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# INTERNATIONAL STANDARD

# NORME INTERNATIONALE

colour inside

## Radiation protection instrumentation – Measuring the imaging performance of X-ray computed tomography (CT) security-screening systems

## Instrumentation pour la radioprotection – Mesure des performances d'imagerie des systèmes de contrôle de sécurité utilisant la tomographie par ordinateur (CT) à rayons X



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# RADIATION PROTECTION INSTRUMENTATION – MEASURING THE IMAGING PERFORMANCE OF X-RAY COMPUTED TOMOGRAPHY (CT) SECURITY-SCREENING SYSTEMS

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The text of this International Standard is based on the following documents:

| FDIS | Report on voting |
|---|---|
| 45B/908/FDIS | 45B/910/RVD |

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

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# INTRODUCTION

This document establishes standard test methods and test objects for measuring the imaging performance of x-ray computed tomography (CT) security-screening systems. The quality of data for automated analysis is the primary concern. This document 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.

Three annexes are included. Annex A (normative) provides mechanical drawings of the imaging test objects that compose the test article. A sample test report form is given in Annex B (informative). Annex C (informative) offers statistical guidance on multiple scans, summary statistics, and comparison of results. Finally, a bibliography is given (informative).

# RADIATION PROTECTION INSTRUMENTATION – MEASURING THE IMAGING PERFORMANCE OF X-RAY COMPUTED TOMOGRAPHY (CT) SECURITY-SCREENING SYSTEMS

## 1 Scope

This document provides test methods for the evaluation of image quality of computed tomography (CT) security-screening systems. The quality of data for automated analysis is the primary concern. This document does not address the system's ability to use this image data to automatically detect explosives or other threat materials, nor is it intended for vendor-to-vendor comparisons of threat-detection performance.

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



Historically, government regulators have established evaluation procedures to determine whether a system's automated detection performance is adequate for use in applications within their borders. Typically, a vendor submits a copy of their product, including their software to the regulator's facility. The regulator runs a wide variety of parcels with threats inside through the system as well as parcels without threats that represent the typical stream of commerce. Detection and false alarm rates are determined and compared against performance criteria. If the criteria are met, the system is approved for use. This testing ensures that the system is capable of meeting the required criteria, but how does one ensure 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 document 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. 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 document specifies a set of methods to apply in assessing CT image quality geared towards security screening. An application of this document would be in the factory acceptance testing of equipment. The document 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 document 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 document 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 [1].[1]

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.



IEC 60050-395:2014, *International Electrotechnical Vocabulary – Part 395: Nuclear instrumentation: Physical phenomena, basic concepts, instruments, systems, equipment and detectors*



IEC 60050-881, *International Electrotechnical Vocabulary. Radiology and radiological physics*

ASTM E1695, *Standard Test Method for Measurement of Computed Tomography (CT) System Performance*

ASTM publications are available from the ASTM International, *100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA* (http://www.astm.org/).

ASTM D6100, *Standard Specification for Extruded, Compression Molded and Injection Molded Polyoxymethylene Shapes (POM)*

SAE AMS 4027: *Aluminum Alloy, Sheet and Plate, 1.0Mg – 0.60Si – 0.28Cu – 0.20Cr (6061; -T6 Sheet, -T651 Plate), Solution and Precipitation Heat Treated*

SAE AMS 4117: *Aluminum Alloy, Rolled or Cold Finished Bars, Rods, and Wire and Flash Welded Rings, 1.0Mg – 0.60Si – 0.28Cu – 0.20Cr, (6061; -T6, -T651), Solution and Precipitation Heat Treated*

## 3 Terms and definitions, abbreviated terms, quantities and units

### 3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply. The general terminology concerning x-ray systems and radiological physics is given in IEC 60050-395 and IEC 60050-881.

[1] Numbers in square brackets refer to the Bibliography.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

**3.1.1**
**computed tomography**
**CT**
process of rendering a three-dimensional image of a volume based on x-ray projection data

**3.1.2**
**CT value**
value reported by CT systems on a per voxel basis that is a function of the material's density and atomic number

**3.1.3**
**coronal image**
two-dimensional image produced by summing a three-dimensional volume image along the y-axis

Note 1 to entry: Axes defined in Figure 1.

**3.1.4**
**effective atomic number**
$Z_{\mathrm{eff}}$
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



Note 1 to entry: $Z_{\mathrm{eff}}$ measurements can be scanner-dependent and should not be considered absolute values.

**3.1.5**
**mean**
for $n$ quantities, $x_1, x_2, \ldots x_n$, the quotient of the sum of the quantities by $n$:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

**3.1.6**
**modulation transfer function**
**MTF**
frequency-dependent measure of an imaging system's resolution or ability to reproduce object contrast. In one dimension it is computed from the system's response to an edge of high contrast using ASTM E1695

**3.1.7**
**multi-energy**
x-ray imaging system that collects image data at more than one x-ray energy spectrum

Note 1 to entry: 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.

**3.1.8**
**noise equivalent quanta**
**NEQ**
spatial-frequency-dependent measure of noise, interpreted as the number of quanta (radiation exposure) that an ideal detector would have needed to yield the same signal-to-noise ratio as an actual imaging system. It is computed from measurements of average CT value in an imaged object, the system's modulation transfer function and noise power spectrum

**3.1.9**
**noise power spectrum**
**NPS**
spatial-frequency-dependent variance of an imaging system's noise, computed using the Fourier transform of uniform noise-limited images

**3.1.10**
**projection image**
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

**3.1.11**
**registration**
spatial relationship between the coordinate systems of multiple imaging subsystems. It determines the ability to accurately correlate observations from one image to the others



**3.1.12**
**slice**
cross-sectional image of the inspected object



Note 1 to entry: The normal of the plane of the image is in the direction of the conveyer belt motion (*z* axis).

**3.1.13**
**slice sensitivity profile**
**SSP**
frequency-dependent measure of CT image resolution along the direction of the conveyer belt motion (*z* axis)

**3.1.14**
**standard deviation**
sample standard deviation, $\sigma_n$, of *n* quantities, $x_1$, $x_2$, ... $x_n$ given by:

$$\sigma_n = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2} \text{ where } \bar{x} \text{ is given by 3.1.5}$$

**3.1.15**
**standard mode of operation**
mode of operation normally recommended by the manufacturer for inspection of parcels

Note 1 to entry: Some systems have special modes for collecting extra data for training. This would not be considered a standard mode of operation.

**3.1.16**
**test article**
item, to be imaged by the system, containing multiple test objects in a specific geometric layout

Note 1 to entry: As used in this document, test article refers to the specific items defined in 4.2.

**3.1.17**
**test object**
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

**3.1.18**
**voxel**
volume element representing a rectangular prism-shaped region in space within a volumetric image

### 3.2 Abbreviated terms

CT computed tomography

MTF modulation transfer function

NEQ noise equivalent quanta

NPS noise power spectrum

POM polyoxymethylene

NOTE POM is the acetal copolymer $(CH_2O)_n$ of which the test objects of this document are fabricated.

ROI region of interest (in an image)

SNR signal-to-noise ratio

SSP slice sensitivity profile

### 3.3 Quantities and units



In this document, the units are the multiples and sub-multiples of units of the International System of Units (SI) [2]. The definitions of radiation quantities are given in IEC 60050-395:2014.



The following units may also be used:

- for energy: electron-volt (symbol: eV), 1 eV = 1,602 x $10^{-19}$ J;
- for time: years (symbol: y), days (symbol: d), hours (symbol: h), minutes (symbol: min):
- for temperature: degrees Celsius (symbol: °C), 0 °C = 273,15 K.

Multiples and submultiples of SI units are used, when practicable, according to the SI system.

## 4 Imaging performance evaluation procedures

### 4.1 General test performance requirements

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 ensure 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. Changes in CT image reconstruction software should be followed by gathering a new baseline measurement set. Alternatively, new baseline results may be recomputed offline if the data are available.

The test articles (see 4.2) 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 centerline of the system conveyor. Results for rotations more than 2 degrees off parallel from conveyor centerline shall be rejected. This document requires that the test articles be measured at the center of the belt, directly on the belt, within ± 2 cm of the conveyor centerline. If the user decides to also run the test articles off centerline, 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 document.

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 document 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.



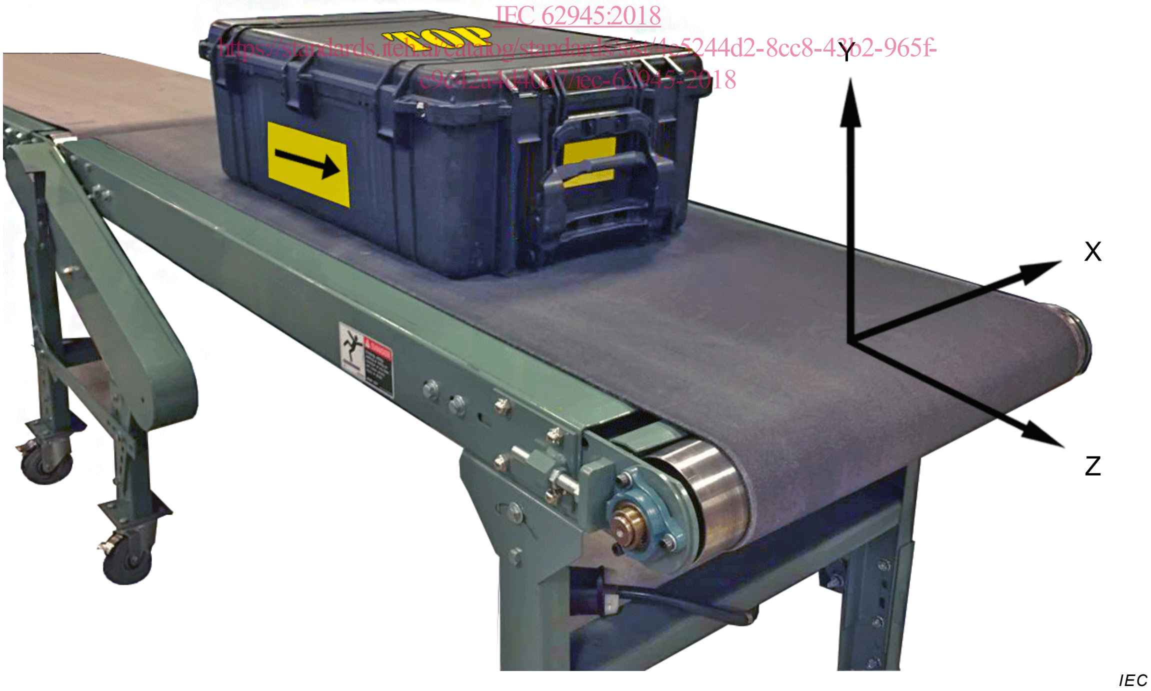


**Figure 1 – Reference axes for testing procedures**

## 4.2 Description of test articles

Execution of this document 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 or custom-built carrying case.