols, and abbreviations should be intuitive and easily recognized, with minimum character height of 2.3 mm (0.1 in) or larger; preferred height would be 2.9 mm to 3.3 mm (0.116 in to 0.128 in).
- Text labels, system actions, and feedback should be placed in close proximity to the event with which they are associated.
- Display image should follow a color and grayscale look-up table such that all manufacturers use a universal color scheme to represent density, inorganic, organic, and heavy metals.
- Function keys and icons preferably should be assigned a single function. If a function key or icon has multiple functions, the system should display which function is activated.
- Use of embedded menu systems or multi-step processes should be intuitive and follow conventional patterns of use.

IEEE STANDARDS ASSOCIATION   IEEE

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

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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

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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°C ± 5°C (73.4 °F ± 9 °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.

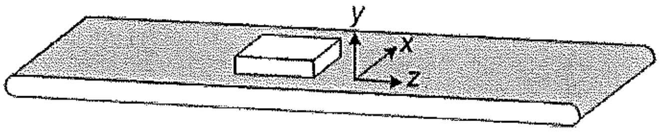


Figure 1—Reference axes for procedures

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.

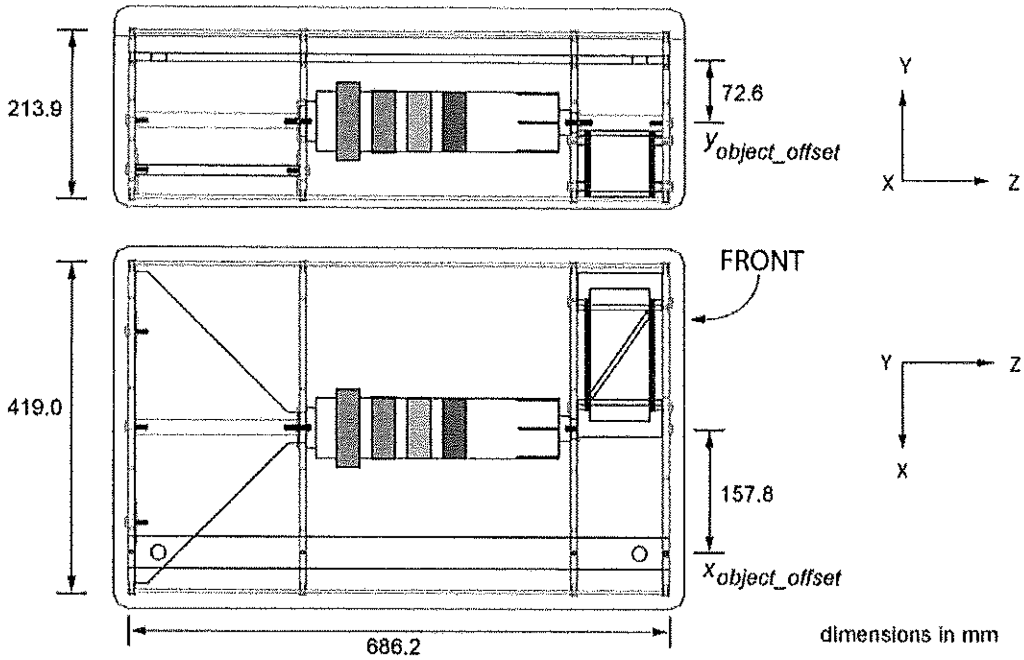


Figure 2—Test article A

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

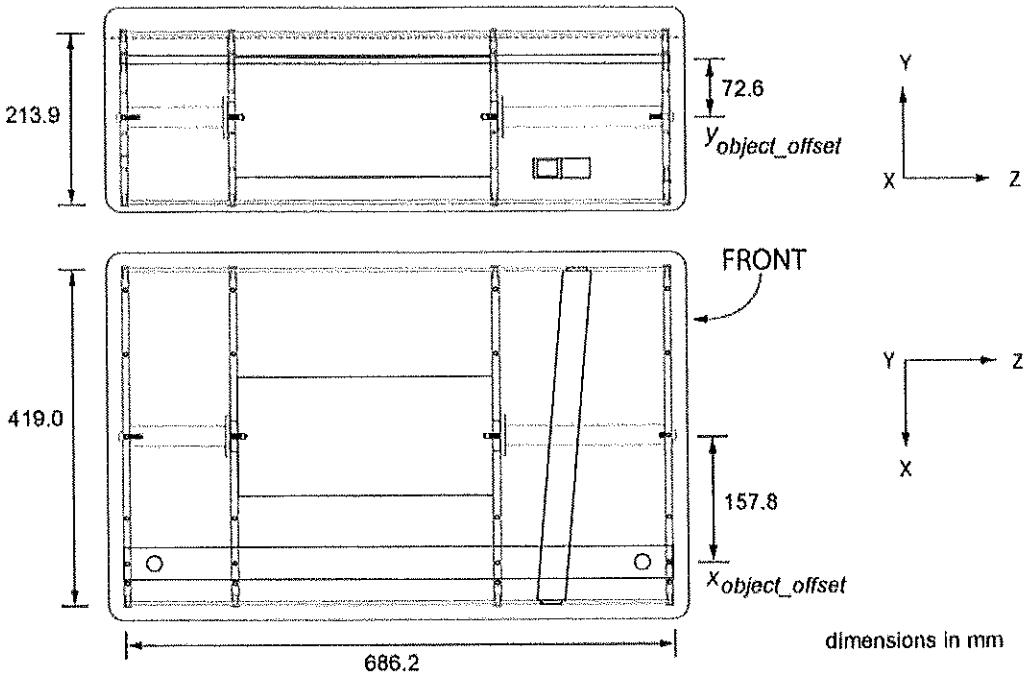


Figure 3—Test article B

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 Zeff	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
Zeff 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/cm^3, 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.

d) Serial number: Record the unique serial number for the system under evaluation.

e) Configuration: Describe the configuration of the system under evaluation. Is it set up for in-line use or stand alone use?

f) Scanning mode: Describe the system's mode of scanning. (Helical scan, static slice, non-rotating gantry, etc.)

g) Belt speed: Record the speed of the system's conveyor belt based on manufacturer specification. If the system operates at multiple speeds during the evaluation, state the maximum speed and any speeds applicable for actual scanning.

6.2.2.2 X-ray source information

a) X-ray source type: If multiple sources are used, state how many. Describe source characteristics, such as anode material, multi-anode, multi-cathode, continuous emission or voltage grid controlled, scanning beam, etc. If more than one source type is used, describe all applicable types and state the number of each type.

b) X-ray source voltage: State voltage in kV. If more than one voltage is used, state all.

c) X-ray source current: State current in mA. If more than one current is used, state all.

d) Number of hours: If the system records the number of hours of operation for the x-ray source, record it here. Otherwise, state not applicable (N/A). If data is available for more than one source, record all available.

In some systems, multiple sources may be used. In those cases, the total number of sources should be stated and descriptions of unique operating conditions should be provided. For example, if a system has six sources of the same type and running at the same current, but two run at 100 kV and four at 180 kV, then the description would be as follows:

Type:	6 tungsten cathode, continuous emission source
Voltage:	2 at 100 KV and 4 at 180 kV
Current:	10 mA
Number of Hours:	Tubes 1, 3, 4, 5, 6 – 2122 hours, Tube 2 – 135 hours

6.2.2.3 Reconstruction information

a) Reconstruction method: Record the method for reconstruction. (Filtered Back Projection, Fourier Inversion Method, Iterative, etc.).

b) Voxel spacing: State the distance between reconstructed voxels in mm in the x, y, and z direction.

6.2.2.4 System software

Record the manufacturer's version numbers for each of the following elements of software. If the manufacturer does not separate out a particular element, state what software element it is included within.

a) Display: Software controlling the operator display.

b) Reconstruction: Software that converts projection data in to CT images.

c) System Control: Software that manages control of the system, driving system state, hardware control, interaction with baggage handling system, etc.

d) Operating system: Operating system(s) for the computers of the system. (Windows Vista®, Fedora Core 6 Linux, etc.).[5]

[5] This information is given for the convenience of users of this standard and does not constitute an endorsement by the IEEE of these products. Equivalent products may be used if they can be shown to lead to the same results.

6.2.3 Evaluation environment data

The following data are related to the environment in which the evaluation was carried out. In general, the evaluation is based on single scanning of each test article and reporting results. In cases where many scans would be run, such as establishing a baseline expectation for a particular scanner, the environmental data should be modified to show the date, time, temperature, etc. for the beginning of the scanning and for the end.

The evaluators shall provide the following data:

a) Local date: Record the local date in year/month/day format.

b) Local time: Record the local time for the start of the evaluation in hours:minutes format, where hours run from 0 to 24.

c) Location: Record the full address of the location where the scanning for the evaluation was carried out.

d) Ambient temperature: Record the temperature of the environment surrounding the system in degrees Celsius.

e) Ambient humidity: Record the relative humidity of the environment surrounding the system.

f) Detector temperature: If the system provides temperature readings for its detector array(s), record the value after the system has been allowed to warm up and just before scanning the test articles. If the system provides multiple detector readings, record the max, min, and median values. Record in degrees Celsius.

g) Personnel: Record the full names and affiliations of the personnel who carried out the evaluation.

h) Telephone number: Record a telephone number where the lead of the evaluation team may be contacted in case of questions about the evaluation.

i) Test article manufacturer: Record the manufacturer of the test articles used in the evaluation.

j) Test article serial numbers: Record the unique serial numbers for each of the test articles used for the evaluation.

6.2.4 Comments

Under the comments section, the evaluators should note any issues or problems encountered while running the evaluation. If the system tested differed from the standard commercial product used in normal security screening operation mode, the evaluators shall note those differences here (e.g., "system was operated without its air conditioner running to simulate operation in a hotter climate").

6.2.5 Deviations from specified methods

Some of the test methods described in this standard explicitly allow the evaluator to use alternate approaches to calculating their values. Under the deviations section, the evaluators shall note any deviations from the test methods as specified in this standard. The notation shall specify which specific methods were modified and describe the modifications and the reasons for each.

6.2.6 Presentation of results

The manually recorded data shall be attached to the corresponding results of the other image evaluation methods specified in this standard. The data should be grouped in the same fashion as it is covered in the previous text. Figure 4 shows an example format, but other logical formats for the data presentation would be acceptable as well.

Image Quality Report

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

Manual Data Record

System Under Evaluation

Manufacturer: ____________________
Model: ____________________
Serial Number: ____________________
Configuration: ____________________
Scanning Mode: ____________________
Belt Speed: ____________________

Reconstruction Method: ____________________

Voxel Spacing:
x: ____________________
y: ____________________
z: ____________________

X-ray Source

Type: ____________________
Voltage: ____________________
Current: ____________________
Number of Hours: ____________________

Software Versions

Display: ____________________
Reconstruction: ____________________
System Control: ____________________
Operating System: ____________________

Evaluation Conditions

Local Time: ____________________
Date: ____________________

Location: ____________________
____
____

Ambient Temperature: ____________________
Ambient Humidity: ____________________
Detector Temperature: ____________________

Scanning Personnel: ____________________
____
____

Telephone Number: ____________________

Test Article Manufacturer: ____________________
Test Article S/Ns: ____________________

Comments: ____________________
____

Deviations from Specified Methods: ____________________
____

Figure 4—Format example for manually recorded data

6.3 Object length accuracy

6.3.1 Purpose

This test assesses the system's accuracy of measuring the length of an object. This accuracy can be affected by the coordination between belt speed and gantry rotation speed (or other source motion). Errors in length accuracy can affect the system's ability to consistently determine object size and mass.

This test shall apply to all systems.

Because mass is a critical parameter in most security screening applications, it is important to ensure that it is measured with a high-level of consistency. The absolute accuracy of the measurement is not as important as the consistency. If a system consistently measures an object short or long, the detection software can compensate appropriately. However, if the measurement varies from machine to machine, the software would not be able to compensate and the system's ability to estimate mass of an object would vary.

This method also measures the angle of test object presentation. Due to the sensitivity of some of this standard's test methods to test object angle, this measurement is used as a go/no-go on whether to perform the test methods on this particular scan. A copy of the test object will be housed in both test articles, so this test method shall be run on both articles.

6.3.2 Test object description

The test object for this assessment is shown in Figure 5. It consists of a long rectangular acetal plate with a 19.1 mm diameter hole drilled at each end. The object is placed in the test article such that its long axis is parallel to the long axis of the test article, and the axes of the holes are perpendicular to the test article bottom.

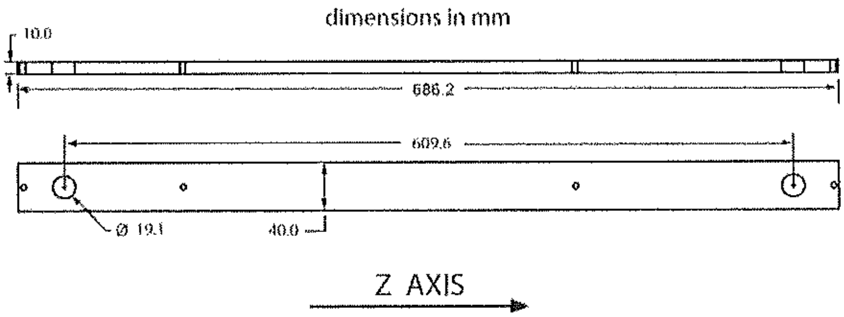


Figure 5—Object length test object

6.3.3 Test method

The test method shall measure the angle of presentation of the object and the measured length in mm. It shall isolate the voxels representing the circular holes in the test object ends and calculate their centers of mass. Because this calculation is over many voxels, it determines the location of the hole to a precision less than the voxel size. The locations of the centers of mass shall then be used to determine the length of the object and that the test article is presented at an acceptable angle.

The following method is an example of how the centers of mass for the holes may be calculated and used where continuous volumetric data are available. Alternative procedures are acceptable as long as they find the center of mass for each of the two holes and base the length and angle measurements on the relative locations of the centers.

a) Within the CT data, designate a subvolume that isolates the test object.

b) Sum all CT values along the y axis direction to create a coronal image, $f(x,z)$, of the test object whose length and width is equal to the length and width of the subvolume.

c) Find the maximum value, f_{max}.

d) Create $f_1(x,z)$

$$f_1(x,z) = \begin{cases} 1, \text{if } f(x,z) > \dfrac{f_{max}}{2} \\ 0, \text{if } f(x,z) \le \dfrac{f_{max}}{2} \end{cases}$$

e) Starting at the edge of $f_1(x,z)$, replace the outer image zero pixel values with ones. Make sure that the process progresses to all edges of the image. This process will result in a mask image that has zeros only in the location corresponding to the holes in the test object.

f) Create $f_2(x,z)$ such that $f_2(x,z) = 1 - f_1(x,z)$. $f_2(x,z)$ represents the pixels that correspond to the holes in the test object.

g) Calculate the center of mass for the first hole.

For each pixel in $f_2(x,z)$ that equals 1 in the area of the first hole

$$xsum = \sum_z \sum_x f_2(x,z) \times (f_{max}/2 - f(x,z)) \times x$$

$$zsum = \sum_z \sum_x f_2(x,z) \times (f_{max}/2 - f(x,z)) \times z$$

$$nsum = \sum_z \sum_x f_2(x,z) \times (f_{max}/2 - f(x,z))$$

$x_{c1} = xsum/nsum$

$z_{c1} = zsum/nsum$

h) Repeat calculation for second hole.

i) Convert x_{c1}, z_{c1}, x_{c2}, and z_{c2} to millimeters.

j) Calculate

$$length = \sqrt{(z_{c1} - z_{c2})^2 + (x_{c1} - x_{c2})^2}$$

$$\alpha = \sin^{-1} \frac{(x_{c2} - x_{c1})}{length}$$

k) Calculate

$$x_{center} = (x_{c1} + x_{c2})/2$$

l) Calculate

$$bag\_offset_x = x_{center} - x_{width}/2 - x_{object\_offset}$$

where

x_{width} is the width of the full image volume in mm

x_{object_offset} is the physical offset in x direction of the center of the test object from the center of the test article (value shown in Figure 2)

m) Using the original subvolume that isolated the test object, designate two additional rectangular subvolumes that fully contain each hole. These subvolumes shall be centered on the hole and have dimensions twice the diameter of the hole in x and z and twice the thickness of the plate in y. Designate these subvolumes as $h_1(x,y,z)$ and $h_2(x,y,z)$.

n) Find the maximum value in the two subvolumes. Record it as h_{max}.

o) Set all values in $h_1(x,y,z)$ and $h_2(x,y,z)$ that are less than $h_{max}/2$ to zero.

p) Calculate the y center of mass for the first hole.
For each voxel in $h_1(x,y,z)$

$$ysum = \sum_z \sum_y \sum_x h_1(x,y,z) \times y$$

$$nsum = \sum_z \sum_y \sum_x h_1(x,y,z)$$

$y_{c1} = ysum/nsum$

q) Repeat calculation for second hole.

r) Convert y_{c1} and y_{c2} to millimeters.

s) Calculate
$y_{center} = (y_{c1} + y_{c2})/2$

t) Calculate
$bag\_offset_y = y_{center} - y_{height}/2 - y_{object\_offset}$
where
y_{height} is the height of the full image volume in mm
y_{object_offset} is the physical offset in y direction of the center of the test object from the center of the test article (value shown in Figure 3)

6.3.4 Presentation of results

The results shall be presented as shown in Figure 6. The results shall state the version of the test article run (A or B), the horizontal and vertical offsets in mm, the measured angle of presentation in degrees, and the allowed tolerance on the angle[6] in degrees. If the angle is within the rotational tolerance, the length of the test object shall be reported in millimeters and as a percentage of the physical value, as

$$value = \frac{length}{length_{physical}} \times 100$$

where
$length_{physical}$ is the specified distance between the centers based on the test object drawing.

Test Article Version: *(A or B)*

Presentation Statistics
xx.x mm Bag horizontal offset from center of system
yy.y mm Vertical offset from center of system
$\alpha\alpha.\alpha$° Angle of presentation
+/- bb.b ° Allowed angular tolerance

Object Length: *ll.l* mm, *vv.v*% of physical length

Figure 6—Output from object length procedure when test article is submitted within angular tolerance

If the angle is outside of the rotational tolerance, the report shall indicate so and no length shall be reported, as shown in Figure 7.

[6] The rotational tolerance is specified in Clause 4.

Test Article Version: *(A or B)*

Presentation Statistics

xx.x mm Bag horizontal offset from Center of system
yy.y mm Vertical offset from Center of system
$\alpha\alpha.\alpha$ ° Angle of presentation
+/- bb.b ° Allowed angular tolerance

Warning: Angle of presentation for the test article is outside of allowable tolerance. Please re-scan.

Figure 7—Output from object length procedure when test article rotation is outside of angular tolerance

6.4 Path length CT value and Z_{eff}

6.4.1 Purpose

Objects with a large dimension in the CT slice plane (resulting in a long path length) can appear to have a different CT value and Z_{eff} than objects of the same material with smaller dimensions. How much they differ in a given system depends on several aspects of the system's design. This procedure describes how to measure this difference.

6.4.2 Test object description

The test object for this assessment is shown in Figure 8. It consists of a flat triangular piece of acetal. The test object is placed flat and parallel to the belt.

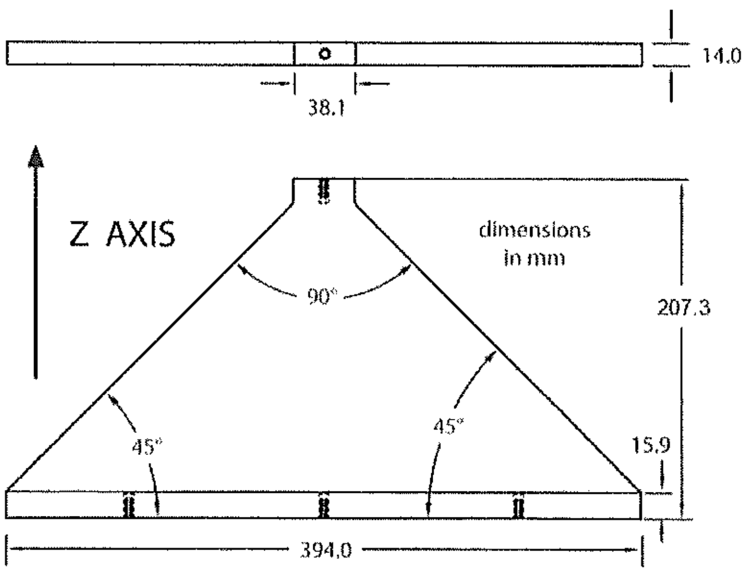


Figure 8—Path length test object

6.4.3 Test method

The test object is scanned. The maximum separation between slices shall be 10 mm. The CT slices will contain consecutively longer lines. The method shall isolate the object within each slice, determine the length in the slice, and find the maximum CT value at the center of the object in the slice.

For multi-energy CT systems, the procedure shall be repeated for all image values used by the detection algorithm. Some systems might use an image built from the high-energy data and a second from a Z_{eff} calculation. Others might use a Z_{eff} image and a Compton scattering image. The measurements shall be made and reported for each type of CT image used.

The following method is an example of how to calculate the path length dependency of the density and Z_{eff}:

a) Establish an ROI that contains the test object, but excludes any mounting region.

b) Within this ROI, threshold each slice to eliminate air. Project maximum along each vertical column to a line. Find the ends of the line to calculate path length. Select all the pixels within the center 2 cm of the line and calculate the median value. Record the path length and median value for each slice.

c) Using the slice that has the path length closest to 10 cm, calculate the median of the projected maximums for the entire line length. Normalize all center median values by this value.

6.4.4 Presentation of results

The results shall be presented as a plot of the normalized center median values against their path lengths for each image used. Figure 9 shows an example of a results plot. A plot shall be generated for each image used by the algorithm with notation citing the image used.

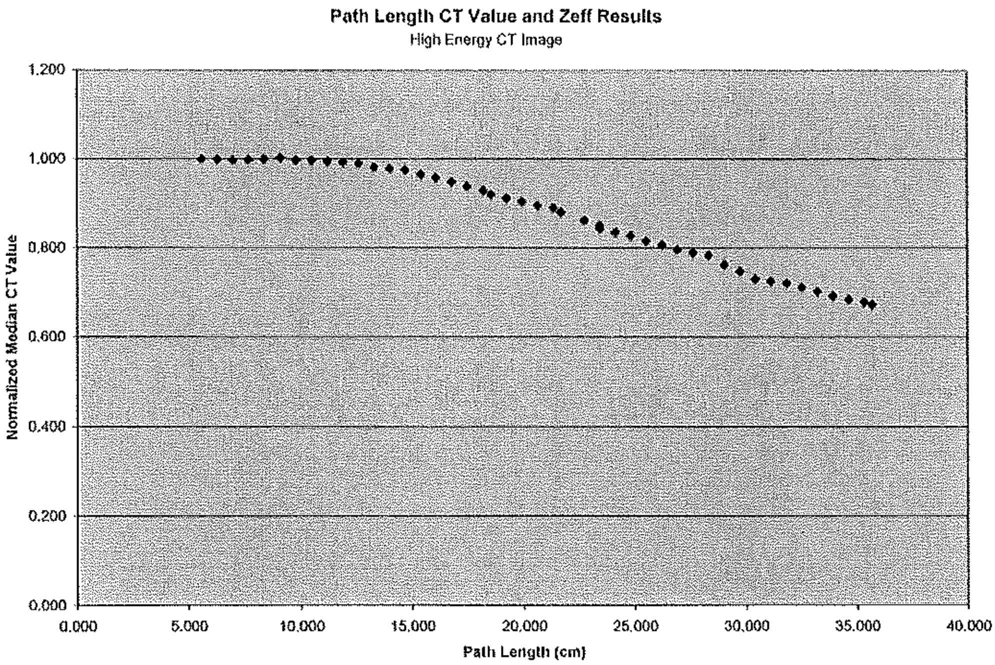


Figure 9—Example plot of path length test results

6.5 Noise equivalent quanta (NEQ)

6.5.1 Purpose

NEQ is the spatial-frequency-dependent SNR. It can be computed from measurements of average CT value of the object, MTF, and noise power spectrum as shown in the following equation:

$$NEQ = SNR^2 = \frac{S_{out}^2\ MTF^2}{NPS}$$

where

- SNR is the signal-to-noise ratio
- S_{out} is the average CT value of the object
- MTF is the modulation transfer function
- NPS is the noise power spectrum

The noise power spectrum quantifies the frequency characteristic of the variations in the image and can be measured by computing the Fourier transform of the noise images as shown in the following equation:

$$W(f_x, f_y) = \frac{1}{A}\left\langle \left| \iint dx\, dy\, D(x,y) e^{-2\pi i (x f_x + y f_y)} \right|^2 \right\rangle$$

where

- $W(f_x, f_y)$ is the noise power spectrum
- $D(x,y)$ is the noise image
- A is the area over which $D(x,y)$ is defined
- $\langle\ \rangle$ is the ensemble average over all noise images

6.5.2 Test object description

The test object for the determination of the NPS and the MTF shall be a cylinder (see Figure 10). The circumference of the cylinder is used as an edge to measure the MTF. The inside of the cylinder is used to calculate NPS.

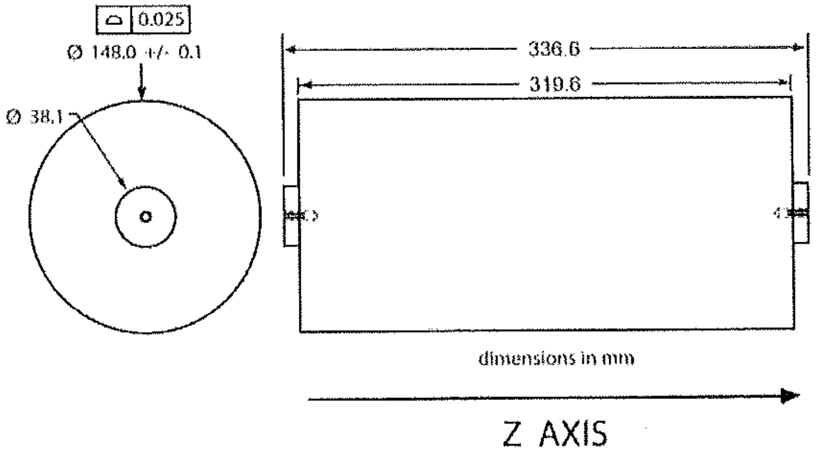


Figure 10—NEQ test object

6.5.3 Test method

6.5.3.1 Modulation transfer function

The modulation transfer function (MTF) shall be measured according to the ASTM E1695-95.[7]

6.5.3.2 Noise power spectrum (NPS)

6.5.3.2.1 General

The following procedures shall be used to estimate NPS from a series of images obtained by scanning a uniform cylindrical test object. These methods are a slight modification of that used by Hanson [B2]. The NPS shall be calculated using both of the following methods. In method one, any contribution due to stationary noise is eliminated, while in method two, it is included in the estimation of the NPS. The methods as stated below are required. There are no optional methods in this procedure.

6.5.3.2.2 NPS method 1

a) Obtain 64 images of the cylindrical test object. If the system cannot create 64 images of the test object (due to slice size, etc.), take the maximum number possible while avoiding the leading and trailing edges of the object.

   NOTE—In some systems, there may be stationary image artifacts related to specific angles in the rotation of the gantry. Under this condition, it may be preferable to use image pairs that are one full rotation apart. This is acceptable. However, the manufacturer must specifically indicate this deviation is necessary and the deviation, along with the specific separation used, shall be noted in the presented results.

b) Form 32 pairs of adjacent images. If fewer than 64 images were obtained, form as many pairs as possible using each image only once.

c) Calculate the average center of mass for the circle images in each pair.

d) Create a noise image for each pair by taking the difference between the paired images.

e) For each noise image, establish a circle of interest with radius, R, equal to the radius of the test object centered on the average center of mass for the pair. Apply a radial Hanning window defined as shown in the following equation:

$$f(r)=\begin{cases}\cos^2 \dfrac{r}{2R}\pi, & r<R\\ 0, & r\geq R\end{cases}$$

   where

   r the radial distance of the voxel from the center of the circle of interest

   R the radius of the circle of interest

f) Apply a two-dimensional Fourier transform to each image from step e).

g) Compute the square amplitude of the Fourier transformed images from step f). This results in a two dimensional NPS.

h) Average all the 2D NPS obtained in step g).

i) Obtain the 1D radial frequency NPS by averaging the 2D NPS obtained in step h) over annuli in frequency space.

[7] For information on references, see Clause 2.

6.5.3.2.3 NPS method 2

a) Using the same original images, subtract the average cylinder value in each image from the entire image (forming up to 64 noise images).

b) Repeat steps c) through i) from the previous NPS method 1 procedure using all original images to create the 1D radial frequency NPS.

6.5.3.3 Calculate NEQ

For each NPS calculated above, calculate an NEQ estimate as follows:

a) Calculate mean values of the original images inside the circle of interest and average together.

b) Use the mean value obtained (S_{out}), the 1D NPS obtained, and the MTF as shown in the first equation in 6.5.1 to estimate the NEQ.

6.5.4 Presentation of results

The measurement results for NEQ shall be given as numbers in a table. The NEQ shall be reported at 0.5 cm^{-1} intervals starting at 0.5 cm^{-1} and continuing to the first interval beyond the frequency at which the MTF value is below 20%. The values shall be reported logarithmically as follows:

$$10\log_{10}(\text{NEQ})$$

The values of the MTF at those intervals shall also be reported. Additionally, the report shall state the number of images used for each method and the number of pairs and separation of pairs for NEQ method 1.

Table 2—NEQ procedure results

Frequency (cm^{-1})	NEQ Method 1	NEQ Method 2	MTF
0.5	*aa.aa*	*bb.bb*	*0.ccc*
1	*dd.dd*	*ee.ee*	*0.fff*
1.5	*gg.gg*	*hh.hh*	*0.iii*
⋮	⋮	⋮	⋮
f_{max}	*xx.xx*	*yy.yy*	*0.zzz*

	NEQ Method 1	NEQ Method 2
Number of Images	*xx*	*yy*
Number of Pairs	*zz*	—

6.6 CT value consistency

6.6.1 Purpose

The purpose of this measurement is to determine spatial consistency of CT value in a uniform object.

6.6.2 Test object description

The test object for the measurement of CT value consistency is the same as the one used to measure MTF and NPS in 6.5.

6.6.3 Test method

Define a circle of interest in each image used in 6.5.3.2 that has a radius 10 mm less than the radius of the test object, centered on the test object within the image. Define the group of voxels that are completely enclosed within the circle of interest for each image.

Calculate mean and standard deviation of the CT value for each voxel group. Calculate the median and the standard deviations of the set of means and the set of standard deviations.

NOTE—In certain systems, the test object's CT value in each slice image will vary with the specific rotational position of the gantry. Consequently, using an arbitrary number of slices can result in a significant variance in the reported overall median CT value on a given machine. This makes machine-to-machine comparisons more difficult. Under this condition, it may be preferable to calculate the specified statistics for the object across a number of images equivalent to one full rotation. This is acceptable. However, the manufacturer must specifically indicate this deviation is necessary and the deviation, along with the specific number of slices used, shall be noted in the presented results.

6.6.4 Presentation of results

Report the median and standard deviation values for both the means and the standard deviations.

6.7 Z_{eff} and CT value uniformity

6.7.1 Purpose

This test assesses the system's ability to measure effective atomic number (Z_{eff}) and CT value of scanned objects. Variation in the values for a given object in the presence of different materials is expected and can be compensated for by the systems detection software. Consistency from machine to machine, however, is important to assure proper operation.

This procedure describes how to measure the Z_{eff} and CT values in the presence of various metals as well as the variance of those measurements. The procedure is applicable to both multi-energy machines as well as single energy. Single energy machines, however, shall only report results for the CT values.

6.7.2 Test object description

The test object is divided into two sections: one for evaluating the Z_{eff} and CT uniformity and the other for measuring streak artifacts (used in 6.8). The portion of the test object for Z_{eff} uniformity measurement consists of an acetal cylinder with sections covered by different thicknesses of aluminum, copper, tin, and lead as shown in Figure 11. The streak test object consists of tungsten alloy pins inserted into four holes drilled along the axis of the cylinder as shown in the figure.

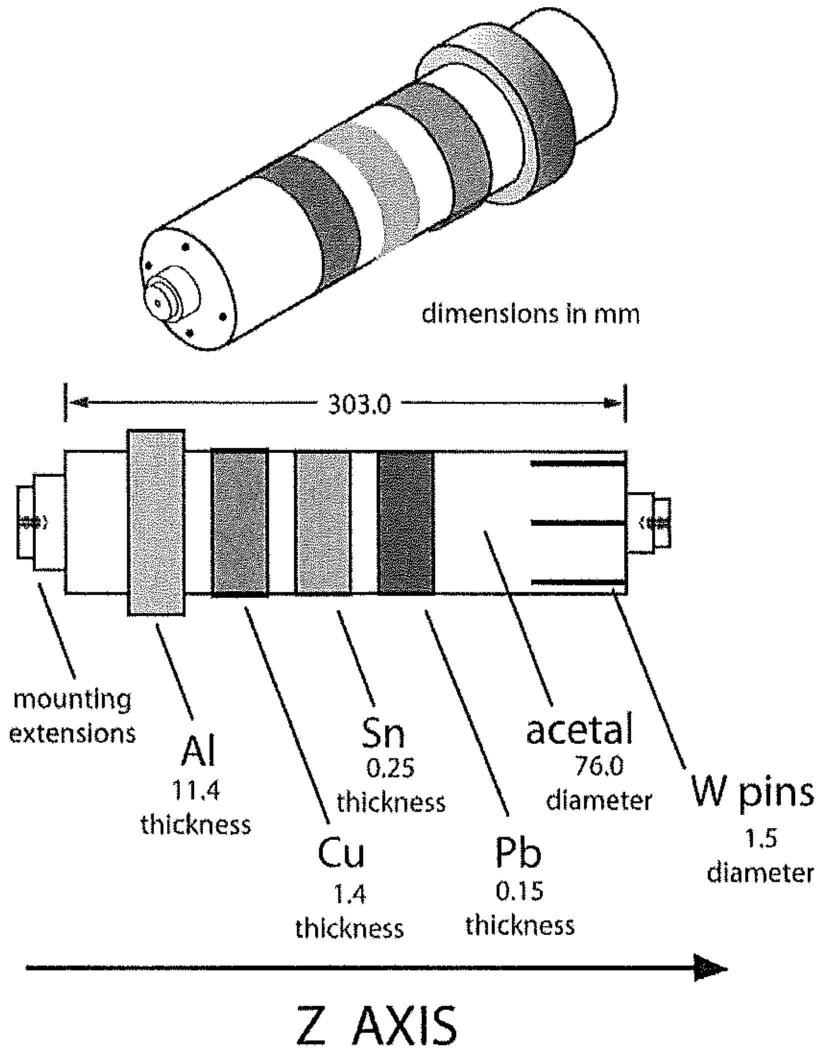


Figure 11 — Z uniformity test object and streak artifact test object

6.7.3 Test method

The Z_{eff} and CT values of acetal in sections covered by different metals are measured to test the accuracy and uniformity of the system's image. The ratio of CT and Z_{eff} values measured in sections covered by metals to CT and Z_{eff} values measured in the area outside metal is also reported. In addition, the aluminum material is measured to test the Z_{eff} accuracy. *All steps in this procedure shall be performed as described.*

a) Within the image $I(x,y,z)$, designate a subvolume that isolates the portion of the test object that is used for Z_{eff} uniformity measurement. The subvolume is defined by the first slice k_{start} and the last slice k_{end}.

b) Identify slices that pass through the center of the aluminum, copper, tin, and lead bands and also through acetal alone as follows:

1) Center-most slice of each metal section is defined as k_c.
2) Selected slice outside of the metal section is denoted as k_o.

c) Compute the center of the test object cross-section in each slice k_c.

d) For each metal section:

1) In slice k_c, define an ROI as the largest set of voxels completely enclosed within a 4 cm × 4 cm ROI centered within the test object.
2) Compute means of the CT values and Z_{eff} in the ROI.
3) Compute standard deviation of the CT values and Z_{eff} in the ROI.

e) Compute CT value and Z value statistics in the slice in the control region.

1) In slice k_o, define an ROI as the largest set of voxels completely enclosed within a 4 cm × 4 cm ROI centered within the test object.
2) Compute the means of the CT values and Z_{eff} in the ROI.
3) Compute standard deviation of the CT values and Z_{eff} in the ROI.

f) Compute the ratio of the mean CT value measured in each metal section to the mean CT value measured in the control region.

g) Compute the ratio of the standard deviation of the CT value measured in each metal section to the standard deviation of the CT value measured in the control region.

h) Compute the ratio of the mean Z_{eff} value measured in each metal section to the mean Z_{eff} value measured in the control region.

i) Compute the ratio of the standard deviation of the Z_{eff} value measured in each metal section to the standard deviation of the Z_{eff} value measured in the control region.

j) In the slice k_c for the aluminum, find the set of voxels within the aluminum band.

1) Select voxels comprising the largest set of voxels completely enclosed between two circles centered on the test object. The circle radii shall be equal to the inner and outer radii of the aluminum band.

k) Compute the mean and standard deviation of CT values over voxels belonging to aluminum.

l) Compute the mean and standard deviation of Z_{eff} values over voxels belonging to aluminum.

6.7.4 Presentation of results

Results of the CT and Z_{eff} uniformity test are summarized and reported as shown in Table 3.

The first section reports results for CT value uniformity in the region outside of the metal sections (CTRL), within the metal-covered sections and in the aluminum band. The mean and standard deviation are reported.

The second section reports results for Z_{eff} uniformity in the control area (CTRL), within the metal-covered sections and in the aluminum band. Mean and standard deviation are reported.

Table 3—Z_{eff} and CT value uniformity results

			Absolute measurements		Measurements relative to CTRL values	
			MEAN	STD	MEAN	STD
CT value uniformity	Acetal	CTRL	*mm.mm*	*σσ.σσ*	1	1
		Al	*mm.mm*	*σσ.σσ*	*mm.mm*	*σσ.σσ*
		Cu	*mm.mm*	*σσ.σσ*	*mm.mm*	*σσ.σσ*
		Sn	*mm.mm*	*σσ.σσ*	*mm.mm*	*σσ.σσ*
		Pb	*mm.mm*	*σσ.σσ*	*mm.mm*	*σσ.σσ*
	Aluminum	Band CT value	*mm.mm*	*σσ.σσ*	n/a	n/a
Z_{eff} uniformity	Acetal	CTRL	*mm.mm*	*σσ.σσ*	1	1
		Al	*mm.mm*	*σσ.σσ*	*mm.mm*	*σσ.σσ*
		Cu	*mm.mm*	*σσ.σσ*	*mm.mm*	*σσ.σσ*
		Sn	*mm.mm*	*σσ.σσ*	*mm.mm*	*σσ.σσ*
		Pb	*mm.mm*	*σσ.σσ*	*mm.mm*	*σσ.σσ*
	Aluminum	Band Z_{eff}	*mm.mm*	*σσ.σσ*	n/a	n/a

6.8 Streak artifacts

6.8.1 Purpose

Metals are common in scanned luggage and produce streaks in the images. This procedure measures the amount of streaks produced by metal pins in a plastic object.

6.8.2 Test object description

The test object is shown in Figure 11. The test object is divided into two sections: one for evaluating the Z_{eff} and CT value uniformity and the other for measuring streak artifacts. The streak test object section consists of tungsten alloy pins inserted into four holes drilled along the axis of the cylinder.

6.8.3 Test method

The streak artifacts are evaluated by measuring the CT value of acetal in a ROI in the slice with tungsten wire inserts. In the same slice, the peak-to-peak variation of CT values across diagonal profiles halfway between the tungsten inserts is also measured. The same measurements are performed in the area without metal pins to provide "control" measurements.

a) Locate the center most slice k_{STR} (relative to the tungsten pins) for the streak artifact measurements (STR)

b) Locate the center most slice k_{CTRL} for the control (CTRL) measurement

c) For streak artifact measurements, perform the following computations in the slice k_{STR}:

   1) Find the center and radius of the test object in the slice.

   2) Define the set of all voxels completely contained within a circle centered on the test object with radius equal to the acetal rod.

3) Find the metal pins using an appropriate threshold.

4) Define two lines, L1 and L2, passing through the midpoints between the neighboring pins:

   i) L1: Line passing through the midpoint between pins #1 and #2 and through the midpoint between rods #3 and #4, see Figure 12.

   ii) L2: Line passing through the midpoint between pins #1 and #3 and through the midpoint between pins #2 and #4, see Figure 12.

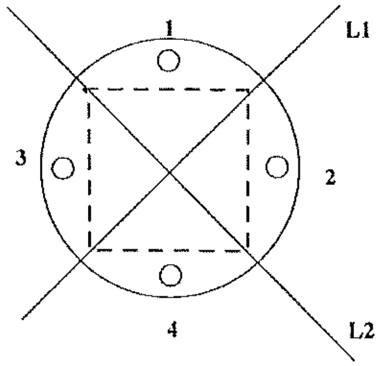


Figure 12—Pins in test object axial slice (large circle), midpoints between neighboring pin pairs (small circles), traced line, and rectangular ROI

5) Identify the set of voxels P whose boundaries cross over or touch line L1 or line L2 within the test object.

6) Compute line streak CT value statistics

   i) Compute the mean CT value of the voxels within P

   ii) Compute the standard deviation of the CT values of the voxels within P

   iii) Compute the peak to peak variation of the CT values of the voxels within P

7) Compute region streak CT value statistics for an ROI defined as the largest set of voxels completely enclosed within a 4 cm × 4 cm square ROI centered within the test object.

   i) Compute the mean CT value of the voxels within the ROI

   ii) Compute the standard deviation of the CT values of the voxels within the ROI

   iii) Compute the peak to peak variation of the voxels within the ROI

d) For slice CTRL, perform the following computations for slice k_{CTRL}

1) Find the center and radius of the test object

2) Define the set of all voxels completely contained within a circle centered on the test object with radius equal to the acetal rod.

3) Define two lines, L1 and L2, passing through the center of mass of the test object at +45° and −45° from the y axis.

4) Identify the set of voxels *P* whose boundaries cross over or touch line L1 or line L2 within the test object.

5) Compute line CTRL CT value statistics.

   i) Compute the mean CT value of the voxels within *P*

ii) Compute the standard deviation of the CT values of the voxels within P

iii) Compute the peak to peak variation of the CT values of the voxels within P

6) Compute region CTRL CT value statistics for an ROI defined as the largest set of voxels completely enclosed within a 4 cm × 4 cm square ROI centered within the test object.

i) Compute the mean CT value of the voxels within ROI

ii) Compute the standard deviation of the CT values of the voxels within ROI

iii) Compute the peak to peak variation of the CT values of the voxels within ROI

6.8.4 Presentation of results

Report streak artifacts results in the slice with metal pins and in the control area (CTRL). Measurements in the rectangular ROI and along the lines intersecting the test object are to be reported. Mean, standard deviation, and peak-to-peak variation are to be reported.

The first vertical section Table 4 reports absolute values of the measurements. The second vertical section reports measurements relative to the CTRL values (acetal area without pins for streak artifacts test).

Table 4—Streak artifact procedure results

		Absolute measurements				Measurements relative to CTRL values			
Streak artifact results		MEAN	STD	STD/ MEAN	(Max – Min)/ Mean	MEAN	STD	STD/ MEAN	(Max – Min)/ Mean
CTRL	Line	*mm.mm*	*σσ.σσ*	*nn.nn*	*pp.pp*	1	1	1	1
	Region	*mm.mm*	*σσ.σσ*	*nn.nn*	*pp.pp*	1	1	1	1
Pin area	Line	*mm.mm*	*σσ.σσ*	*nn.nn*	*pp.pp*	*mm.mm*	*σσ.σσ*	*nn.nn*	*pp.pp*
	Region	*mm.mm*	*σσ.σσ*	*nn.nn*	*pp.pp*	*mm.mm*	*σσ.σσ*	*nn.nn*	*pp.pp*

6.9 Slice sensitivity profile (SSP)

6.9.1 Purpose

This test assesses the resolution along the slice direction by analyzing CT values in coronal slices through the center of the SSP slanted edge test object mounted within the test article at an angle of 5° ± 0.5° off perpendicular to the long axis of the test article.

The analysis is analogous to the procedure cited in ASTM E1695-95 and amounts to measuring the resolution using the slice sensitivity profile derived from the variation in CT values across the slanted edge of the test object.

6.9.2 Test object description

The test object for this assessment is a rectangular block of acetal of dimensions 411.5 × 35 × 24 mm^3 presented as shown in Figure 13.

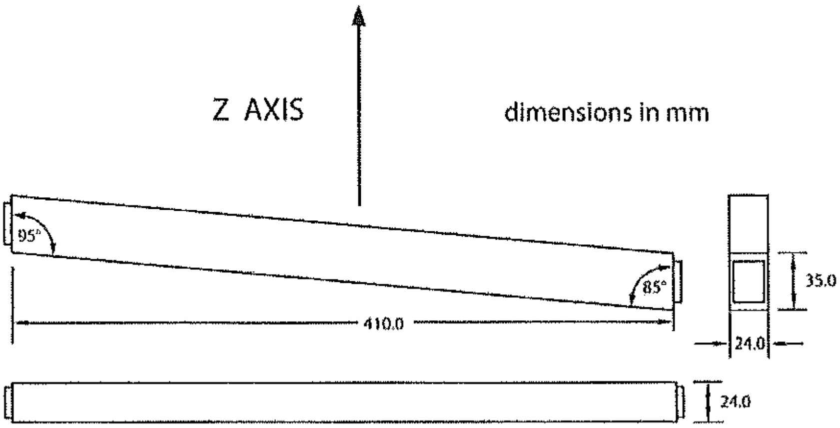


Figure 13—Slanted Edge Test object used to measure z resolution

6.9.3 Test method

The acquired 3D images *I*(x,y,z) are analyzed to generate the slice sensitivity profile as follows:

a) Locate the test object and designate a rectangular ROI containing the leading, trailing, top and bottom faces of the test object but not the side faces.

b) Generate a coronal image $I_c(x,z)$ of the test object by projecting the ROI along the y-axis. The coronal image is oriented so that each horizontal row is specified by a different x value.

c) Compute the center line of the test object

1) Calculate a center of mass, com_x, for each row in the ROI as shown in the following equation:

$$com_x = \frac{\sum_{z=0}^{z_{max}} z \cdot I_c(x,z)}{\sum_{z=0}^{z_{max}} I_c(x,z)}$$

where

x is the x coordinate of the row

z_{max} is the maximum z value in the ROI

2) Fit a line in the x-z plane to the set of all com_x.

d) For each row in the ROI, compute the edge spread function as follows:

1) Compute the z distance of each pixel in the ROI from the center line.

2) Scale the pixel values by the maximum CT value measured within the ROI to correct for beam hardening and scatter effects.

3) Generate a table of all pixel values within the ROI in the order of their distance from the center line.

4) Using the methods specified in ASTM E1695-95 starting at 7.1.1.5 and continuing through 7.1.3.3, generate the edge response function, point spread function, and the modulation transfer function.

6.9.4 Presentation of results

The values for the SSP shall be given as numbers in a table reflecting the magnitude of the MTF at various spatial frequencies. The SSP shall be reported at 0.5 cm^{-1} intervals starting at 0.5 cm^{-1} and continuing to the first interval beyond the frequency at which the SSP is below 0.2.

Table 5—SSP procedure results

Freq. (cm^{-1})	SSP
0.5	0.*xxx*
1.0	0.*yyy*
1.5	0.*zzz*
⋮	⋮
f_{max}	(<0.200)

6.10 Image registration

6.10.1 Purpose

Some CT-based security systems are made up of multiple imaging subsystems. The data collected from the subsystems are combined to reach and/or display a final result. It is important to assure that the data from the different subsystems are correlated spatially along the z-axis with regard to the frame of reference of the item being inspected. This correlation is commonly referred to as image registration.

This procedure measures how well the data from one subsystem is correlated to another. It also applies to systems with one imaging subsystem that make multiple data collection passes for the bag. Systems that create multiple images but use only one imaging subsystem and one data collection pass do not need to execute this procedure.

6.10.2 Test object description

The registration test object is designed so that

a) It can be identified in both CT and projection images.

b) The position may be measured accurately in an x-ray projection image.

c) The z position of a CT slice relative to the test object can be measured accurately.

Figure 14 shows a top view of the registration test object (not to scale). The test object has an acetal top and bottom for rigidity. The sides and diagonal section are also acetal. The front and back are aluminum, selected to provide good contrast in a projection image.

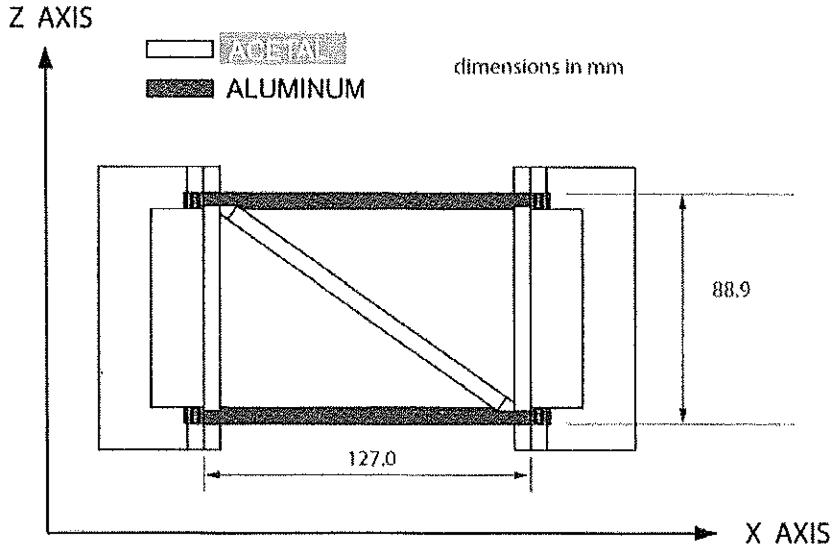


Figure 14—Registration test object (not to scale)

6.10.3 Test method

The image registration method consists of the following steps:

a) Acquire images normally used in automated detection.

b) Establish a region of interest in each image that contains the registration test object only.

c) Measure the test object position in the z direction in each image.

d) Compute registration accuracy, which is the difference between the z-axis position measurements in each image.

6.10.3.1 Measuring the test object position using a CT slice

The procedure for finding the test object in a CT slice uses the nature of the intersection of the three plastic walls with the slice plane. If the slice is taken at the center of the object, the intersection of the center, diagonal wall shall be equidistant from the side walls. Slices taken off center shall show the center wall proportionally displaced to one side or the other. By measuring the amount of displacement, the exact location of the slice relative to the center of the object can be calculated.

a) Select a CT slice (x-y plane) that passes through the test object within 20 mm of its center. The example in Figure 15 shows a portion of a CT slice containing the test object, slightly off center in the z axis.

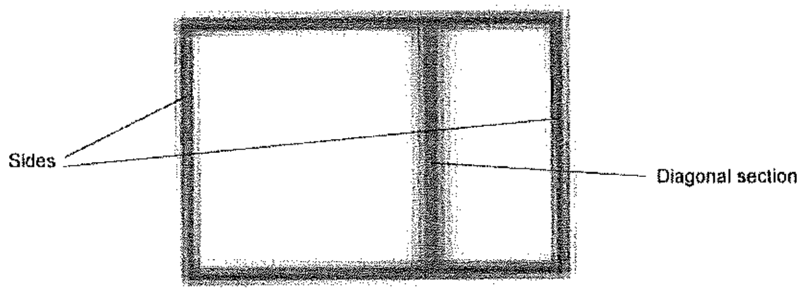


Figure 15—CT image of registration test object, slice plane 1

b) Designate a region of interest (ROI) within the slice that contains the plastic side walls plus at least one layer of air voxels, but excludes the aluminum plates and any other test object.

c) Within the ROI, select the horizontal line (x-axis direction) closest to the center of the test object and examine the profile of the line (as shown in Figure 16). Set *threshold* to equal 20% of the maximum value on this line.

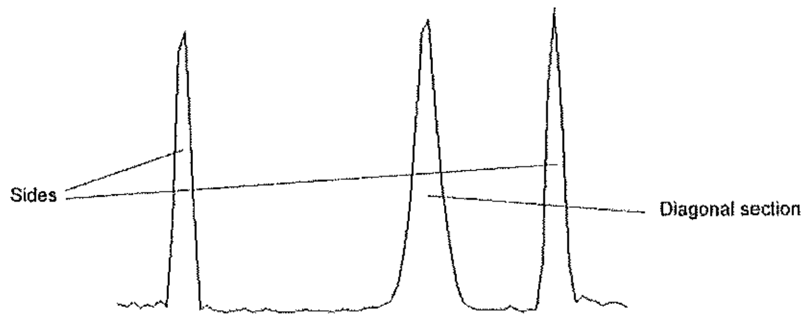


Figure 16—Horizontal line profile through CT slice of the registration test object

d) For each horizontal line in the ROI, examine the profile of the line and find all local maxima

1) Working from one end of the line, find the first point greater than *threshold*. Set *edge*1 equal to the location of this point.

2) Continuing in the same direction, find the last consecutive point after *edge*1 that is greater than *threshold* and set *edge*2 equal to its location.

3) If *edge*1 or *edge*2 are not found before reaching the end of the line, then no local maxima is found.

4) Compute the position of the peak based on its center of gravity as shown in the following equation:

$$position = \frac{\sum_{j=edge1}^{edge2} j \cdot f(j)}{\sum_{j=edge1}^{edge2} f(j)}$$

where

$f(j)$ is the value of the line profile at location j

5) Continue to process the line until all local maxima are found.

e) For each horizontal line, if there are exactly three peaks, and the distance between the first and last peak is within 5% of the width of the test object, select the line. Otherwise, do not include the line in the computation.

f) Calculate the average position of the first, middle, and last peak for the set of selected lines (*pLeft*, *pRight*, and *pCenter*, respectively, in mm).

g) Compute the position of the slice, with respect to the center of the test object, as shown in the following equation:

$$z_{rel} = z_{length} \cdot \left(-0.5 + \frac{pCenter - pLeft}{pRight - pLeft} \right)$$

where

z_{length} is the distance in mm between intersections of the centerline of the diagonal piece and the centerlines of the test object's two vertical acrylic sides, (specified in test article drawing in Annex B)

z_{rel} is the distance in mm of the slice from the center of the test object

h) Compute z_{CT}, the position of the center of the registration test object as measured with CT slices, as shown in the following equation:

$$z_{CT} = z_{Slice} + z_{rel}$$

where

z_{Slice} is the z coordinate in mm of the slice used for the analysis in the CT frame of reference

6.10.3.2 Measuring the test object position using a projection image

The procedure for finding the test object position in a projection image makes use of the aluminum plates at the leading and trailing edge of the object. In a projection image created with linear arrays of detectors across the direction of belt motion, these plates shall line up with the source/detector plane creating a large, sharp attenuation peak. By finding both peaks, the center of the object in the image can be calculated.

a) Designate an ROI within the projection image that contains the entire test object and a buffer of "air voxels" in the z-axis direction and the central 80% of the object in the x-axis direction.

b) Select a vertical line (z-axis direction). Figure 17 shows a projection image of the test object along with a line profile taken along the z-axis direction. Set *threshold* equal to 20% of the maximum value on this line.

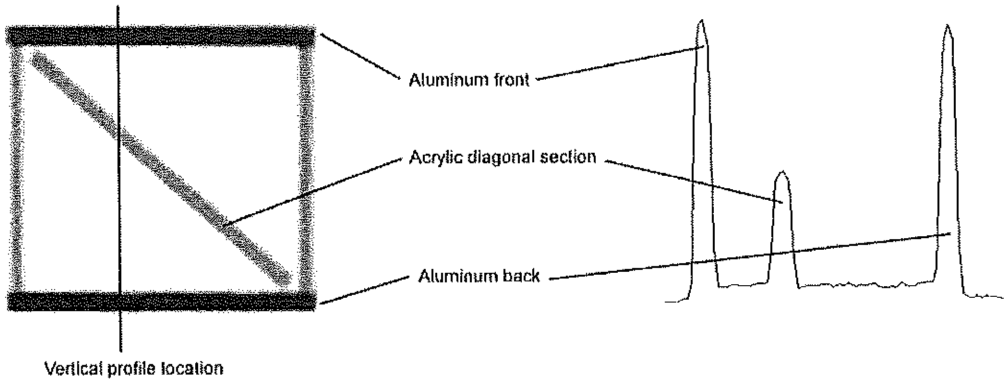


Figure 17—Projection image of the registration test object and vertical profile through image

c) For each vertical line in the ROI, examine the profile of the line and find all local maxima using the same method described in 6.10.3.1.

d) For each vertical line, if there are at least two peaks and the distance between the first and the last peak is within 5 % of the length of the test object, select the line. Otherwise, do not include the line in the computation.

e) Calculate the average position of the first and last peak for the set of selected lines (p_{First} and p_{Last} respectively in mm).

f) Calculate the position of the test object's center in the projection image as shown in the following equation:

$$Z_{SP} = \frac{1}{2}(p_{First} + p_{Last})$$

6.10.4 Presentation of results

The reported result shall be the difference between the test object's center location in each image used by the system. If the system uses only two imaging subsystems, the results shall be reported as a single signed number, labeled as "Registration Error" and reported in mm with one decimal place as follows:

Registration Error *x.x* mm

If the system uses more than two imaging subsystems, the results shall be reported as a table showing the differences from each image to all other images. The report shall also separately report the maximum difference.

Annex A

(informative)

Bibliography

[B1] ASTM F792-08, Standard Practice for Evaluating the Imaging Performance of Security X-Ray Systems.

[B2] Hanson, K. M:, "Detectability in computed tomographic images", *Medical Physics*, vol. 6, pp 441–451, 1979.

Annex B

(normative)

Detailed test article drawings

B.1 General

This annex provides details sufficient to build compliant copies of the test articles needed to carry out this standard. In conjunction with the drawings of the assembled test articles (Figure 2 and Figure 3) and the material specifications cited in Table 1, the user should be able to fabricate the test objects and build the test articles for use with this standard. It provides a list of commercial parts required to build the test articles. It provides a list of modifications done to a specific example of an outer case. (The actual modifications would be based on the exact case chosen by the user). It also provides detailed drawings of the custom parts that would need to be fabricated in order to assemble the test articles required.

B.2 Commercial parts

In addition to the materials noted on the drawings, the assembled test article requires the parts listed in Table B.1.

Table B.1—Commercial parts required for test article fabrication

Description	Quantity
Hard-plastic transportable case	2
Support structure A fasteners: M5-20 (nylon)	76
Support structure A fasteners: M6-20 (nylon)	14
Support structure A threaded rod: M6-35 (nylon)	2
Support structure B fasteners: M5-20 (nylon)	76
Support structure B fasteners: M6-20 (nylon)	2
Support structure B threaded rod: M6-35 (nylon)	2
polycarbonate rods, approx. 4.5 mm diameter for case hinge pins	6
polycarbonate rods, approx. 3.0 mm diameter for clamp hinge pins	6
Tin foil; 2.90 cm × 23.5 cm × 0.04 cm; 99.9 % pure	1
Lead foil; 2.90 cm × 23.48 cm × 0.015 cm; 99.9 % pure	1
Tungsten wire (pins); 0.15 cm OD, 5.0 cm long	4

B.3 Outer case modifications

The test articles described in this standard can be easily damaged. Therefore it is important to enclose them in an appropriate, rugged outer case to protect them from damage. The case may be selected for its size, ruggedness, and convenience. It shall not have any metal components or significant structures that might cause unintended artifacts in the images. It is permissible to use a commercially available case and modify it to remove problematic structures. As an example, this subclause discusses such modification made on a Pelican™ brand transportable case, model 1650-001-110 (the test article does not fit into the model currently in production, 1650-021-110, due to wheel wells).[8]

[8] Pelican brand cases are trademarks of Pelican Products, Inc., its affiliates or subsidiaries.

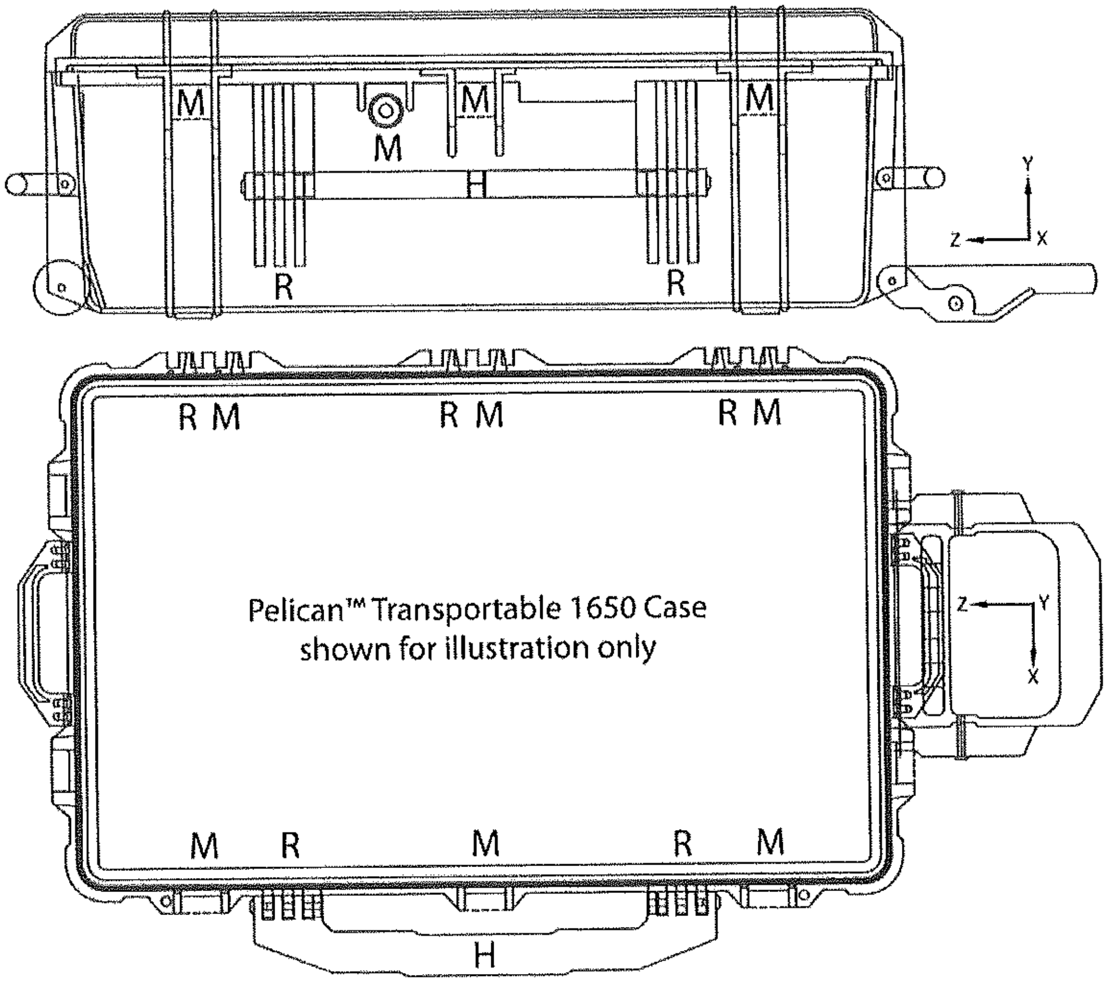


Figure B.1—Examples of modifications and their locations to prepare a commercial case for use in the test articles

The example case has nominal inner dimensions of 72 cm (z direction) by 45 cm (x direction) by 26 cm (y direction, refer to Figure B.1). To eliminate potential for image artifacts, the following steps were performed:

— Remove any handle along the sides (see "H" on drawing Figure B.1).

— Remove any plastic ribbing along the sides (see "R" on drawing Figure B.1).

— Replace any metal case hinge pins with ≥ 4.5 mm diameter polycarbonate rods, enlarging hinge slots if needed (see "M" on drawing Figure B.1).

— Replace any metal clamp hinge pins with ≥ 3 mm diameter polycarbonate rods, enlarging hinge slots if needed (see "M" on drawing Figure B.1).

— Any other metal components, such as a purge valve, should also be removed (see "M" on drawing Figure B.1).

Note that in this case, the handles at the front and back edges were left in place, as they are not imaged at the same time as the interior case.

To firmly support the test article support structure and test objects the following steps were performed:

— Line the lid of the case with rectangular open-cell polyurethane foam of 2.5 cm thickness (see Figure B.2).

— Line the bottom of the case with rectangular closed-cell polyethylene foam of 2.5 cm thickness (see Figure B.2).

— Line the four sides of the case with custom closed-cell polyethylene foam wedges (see Figure B.2).

— The closed-cell polyethylene foam shall have a density of 27 kg/m^3 to 35 kg/m^3 (1.7 lbs/ft^3 to 2.2 lbs/ft^3).

— This support shall be sufficient to ensure that the test article is centered within the case in the x direction to ± 2 mm.

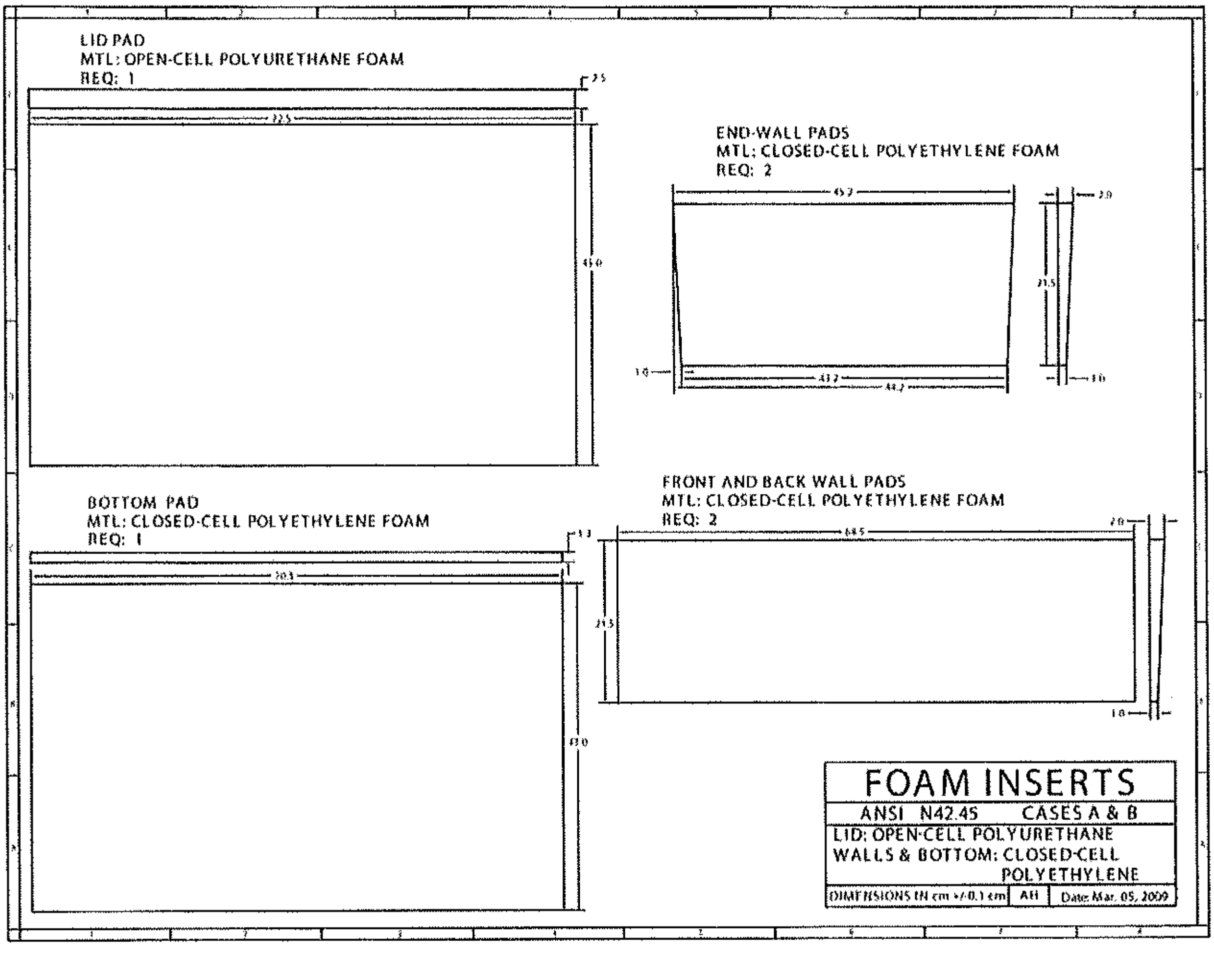


Figure B.2—Foam inserts for example outer case

B.4 Detailed drawings of custom components

The following detailed drawings provide the information needed to construct the unique parts of the test articles. Figure B.3 through Figure B.7 show the components needed to build test article A, while Figure B.8 through Figure B.11 show the components for test article B.

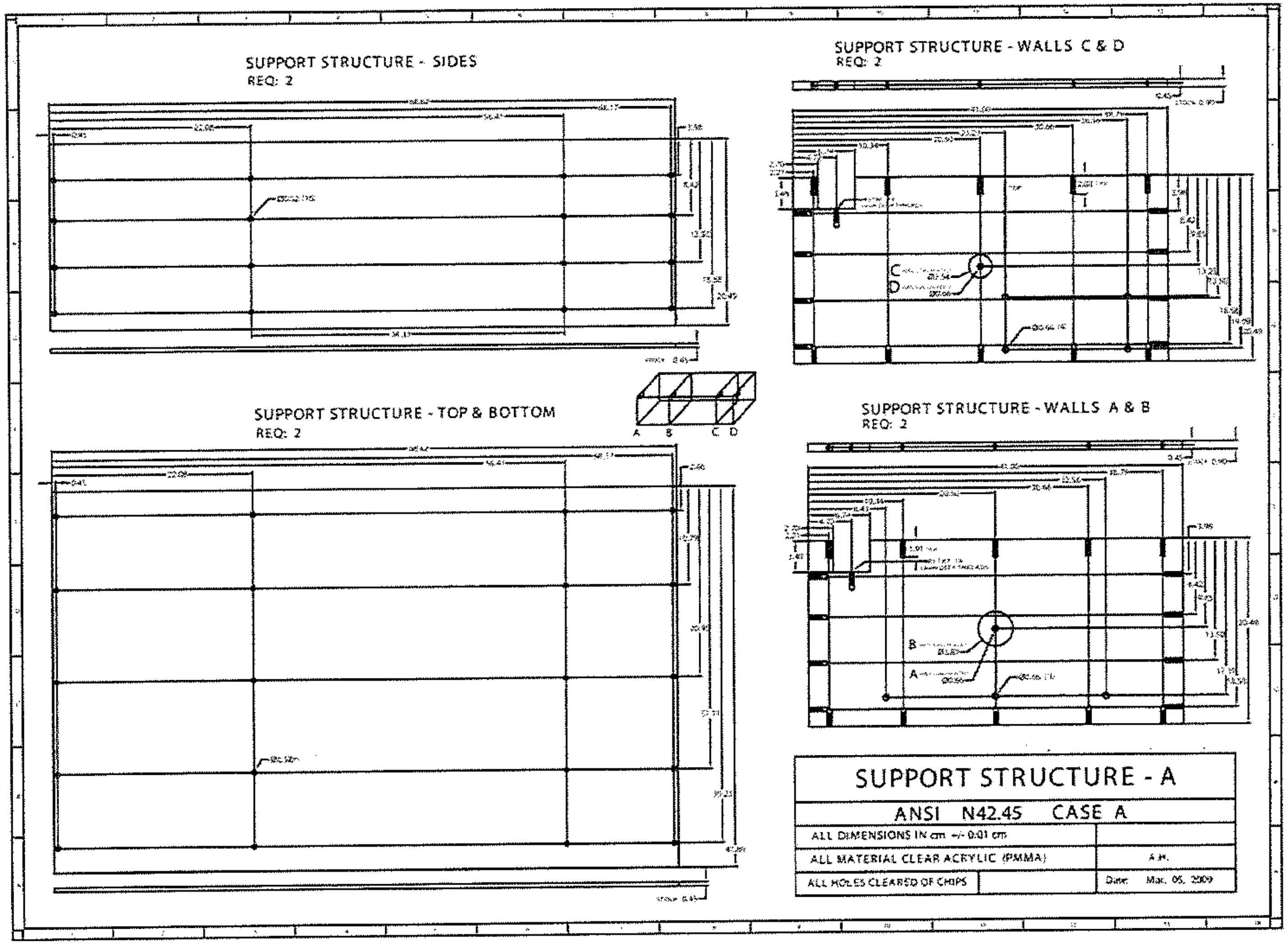


Figure B.3—Support structure for test article A

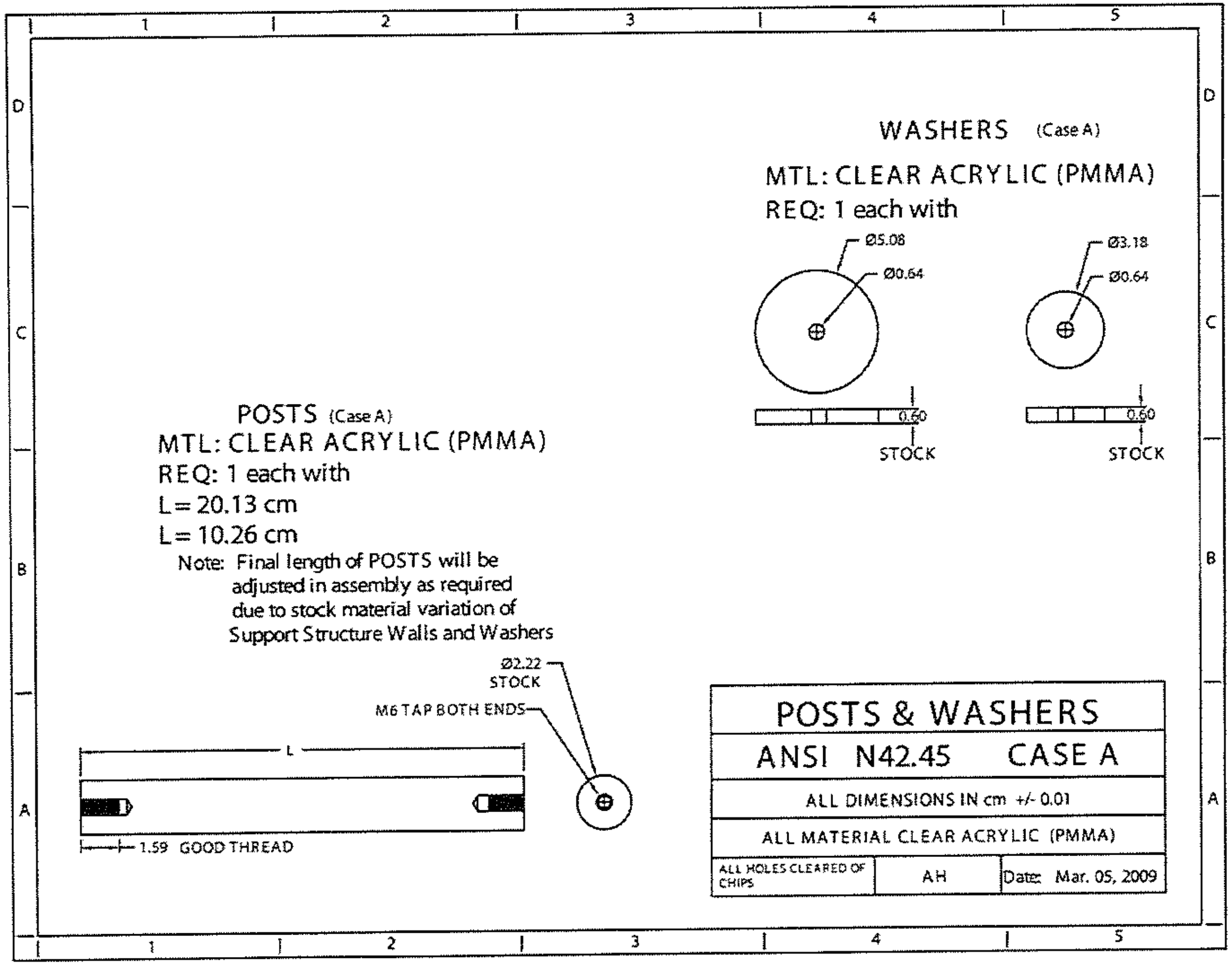


Figure B.4—Posts and washers for test object support in test article A

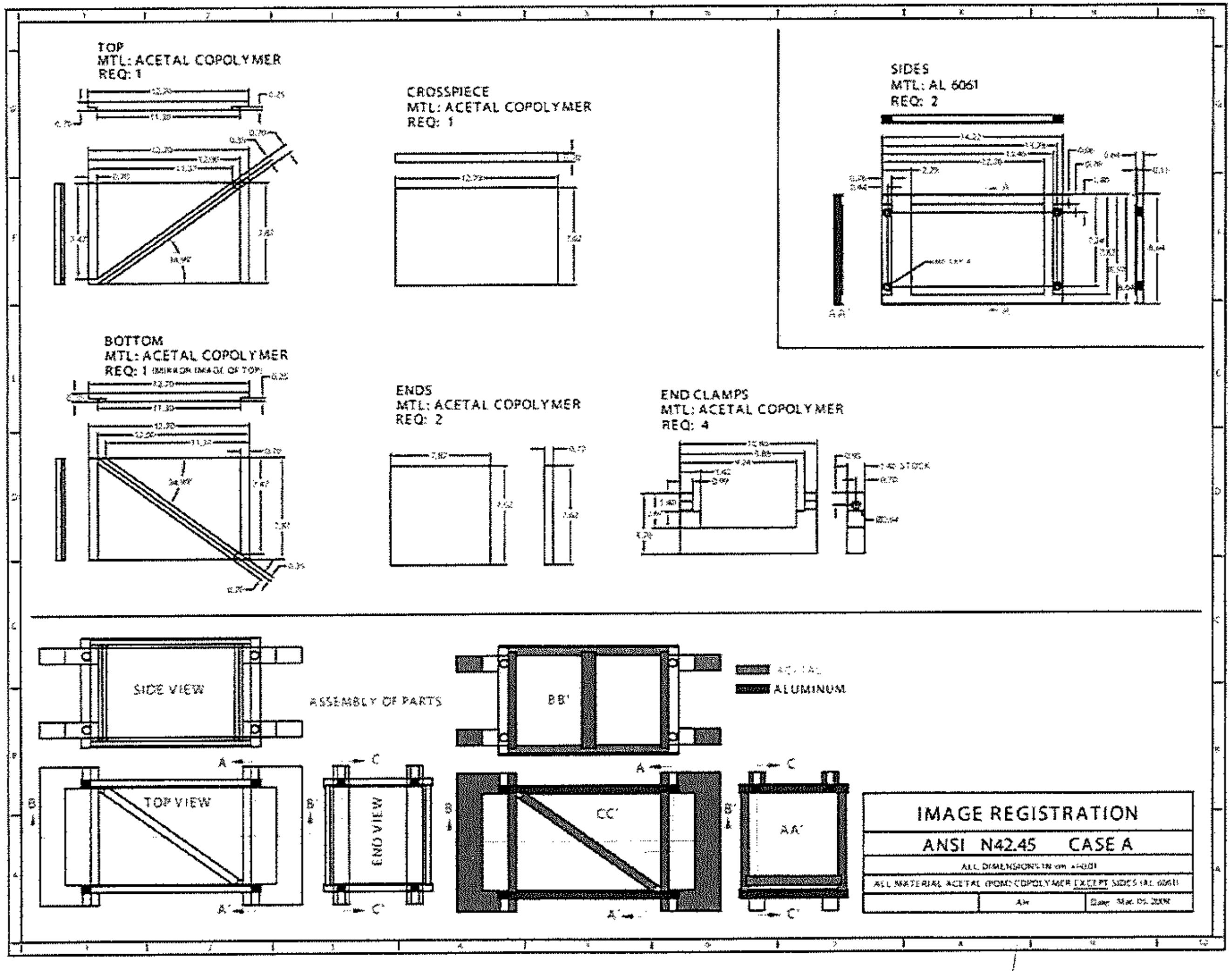


Figure B.5—Test object for the image (subclause 6.10)

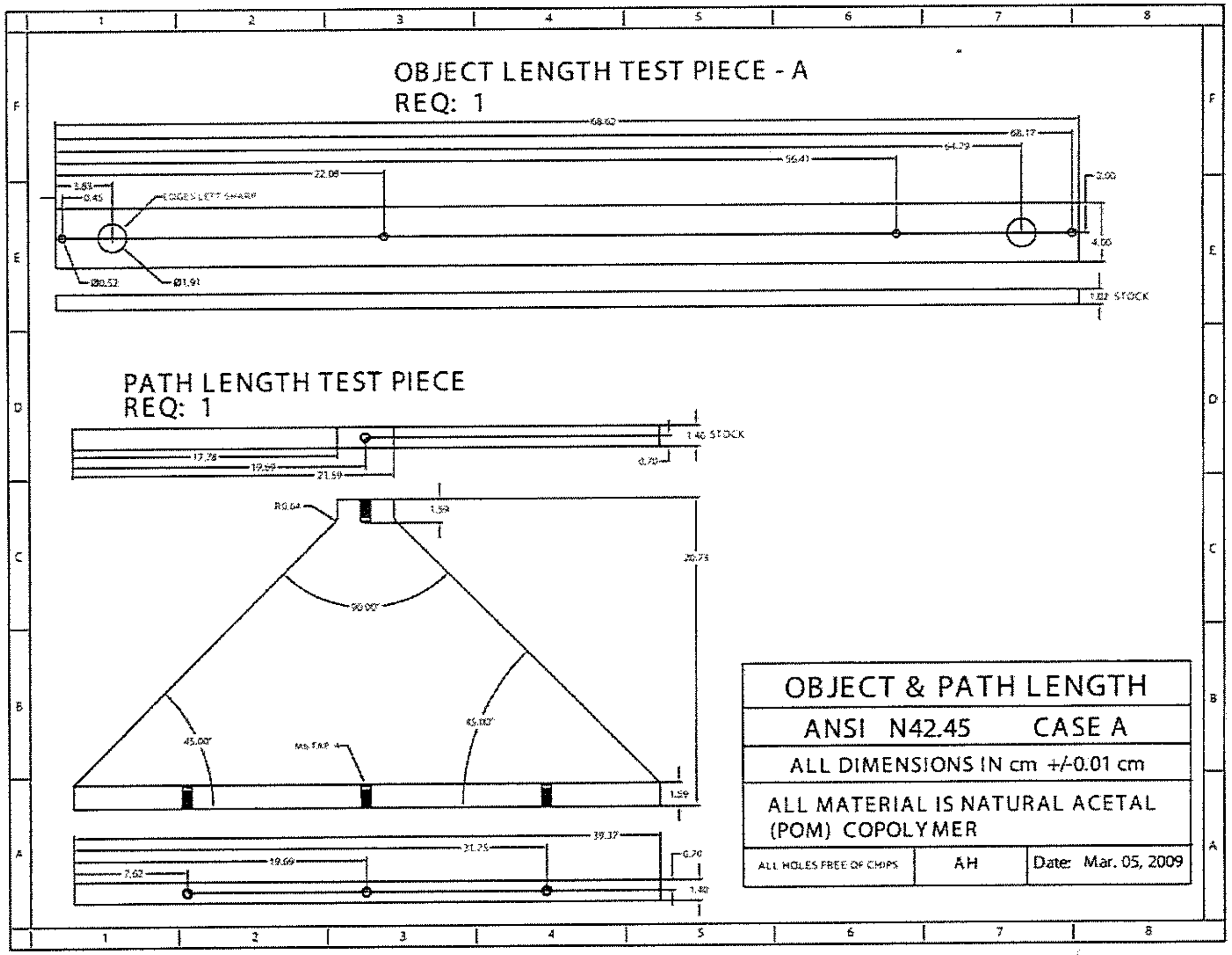
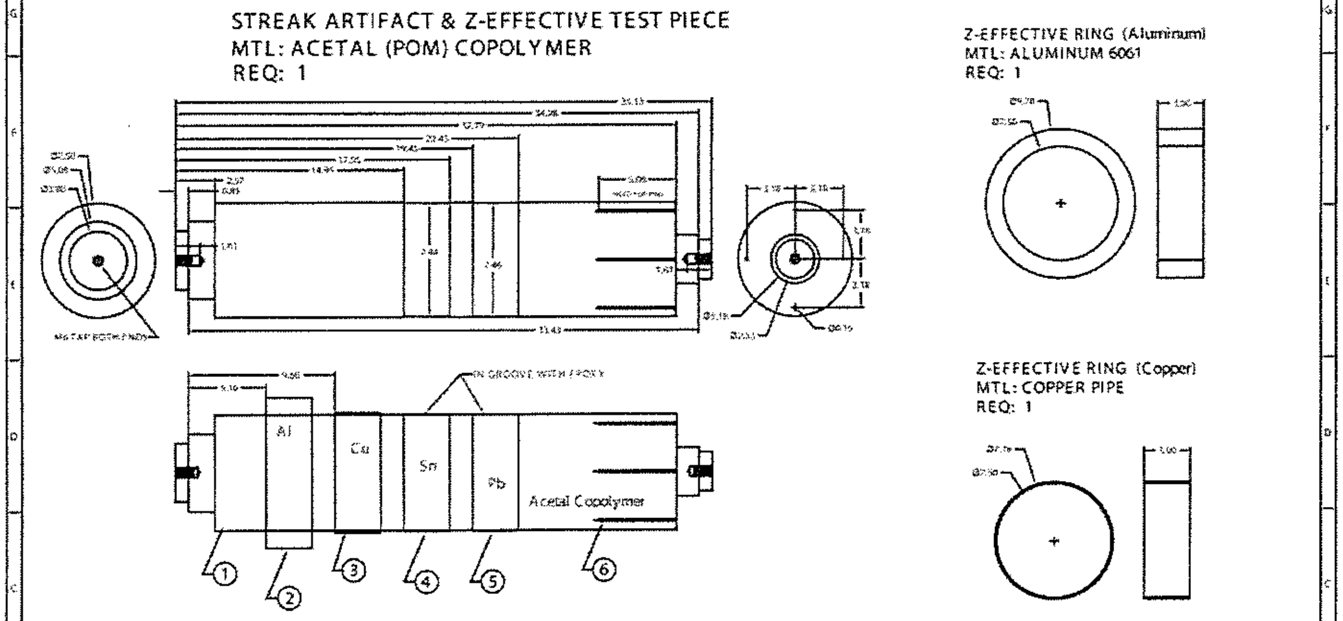


Figure B.6—Test objects for object length accuracy and path length CT value and Z_{eff} (subclauses 6.3 and 6.4)



Parts List

ITEM	QTY	COMPOSITION	THICKNESS
1	1	ACETAL COPOLYMER	
2	1	AL (6061)	1.14 cm
3	1	COPPER (99.9%)	0.14
4	1	TIN (FOIL) (99.9%)	0.04
5	1	LEAD (FOIL) (99.9%)	0.015
6	4	TUNGSTEN (PIN)	0.15 dia

STREAK & Z-EFFECTIVE
ANSI N42.45 CASE A
ALL DIMENSIONS IN cm +/-0.01 cm
TAPE/FOIL GAPS < +0, -0.025 cm
MATERIAL AS SPECIFIED
AH | Date: Mar. 05, 2009

Figure B.7—Test object for Z_{eff} and CT value uniformity and streak artifacts (subclauses 6.7 and 6.8)

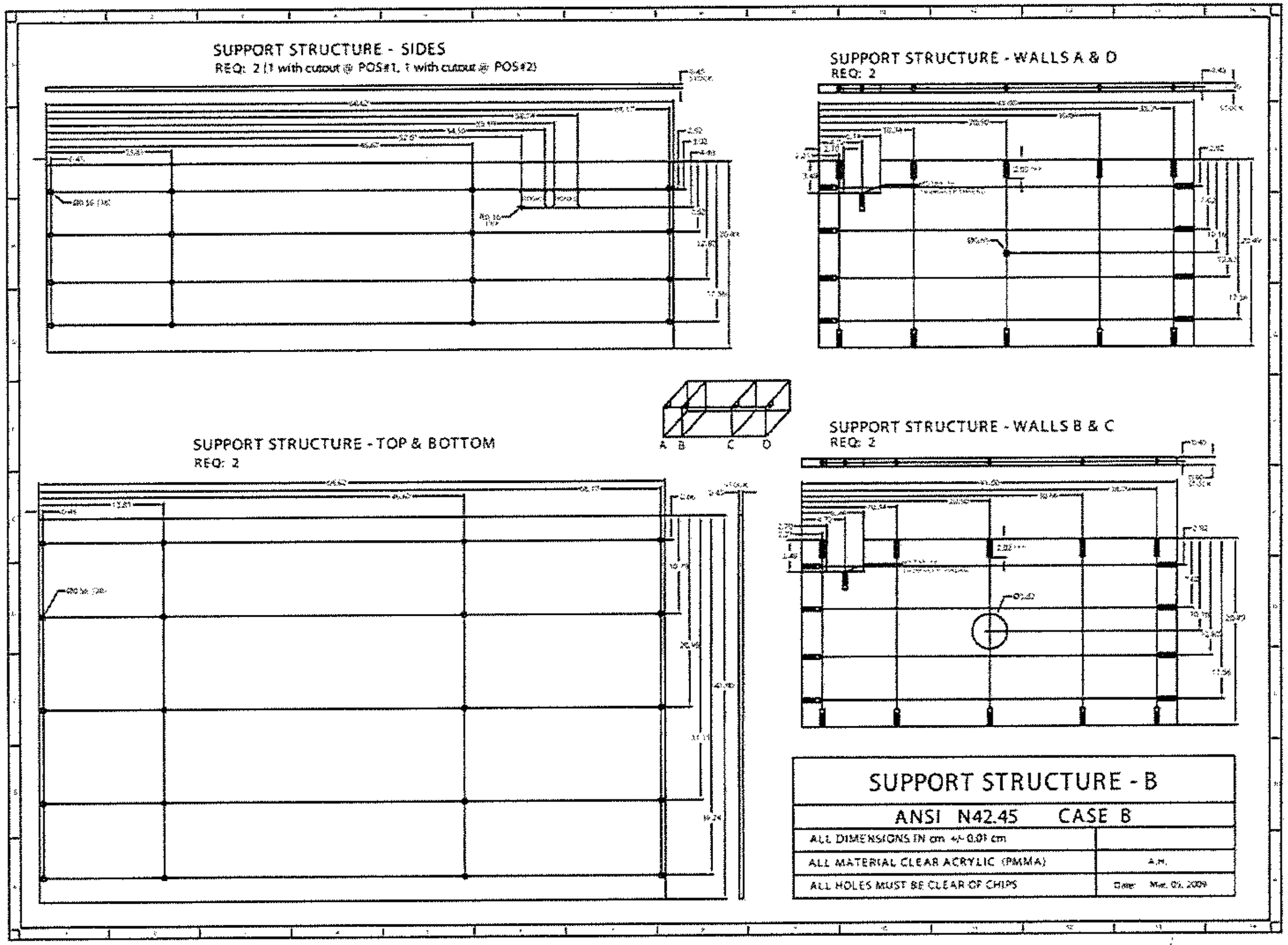


Figure B.8—Support structure for test article B

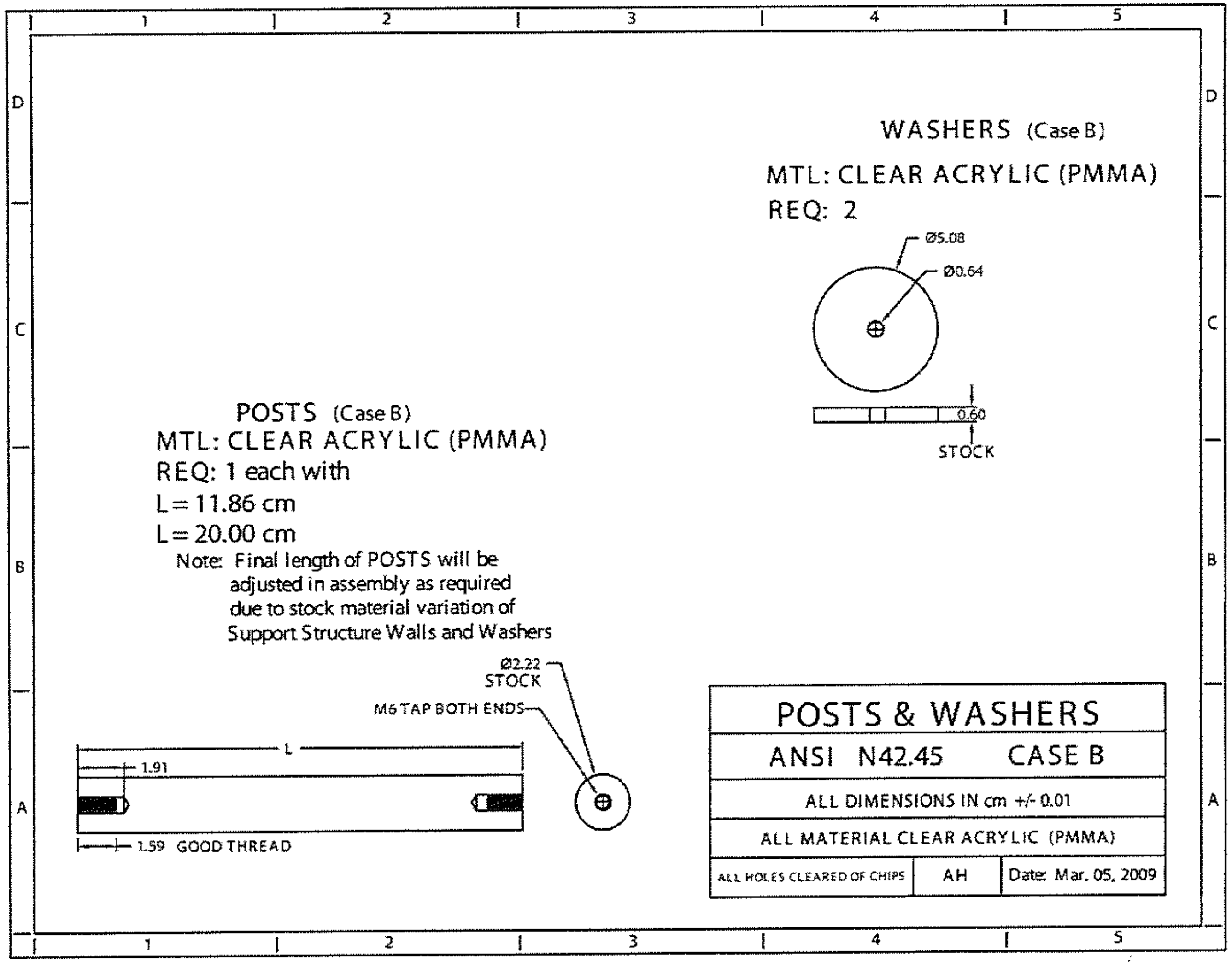


Figure B.9—Posts and washers for test object support in test article B

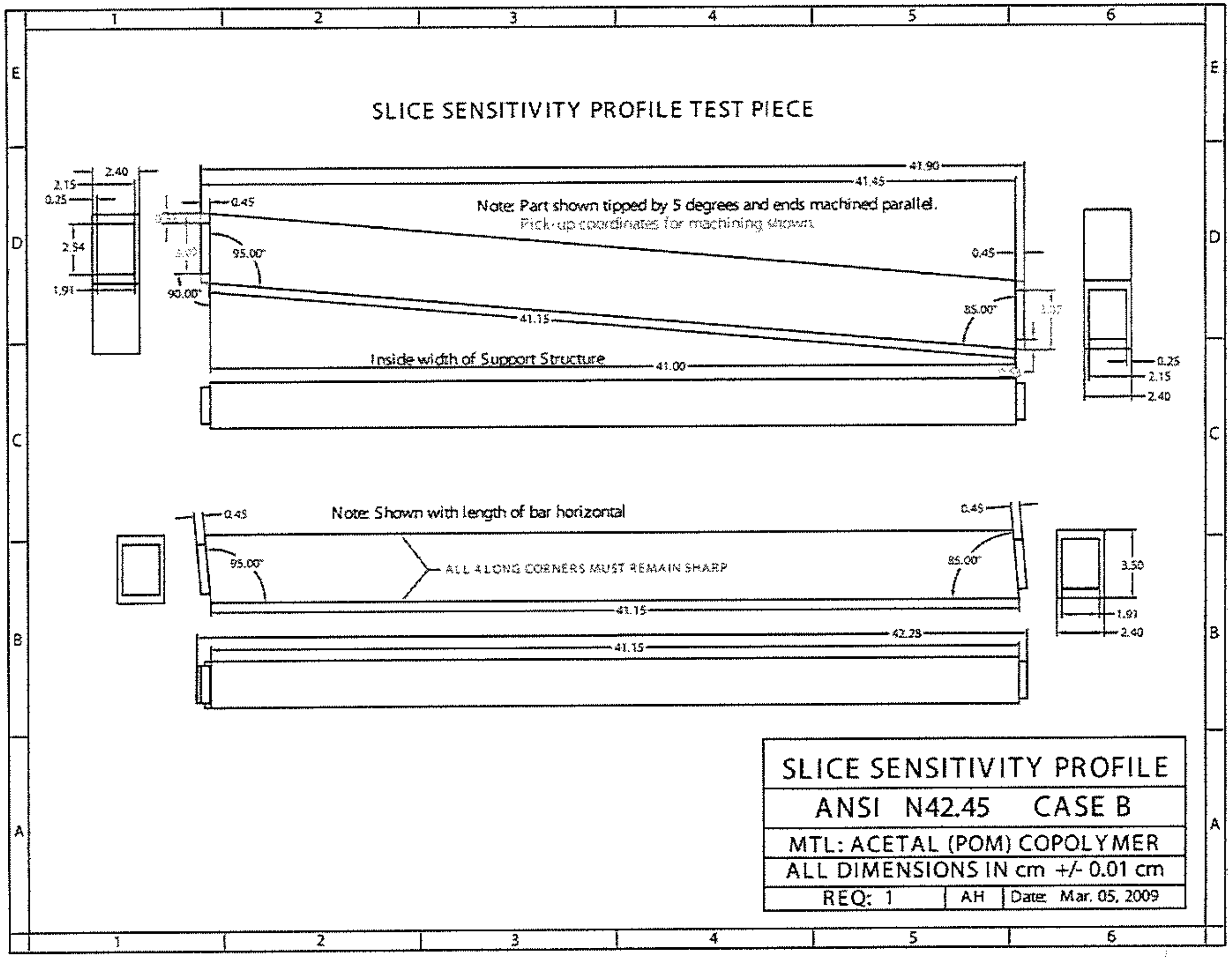


Figure B.10—Test object for slice sensitivity profile (SSP) (subclause 6.9)

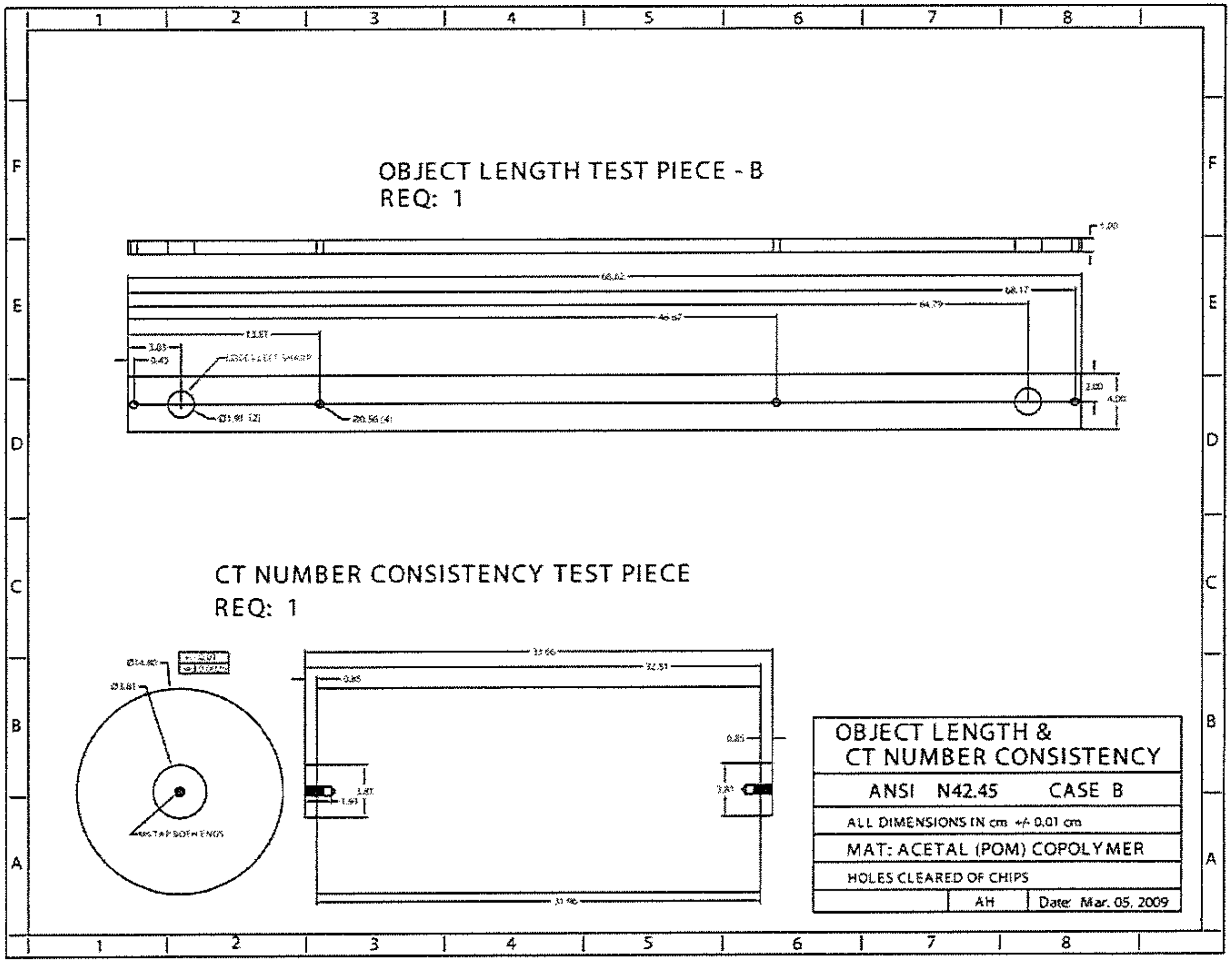


Figure B.11—Test articles for object length accuracy, noise equivalent quanta (NEQ), and CT value consistency (subclauses 6.3, 6.5, and 6.6)

Annex C

(informative)

Sample report

C.1 General

The following is an example of a report that would be generated in executing this standard. The first part is manually recorded observations of the test environment. The second part is the result of analysis of test article A, and the third part is from the analysis of test article B. The example machine is a single energy CT system with only one imaging subsystem. A dual energy system report would also include Z_{eff} data for several of the procedures. A system with multiple imaging subsystems or passes would also perform the Image method and report results (not shown here).

Image Quality Report

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

Manual Data Record

System Under Evaluation

Manufacturer:	X-ray Corp of America
Model:	Ameriscan 2000
Serial Number:	54321678
Configuration:	Stand Alone
Scanning Mode:	Helical Scan
Belt Speed:	20 cm/s

X-ray Source

Type:	1 tube, Continuous
Voltage:	180 kV
Current:	13 mA
Number of Hours:	253

Reconstruction Method: Filtered Back Projection

Voxel Spacing

x:	3 mm
y:	3 mm
z:	3 mm

Software Versions

Display:	1.2
Reconstruction:	1.6.1
System Control:	Am09.3
Operating System:	linux FC6

Evaluation Conditions

Local Time:	18:00
Date:	4/1/2009
Location:	234 22nd St., San Francisco, CA

Ambient Temperature:	22.1 C
Ambient Humidity:	72 %
Detector Temperature:	N/A

Comments: All tests went as planned.

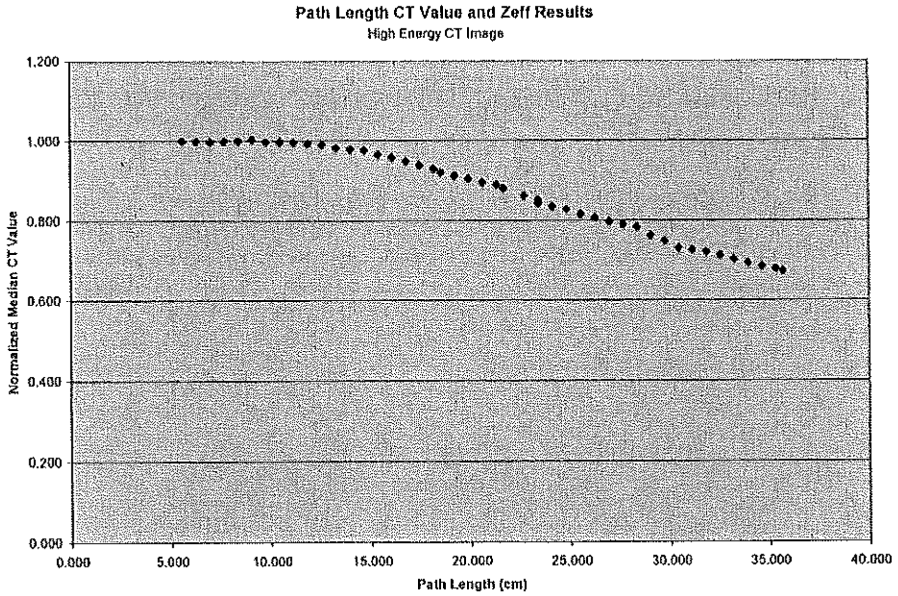
Scanning Personnel:	John Doe, TSA Sam Smith, SFO Airport Lisa Jones, X-ray Corp.
Telephone Number:	412 555 1234
Test Article Manufacturer:	NIST Labs
Test Article S/N's:	A – 021 B – 034

Test Article Version: A

Presentation statistics

−1. 8 mm	Bag horizontal offset from center of system
161.6 mm	Vertical offset from center of system
0.17°	Angle of presentation
±2.0°	Allowed angular tolerance

Object length: 607.35 mm 99.63 % of physical length.



Z_{eff} and CT value uniformity results

			Absolute measurements		Measurements relative to CTRL values	
			Mean	**Std**	**Mean**	**Std**
CT value uniformity	Acetal	**CTRL**	1419.13	6.02	1.00	1.00
		Al	1458.84	10.60	1.03	1.76
		Cu	1844.14	84.80	1.30	14.08
		Sn	1681.29	55.90	1.18	9.28
		Pb	1755.87	90.61	1.24	15.05
	Al	**Ring Density**	2590.75	426.12	1.83	70.76

Streak artifacts results

		Absolute measurements				Measurements relative to CTRL values			
Streak artifact results		MEAN	STD	STD/ MEAN	(Max – Min)/ Mean	MEAN	STD	STD/ MEAN	(Max – Min)/ Mean
CTRL	Line	**1401.74**	**46.19**	**0.033**	**0.20**	**1**	**1**	**1**	**1**
	Region	**1420.99**	**5.17**	**0.004**	**0.02**	**1**	**1**	**1**	**1**
Rod area	Line	**1398.11**	**85.24**	**0.061**	**0.32**	**1.00**	**1.88**	**1.89**	**1.66**
	Region	**1411.93**	**81.37**	**0.058**	**0.32**	**0.99**	**15.99**	**16.10**	**18.44**

Image Results

Not Applicable to this machine

Test Article Version: B

Presentation statistics

–6.93 mm	Bag horizontal offset from center of system
164.55 mm	Vertical offset from center of system
0.30 °	Angle of presentation
± 2.0	Allowed Angular Tolerance

Object length: 605.22 mm 99.28 % of physical length.

Noise equivalent quanta (NEQ) results

Frequency (cm^{-1})	NEQ Method 1 (dB)	NEQ Method 2 (dB)	MTF
0.5	**17.8** ± 0.18 [17.5, 18.1]	**14.1** ± 0.27 [13.7, 14.5]	**0.79** ± 0.004 [0.787, 0.799]
1.0	**13.6** ± 0.31 [13.2, 14.1]	**11.6** ± 0.33 [11.0, 12.3]	**0.45** ± 0.010 [0.426, 0.459]
1.5	**7.0** ± 0.57 [6.2, 7.7]	**5.1** ± 0.56 [4.2, 6.0]	**0.16** ± 0.011 [0.145, 0.174]

	NEQ Method 1	NEQ Method 2
Number of Images	64	64
Number of Pairs	32	

CT value consistency results

Median of means:	1414.43
Standard deviation of means:	7.47
Mean of standard deviations:	21.30
Standard deviation of standard deviations:	3.96

Slice sensitivity profile (SSP) results

Frequency (cm^{-1})	SSP
0.5	**0.80** ± 0.03
1.0	**0.31** ± 0.04
1.5	**0.08** ± 0.03

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