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Test and Evaluation Report for the Assessment of the Australian Image Quality Test Objects for Palletized Cargo X-ray Systems

Michael Snyder
Curtis Bell, Ph.D.

U.S. Department of Homeland Security
Science & Technology Directorate
William J. Hughes Technical Center
Atlantic City International Airport, NJ 08405

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Test and Evaluation Report

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16. Abstract

This document describes the results of an assessment of two palletized cargo X-ray machine image quality test objects developed by the Australian Nuclear Science and Technology Organisation. Testing occurred at the Transportation Security Administration's Transportation Security Integration Facility (TSIF) located at the Ronald Reagan Washington National Airport from June 10-13, 2013. A Rapiscan 632DV and a Smiths 180180-2is cargo screening X-ray machines located at the TSIF were used for the data collection and assessment, as well as a Smiths emulator for playing back archived images. The Critical Operational Issues that were investigated were broken down into five categories. They include spatial resolution, contrast sensitivity, X-ray penetration, point spread function, and modulation transfer function.

A human factors assessment was also conducted, and this document provides suggested improvements for possible inclusion in later versions of the test objects and associated scoring database.

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EXECUTIVE SUMMARY

The Australian Nuclear Science and Technology Organisation developed two test objects that can be used to assess the image quality of palletized cargo X-ray machines that have energy sources from 140 kilovolts and higher. These test objects are appropriate for the larger aperture systems, such as those used to screen palletized cargo. The Explosives Division of the Department of Homeland Security Science and Technology Directorate sponsored an assessment of these test objects by the Transportation Security Laboratory at the Transportation Security Administration Systems Integration Facility located at the Ronald Reagan Washington National Airport.

The Critical Operational Issues (COIs) that were investigated were broken down into five categories. They included spatial resolution, contrast sensitivity, X-ray penetration, point spread function, and modulation transfer function. However, the last two COIs could not be investigated due to the fact that test engineers could not open image files that were in Smiths proprietary format.

The results show that the Australian image quality (IQ) test objects are well designed, constructed, and easy to use. The two-degree incremental adjustments make the task of setting the objects perpendicular to the X-ray beam relatively quick to accomplish, and the test objects can be expeditiously tailored to the X-ray machine, whose capabilities are going to be assessed. In addition, the spatial resolution and penetration tests have very fine graduations thus allowing accurate system assessments.

When compared to an IQ test object built to the American National Standards Institute (ANSI) N42.46-2008 standard, the Australian test objects provided more precise measurements using its wire based spatial resolution test because it has three more wires than the ANSI test object. Further, the Australian test objects provide users an added benefit of taking measurements in air, as well as behind three different thicknesses of steel. Conversely, the ANSI test object has two more line-pair gauges than the Australian test objects; however, the ANSI test objects require the user to manually rotate the line-pairs and rescan the test objects.

The penetration test of the ANSI test object contains approximately 4.75” more steel than the Australian test objects, and ANSI test objects contain thinner plates allowing for a more precise measurement for penetration testing. The Australian test objects lack a rotatable kite associated with their penetration test, which helps ensure that persons scoring the test can actually perceive the kite through the various steps and does not simply believe they are seeing it. Lastly, the Australian test objects have five different, but related, tests to measure an X-ray machine’s contrast sensitivity, something that is not currently available with an ANSI test object.

Based on very limited data, it appears that the test objects can be within +/- 12 degrees from perpendicular to the X-ray beam before the measurements begin to degrade. However, the scoring of some tests do not appear to differ throughout the full range of tested angles (i.e., +/- 20 degrees). These tests include Tests 1, 6, and 8, which measure spatial resolution; Tests 2, 3, and 7, which measure contrast sensitivity; and Test 9, which measures X-ray penetration. Since this observation is based on only two test engineers' scores, readers should not base any decisions, policy, or qualification testing on this information.

ACRONYMS

ACSTL	Air Cargo Screening Technology List
ANSI	American National Standards Institute
ANSTO	Australian Nuclear Science and Technology Organisation
ASTM	American Society for Testing and Materials
COI	Critical Operational Issues
DHS	Department of Homeland Security
IQ	Image Quality
kV	Kilovolts
MOP	Measure of Performance
TSA	Transportation Security Administration
TSIF	TSA Systems Integration Facility

1. INTRODUCTION

1.1 Background

The Department of Homeland Security (DHS) is interested in developing and enhancing aviation security equipment and procedures to protect the traveling public. One specific area of interest involves the screening of air cargo that is transported using commercial and cargo airliners. In support of the Implementing Recommendations of the 9/11 Commission Act of 2007 (P. L. 110–53), DHS was tasked with screening 100 percent of cargo transported on passenger airlines by 2010. To this end, the Transportation Security Administration (TSA) has developed a process for qualifying X-ray machines and other non-imaging equipment (e.g., explosive trace detection systems and cargo metal detectors) for screening air cargo. After cargo screening systems have successfully met all applicable requirements and operational testing, they are placed on the Air Cargo Screening Technology List (ACSTL). Air cargo that is screened with equipment that is not on the ACSTL is not allowed to be placed on passenger aircraft.

As part of the qualification process, X-ray machines are required to meet minimum image quality criteria. TSA currently uses a device built to the American National Standards Institute (ANSI) N42.46-2008 standard, as well as the American Society for Testing and Materials (ASTM), International's F792-08 X-ray Test Object for measuring conformance to these criteria. However, ASTM does not recognize the use of the latter test object for assessing systems with tunnel apertures larger than 1 meter x 1 meter [1].

The Australian Nuclear Science and Technology Organisation (ANSTO), with funding from the Australian Government, developed two test objects that can "effectively evaluate the performance of most [X-ray] scanners (from 140 kilovolt [kV] and above) within minutes" [2]. These test objects, called XIQ-1 and XIQ-2, are appropriate for the larger aperture systems, such as those used to screen palletized cargo. ANSTO's two test objects are shown in Figure 1. DHS Science and Technology's Explosives Division requested that the Transportation Security Laboratory assess ANSTO's two test objects.

Figure 1. ANSTO image quality test objects.

1.2 Purpose

The purpose of this document is to describe the equipment, procedures, and methodology used to evaluate two image quality (IQ) test objects developed by ANSTO. It also outlines the results of the assessment.

1.3 Scope

Because of the limited funding associated with this effort, the project scope was restricted to the initial use of two large-aperture X-ray machines (categorized as Capacity C systems on the ACSTL) located at the TSA Systems Integration Facility (TSIF). The X-ray systems were only a conduit for collecting data related to the test objects. In addition, a lack of funding limited the test personnel to two federal employees with cargo equipment experience to collect, score, and report the results. This resulted in reporting generalizations of data observed and not statistically based conclusions.

2. ANSTO XIQ-1 AND XIQ-2 TEST OBJECTS DESCRIPTION

The ANSTO test objects incorporate nine different tests. They include XIQ-1 and XIQ-2 and are described within this section.

2.1 XIQ-1 Description

The XIQ-1 (see Figure 2) is composed of five different tests. Each test is described below.

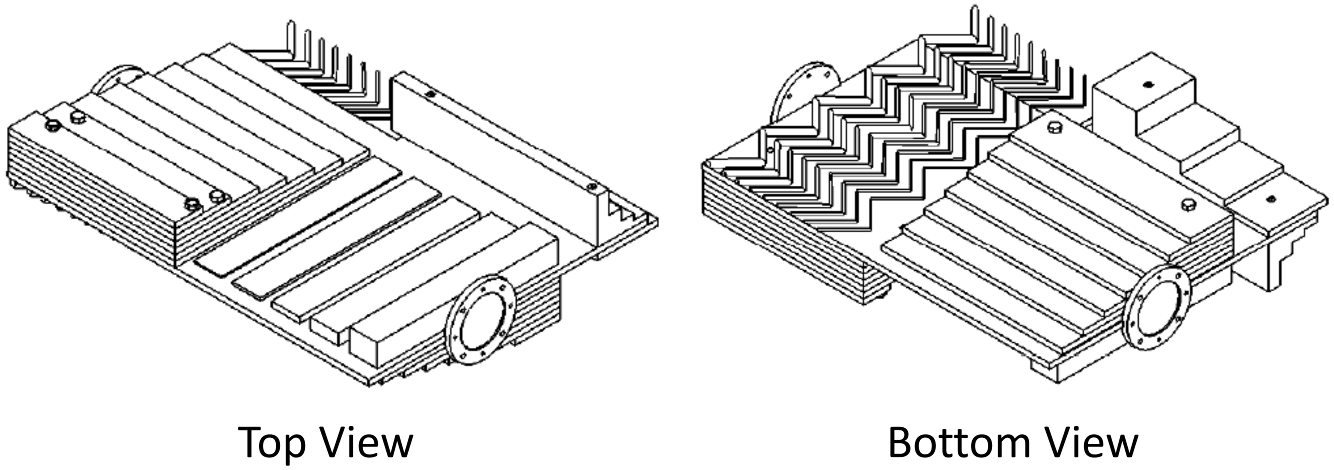


Figure 2. Drawing of the top and bottom view of the XIQ-1 test object.

<u>Test 1</u>

Test 1 is an image resolution test. It is made up of nine wires bent into a zigzag pattern best seen on the left hand side of the bottom view of Figure 2. The wire diameters range from ø (diameter)

10 to ø1. The wires are placed behind a steel step wedge with seven steps, with the first portion of the wires in air. The steel steps are in increments of 10 mm each. The step wedge and air portion create eight subsections of this test. The test is scored by observing how many wires are visible for each thickness of steel and air.

Test 2

Test 2 evaluates the thickness resolution of Delrin. It consists of a Delrin step wedge with steps that are 80mm, 40mm, 20mm, and 10mm thick. The portion of the step wedge used for this test sits in air. The test is scored by observing if each block can be clearly discriminated from its background.

Test 3

Similar to Test 2, Test 3 evaluates the thickness resolution of polyethylene. It consists of a polyethylene step wedge with steps 80mm, 40mm, 20mm, and 10mm thick. The portion of the step wedge used for this test sits in air. The test is scored by observing if each block can be clearly discriminated from its background.

Test 4

Test 4 evaluates contrast sensitivity. The test consists of five steel bars ranging in thickness from 2.5mm to 20mm thick (best seen in the bottom, right hand portion of the top view of Figure 2). The bars are placed behind a steel step wedge. There are seven steps in the wedge with 10mm increments for each step. The test is score by observing how many sections of the bars are visible behind the step wedge.

Test 5

Test 5 evaluates materials discrimination of polyethylene and Delrin. It uses portions of the same step wedges used for Tests 2 and 3. The test consists of small regions where the polyethylene and Delrin step wedges intersect, thus creating a set of boxes when imaged. The test is scored by observing how many regions in the box pattern can be clearly discriminated from its background. Figure 3 shows the resulting image when the XIQ-1 test object is scanned through an X-ray machine.

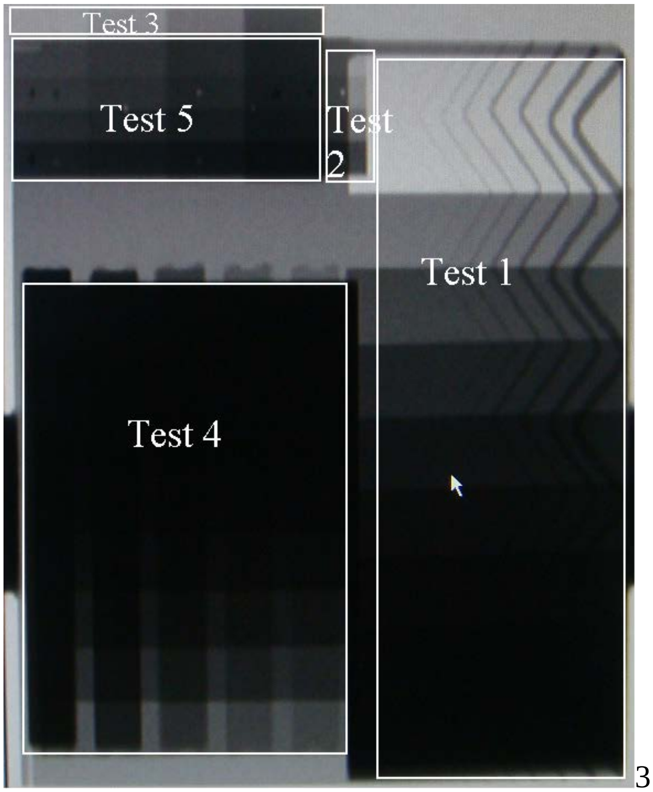
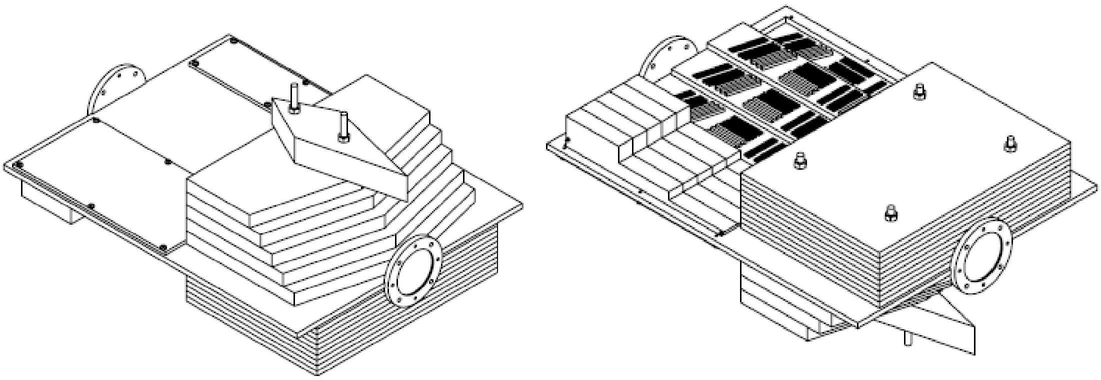


Figure 3. X-ray image of the XIQ-1 test object showing the location of Tests 1-5.

2.2 XIQ-2 Description

The XIQ-2 (see Figure 4) is comprised of four different tests labeled Tests 6 through 9. Each test is described below.



Top View

Bottom View

Figure 4. Drawing of the top and bottom view of the XIQ-2 test object.

Test 6

This test evaluates spatial resolution through Perspex (also called Plexiglas). The test consists of sets of three bars, there are three different thicknesses of bar, and the sets are arranged in three different orientations (see the top, left hand portion of the bottom view of Figure 4). There are nine different groups of wires. The test is scored by observing how many wire groups are clearly resolved without distortion.

Test 7

This test evaluates the thickness resolution and materials discrimination of materials with different effective atomic numbers (Zeff). This test consists of vertical step wedges of polyethylene, Perspex, Delrin, Teflon (i.e., Polytetrafluoroethylene), and aluminum arranged in decreasing Zeff values (see the left hand side of the bottom view of Figure 4). Each wedge consists of three steps that decrease in thickness from 60mm down to 15mm. This arrangement creates a set of rectangles when imaged. The test is scored by observing how many rectangles are clearly discriminated from its background.

Test 8

This test evaluates the spatial resolution through steel. The test consists of the same wire groupings as in Test 1 arranged on increasing thicknesses of steel; there are three different thicknesses of steel on which the tests are mounted. The steel increases in thickness using 10mm steps. The test is score by observing how many wire groups are clearly resolved.

Test 9

This test evaluates X-ray penetration through steel. It consists of a kite shaped plate of steel behind five different thicknesses (i.e., steps) of steel. There is a block of steel 100mm thick (comprised of 20 plates of 5mm of steel each) on one side of the test piece. On the other side is a step wedge consisting of five steps with each step consisting of five 5mm steel plates (totaling 25mm of steel per step), over which the kite shape is placed. The test is scored by observing through how many of the steel plates the kite shape can be observed. Figure 5 shows the resulting image when the XIQ-2 test object is scanned through an X-ray machine.

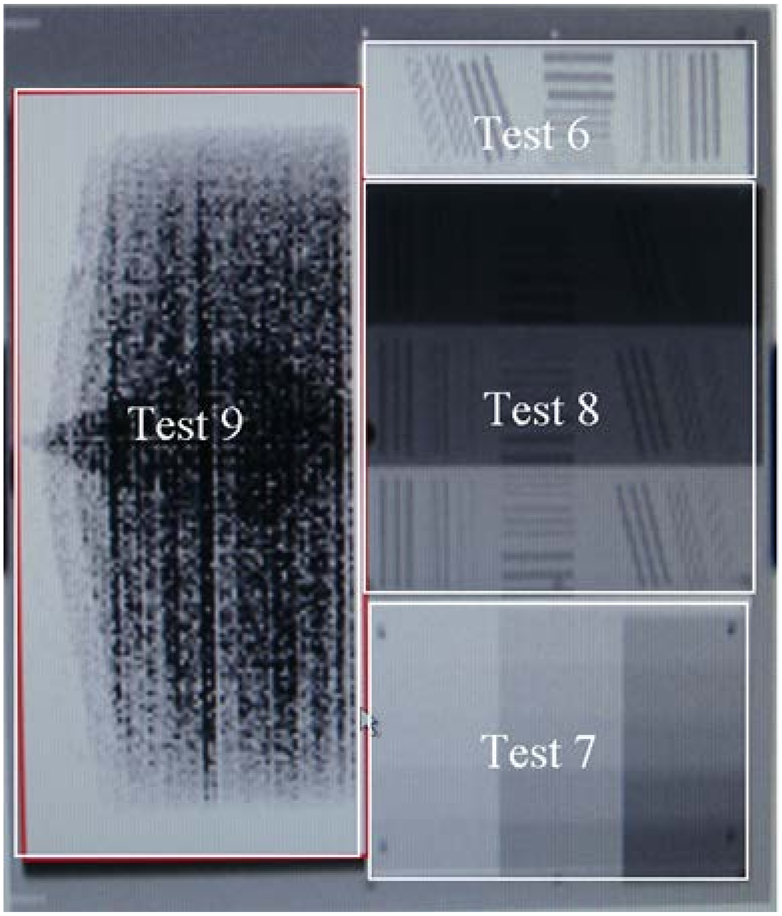


Figure 5. X-ray image of the XIQ-2 test object showing the location of Tests 6-9.

3. CRITICAL OPERATIONAL ISSUES AND MEASURES OF PERFORMANCE

This section identifies the Critical Operational Issues (COIs) and Measure of Performance (MOPs) that were investigated. The COIs include spatial resolution, contrast sensitivity, and X-ray penetration. The original test and evaluation plan [3] called for test engineers to investigate both the point spread function and the modular transfer function, but these were not assessed (see Section 5.4). The MOPs for each COI listed below were used to determine the range of values XIQ-1 and XIQ-2 produced when they were scanned through the X-ray systems.

3.1 Issue 1 – Spatial Resolution

The spatial resolution of the X-ray machine was measured using the two test objects. In addition, researchers also investigated the effect on each test measurement when the test object was not aligned perpendicular to the X-ray beam. The purpose of this investigation was to determine the how many degrees from perpendicular the test objects can be before the measurements severely decline.

MOP 1-1: The number of wires that are visible for each thickness of steel and air using Test 1. This measurement was collected from 20 degrees left of perpendicular to 20 degrees right of perpendicular in 2 degrees increments.

MOP 1-2: The number of wire groups that are clearly discernable using Test 6. This measurement was collected from 20 degrees left of perpendicular to 20 degrees right of perpendicular in 2 degrees increments.

MOP 1-3: The number of wire groups that are clearly discernable using Test 8. This measurement was collected from 20 degrees left of perpendicular to 20 degrees right of perpendicular in 2 degrees increments.

3.2 Issue 2 – Contrast Sensitivity[1]

The contrast sensitivity of each X-ray machine was measured using the two test objects. Researchers also investigated the effect on each test measurement when the test object is not aligned perpendicular to the X-ray beam. Similarly as for spatial resolution, the purpose of this investigation was to determine the how many degrees from perpendicular the test objects can be before the measurements severely decline.

MOP 2-1: The number of blocks that can be clearly discriminated from its background using Test 2. This measurement was collected from 20 degrees left of perpendicular to 20 degrees right of perpendicular in 2 degrees increments.

MOP 2-2: The number of blocks that can be clearly discriminated from its background using Test 3. This measurement was collected from 20 degrees left of perpendicular to 20 degrees right of perpendicular in 2 degrees increments.

MOP 2-3: The number of sections of bars that are clearly visible behind the step wedge using Test 4. This measurement was collected from 20 degrees left of perpendicular to 20 degrees right of perpendicular in 2 degrees increments.

MOP 2-4: The number of regions in the box pattern that can be clearly discriminated from its background using Test 5. This measurement was collected from 20 degrees left of perpendicular to 20 degrees right of perpendicular in 2 degrees increments.

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[1] For a single-energy system, only one parameter (attenuation) is being measured. In this case, contrast sensitivity is a measure of how small a change in attenuation can be reliably measured. It is, in essence, a measure of the system's electronic noise (e.g., X-ray source, acquisition electronics, detectors, and computational). For a dual-energy system, there are two measured parameters (density and Zeff or μ_{High} and μ_{Low}), each having a different system electronic noise. For these systems, the contrast sensitivity will likely be different for each 'energy.' The advantage of these systems comes from having more information (two versus one measurement).energy system, there are two measured parameters (density and Zeff or μ_{High} and μ_{Low}), each having a different system electronic noise. For these systems, the contrast sensitivity will likely be different for each 'energy.' The advantage of these systems comes from having more information (two versus one measurement).

It appears that Test 5 uses two materials of the same thickness and investigates the ability to measure the difference in attenuation. For single-energy systems, this is the contrast sensitivity; for dual energy systems, it is more complicated since you have two parameters. A model would be an error interval versus an error ellipse.

Test 7 is similar to Test 5 but, for single-energy systems, it looks at the ability to measure a change in attenuation between two materials with varying amounts of attenuation (from more than one type of material). For dual-energy systems, this gets more complicated.

MOP 2-5: The number of rectangles that are clearly discriminated from its background using Test 7. This measurement was collected from 20 degrees left of perpendicular to 20 degrees right of perpendicular in 2 degrees increments.

3.3 Issue 3 – X-ray Penetration

MOP 3-1: The number of steel plates through which the kite shape can be observed using Test 9. This measurement was collected from 20 degrees left of perpendicular to 20 degrees right of perpendicular in 2 degrees increments.

3.4 Issue 4 – Point Spread Function (Vertical and Horizontal)

The point spread function is measured by looking at the derivative of the (spatial) attenuation curves. For a given transition from one level of attenuation to another, the minimum of the apparent width of the transition measured as the test piece orientation is varied should yield the Point Spread Function for this system. It was expected that this value would vary with position along the detector array (and indeed with position in the tunnel).

MOP 4-1: Archived images of the nine tests from XIQ-1 and XIQ-2. These measurements were collected from 20 degrees left of perpendicular to 20 degrees right of perpendicular in 2 degrees increments.

3.5 Issue 5 – Modulation Transfer Function

This is, in essence, a measure of the change in attenuation required between two objects to be able to discern these objects as separate. This is typically measured using a set of parallel bars and usually given as line-pairs per unit length. For these objects, the modulation transfer function can be measured for various orientations. There will be one orientation for a given position along the detector array that yields the largest value of "line pairs/length," and this will provide an additional measure of the spatial resolution of the system.

MOP 5-1: Archived images of the nine tests from XIQ-1 and XIQ-2. These measurement were collected from 20 degrees left of perpendicular to 20 degrees right of perpendicular in 2 degrees increments.

4. METHODOLOGY

4.1 Test Site

Data collection activities for the IQ test objects were conducted at TSA's TSIF from June 17-20, 2013. The TSIF had two palletized cargo X-ray systems available for use at this time. The scoring of the archived images was conducted at the TSL from June 25-July 5, 2013 on a Smiths emulator.

4.2 Test Personnel

Two test engineers participated in the evaluation of the IQ test objects. The two individuals recorded live observations and also collected and archived data that were used on an emulator. In addition, two Battelle Memorial Institute staff members served as forklift drivers to load and unload the test objects for each X-ray machine, and they assisted in reconfiguring the test objects (e.g., added or removed steel plates) to tailor the tests for each X-ray system. Battelle staff also trained the test engineers how to start up and shut down the systems, as well as download the images.

4.3 Test Equipment

Two X-ray systems (listed in Table 1) were used to initially assess the IQ test objects. The two X-ray systems are briefly described in Sections 4.3.1 and 4.3.2. Also, test engineers scanned a test object built to the ANSI N42.46-2008 standard so that they could compare and contrast the ANSI test object to those designed and manufactured by ANSTO.

Upon returning from data collection, a test engineer tried to replay the images on a Smiths aTiX 6040 emulator without success. The engineers acquired a Smiths universal emulator that could replay any of Smiths' proprietary images and thus, all image scoring was conducted offline using this capability.

Table 1. X-ray systems used for the assessment

System Vendor	System Model
Rapiscan	632 DV
Smiths Detection	HI-SCAN 180180-2is

4.3.1 Rapiscan 632 DV

The Rapiscan 632 is a low energy (200 kV), large aperture X-ray inspection system (150 cm wide by 165 cm high) designed to inspect consolidated cargo shipments. The system contains two X-ray sources that interrogate the object under inspection. A corresponding detector array measures X-ray photon levels attenuated by the object being interrogated. Digitized radiographic images are constructed from the raw detector data, which can be examined by an operator to determine whether concealed explosive devices are present. The Rapiscan 632 is depicted in Figure 6, and its key system characteristics are provided in Table 2.

Figure 6. Rapiscan 632 X-ray machine

Table 2. Rapiscan 632 DV key characteristics.

Characteristics	
# of Images presented to an Operator:	2 Total
# of X-Ray Sources:	2 Total
Dual Energy Technology:	Pseudo
TSA System (Aperture) Classification:	Capacity C (Large)
Aperture Dimensions:	59.1 in (width) x 65.0 in (height)
System Dimensions:	111 in (width) x 131 in (height) x 307 in (length)

4.3.2 Smiths HI-SCAN 180180-2is

The HI-SCAN 180180-2is is a medium energy (300 kV), large aperture X-ray inspection system (180 cm width by 180 cm height) designed to inspect consolidated cargo shipments. The system contains two X-ray sources that interrogate the object under inspection. Corresponding detector arrays measure X-ray photon levels not attenuated by the object being interrogated. Two digitized radiographic images (vertical and horizontal views) are constructed from the raw detector data, which can be examined by an operator to determine whether concealed explosive devices are present. The HI-SCAN 180180-2is is depicted in Figure 7, and its key system characteristics are provided in Table 3.

Figure 7. Smiths 180180-2is X-ray machine.

Table 3. Smiths 180180-2is key characteristics.

Characteristics	
# of Images presented to an Operator:	2
# of X-Ray Sources:	2
Dual Energy Technology	Pseudo
TSA System (Aperture) Classification:	Capacity C (Large)
Aperture Dimensions:	70.9 in (width) x 70.9 in (height)
System Dimensions:	138.1 in (width) x 144.5 in (height) x 285.8 in (length)

4.4 Test Conduct

The first day of testing, researchers were trained on how the operate each X-ray machine, their functionality, and how to capture and archive images. The afternoon of the first day, the test engineers conducted a series of scans of the test objects through the Smiths and Rapiscan systems to determine the proper angle settings (i.e., the face of the test object being perpendicular to the X-ray beam). Since both machines had two X-ray sources, this had to be performed twice on each system. In addition, test engineers varied the number of steel plates for the penetration test (see Test 9 in Figure 5) for each X-ray machine, in order to obtain a range where the kite (i.e., a steel diamond) could be easily perceived under one or two steps up to a point where no portion of the diamond could be seen under the fourth or fifth step.

After the correct angles and the number of plates were identified for each system, the researchers ran the test objects through each X-ray machine and conducted an initial evaluation as to which of the two systems would provide the best data for assessing the test objects. It was determined that the Smiths scanner would provide the best data for the study, so that system was used to collect all of the remaining information used for the evaluation.

After the researchers selected the system, they scanned the test objects at right angles to the X-ray beam then rotated the test objects two degrees and rescanned them. The test engineers recorded the image scan time, image file name, and associated angle. This process continued until scans were captured every two degrees from +20 degrees from perpendicular to –20 degrees from perpendicular. After these data were acquired, the researchers downloaded the images onto an external hard drive for scoring.

The week following data collection, researchers scored the images individually after they acquired an emulator that could replay them. The researchers' intent was to solicit additional TSL staff to view and score the set of images so that statistical analyses could be conducted on the data and reported. However, the borrowed Smiths emulator had to be returned to a TSA support contractor within six working days and so only the two test engineers had time to score the image set within this timeframe.

5. RESULTS

The scoring results of researchers are provided in Tables 4-6. The values listed in the cells are the sums of each researcher's scores for a particular test and angle of the test object. Since there are only two data points for each angle, conducting statistical analyses was not practical.

5.1 Spatial Resolution

Tests 1, 6, and 8 of the Australian IQ test objects were tests to measure a system's spatial resolution. Table 4 shows the results of the summed scores for spatial resolution. The shaded cells at zero degrees represent the scores for which the other scores should be compared as zero degrees from perpendicular is considered ideal. As can be seen for all three tests, the sum of the scores across all angles does not appear to change as the angle changes from -20 degrees to +20 degrees. This would indicate that using the optimum angle setting of zero degrees is not critical for measuring the spatial resolution of a system with these test objects.

Table 4. Spatial resolution scores broken down by angle

Angle	**-20**	**-18**	**-16**	**-14**	**-12**	**-10**	**-8**	**-6**	**-4**	**-2**	**0**	**2**	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**
Test 1	13	11	11	12	13	11	13	14	12	14	12	12	13	13	10	11	13	12	11	12	11
Test 6	16	16	17	16	16	16	17	17	17	17	17	17	18	18	18	18	17	18	17	18	18
Test 8	47	47	47	48	48	49	48	49	48	50	50	49	52	50	48	48	49	45	44	48	51

5.2 Contrast Sensitivity

Tests 2, 3, 4, 5, and 7 of the test objects were tests to measure a system's contrast sensitivity. Table 5 shows the results of the summed scores for this metric. Again, the shaded cells at zero degrees represent the scores for which the other scores should be compared. The results for tests 2, 3, and 7 are very consistent across all of the angles. There is one outlier for Test 3 at +18 degrees, and it is unclear as to why. It was first thought that the low score may have been due to a small horizontal streak in the image caused by bad detectors. However, upon a second review of the image, this was not the case, therefore, it could simply be difficulty perceiving differentiations in the four thicknesses of polyethylene at this specific angle.

For Test 5, there appears to be a drop off in scores around the 14 to 16 degree range (both in the positive and negative angles). Data points from additional scorers could verify this trend, but this seems to be the test most affected by not using the optimal angle. However, if this is true, the user would only have to be within 12 degrees either direction of perpendicular to obtain a fairly accurate measurement for Test 5.

For Test 4, the results are a little more ambiguous. The scores are slightly lower for some of the negative angles off-center and are very "spotty" on the positive side of zero degrees. However, the cause of these alternating high and low scored as the angle increases is not known.

Table 5. Contrast sensitivity scores broken down by angle

Angle	**-20**	**-18**	**-16**	**-14**	**-12**	**-10**	**-8**	**-6**	**-4**	**-2**	**0**	**2**	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**
Test 2	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	5	6	7
Test 3	8	8	8	8	8	8	8	8	8	8	8	8	8	7	7	8	8	7	8	**3**	8
Test 4	**47**	**45**	**45**	**47**	**47**	**47**	48	51	49	53	53	54	**47**	53	**46**	54	**47**	**38**	53	**46**	49
Test 5	**24**	**25**	**24**	**27**	31	32	32	32	32	32	32	32	32	32	32	32	32	31	**18**	**26**	**24**
Test 7	28	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	29	29

5.3 X-ray Penetration

Test 9 of the Australian IQ test object is a test to measure a system's ability to see a kite (i.e., a diamond) behind layers of steel. Table 6 shows the results of the penetration test. As can be seen in the table, the sum of the scores across all angles is very consistent and basically does not change as the angle changes from -20 degrees to +20 degrees.

Table 6. X-ray penetration scores broken down by angle

Angle	**-20**	**-18**	**-16**	**-14**	**-12**	**-10**	**-8**	**-6**	**-4**	**-2**	**0**	**2**	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**
Test 9	6	7	7	7	7	8	8	6	8	7	6	7	7	6	7	8	6	7	6	7	7

5.4 Point Spread Function and Modulation Transfer Function

Test engineers anticipated the ability to open and view the raw data files generated by the Smiths 180180-2is to calculate the point spread and modulation transfer functions. Unfortunately, the raw data files were saved in Smiths proprietary file format that could not be opened for analyses. Thus, there are no results to report for MOPs 4-1 and 5-1.

5.5 Human Factors Assessment

Another focus of the assessment was the usability of the two test objects. This section describes some of the limitations of the system, suggestions for potential improvements, and a comparison of the Australian IQ test objects to test objects built to the ANSI N42.46-2008 standard.

5.5.1 Aligning the Test Objects to the X-ray Beam

From a design perspective, the test objects were versatile and extremely easy to use. As mentioned, optimal results are expected to occur when the test objects are perpendicular to the X-ray beam. The two test objects have angle settings every two degrees, which the test engineers found to be very quick and easy to adjust. This made finding and securing the ideal angle very expeditious. For the current systems, the only method to determine if the test object is 90 degrees in orientation to the X-ray beam is to keep scanning the test objects until the bolts look like very dark circles (see the bolts within the red circles in Figure 8). This means that the X-ray beam is "looking" straight down the bolt rather than at an off-angle.

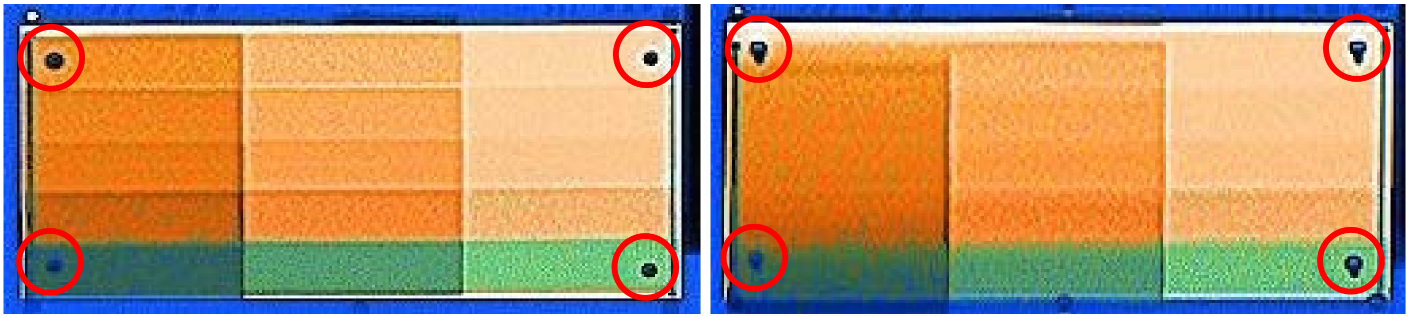

Figure 8. X-ray images of an aligned test object (left image) and one not aligned (right image)

One suggestion for improving this process would be to weld a thick-walled pipe or square tubing to the test objects that is perpendicular to the face of the objects. When a user can see through the pipe or tubing on the X-ray image, one would know that the test objects are at, or near, the optimum angle. Another idea would be to set up sight-like devices similar to what is used on pistol sights. Went the "front" sight is aligned with the "rear" sight, then the user would know the test objects are perpendicular to the X-ray beam (see Figure 9).

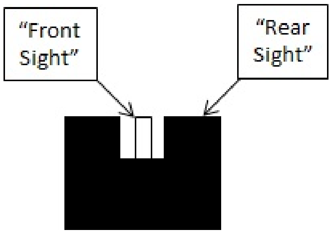

Figure 9. Possible sighting system for test object alignment

5.5.2 Tailoring the Test Objects to the X-ray Machine

Tailoring the penetration test (i.e., Test 9) to the system was very straightforward and easy to accomplish, as well. Various plates can be removed from the step wedges by removing two hex nuts or from the set of plates located on the opposite side by taking off four hex nuts and removing the plates.

In order to make tailoring Test 9 quicker to adjust (that is, adding or removing the steel plates), wing nuts could be used instead of regular hex nuts. This would eliminate the need for an adjustable wrench to tighten or loosen the hex nuts, but would still allow the plates to be secured to the test object.

Test 9 is the only scalable test on the two test objects. As can be seen in the test scores, very few elements of Tests 1 and 4 were discernible even when scanned on a 300KeV system, such as the Smiths 180180-2is, and making full use of the system's functionality (zooming, contrast adjustments, edge enhancements, etc.). At a minimum, making Tests 1 and 4 also scalable would significantly improve the usefulness of the test objects, thus allowing individuals to make finer measurements than what is currently possible.

5.5.3 Comparison of Australian Test Objects to Test Objects Built to the ANSI N42.46-2008 Standard

5.5.3.1 Spatial Resolution

The Australian test objects have two methods of measuring spatial resolution broken down into three tests. The first is using nine wires with different diameters (i.e., gauges) in air and behind steel (Test 1), and the second is using line-pairs with three different widths and thicknesses in air and behind three thicknesses of steel (i.e., 10mm, 20mm, and 30mm) (Tests 6 and 8, respectively). In addition, the line-pairs of the Australian test objects are orientated vertical, horizontal, and diagonal at approximately 45 degrees.

The spatial resolution tests of the ANSI test object include six different gauges of wires measured only in air and five line-pair gauges also only measured in air. Both the wire and line-pairs are measured in vertical and horizontal orientations; however, both tests must be scanned in one orientation; then removing four bolts, rotating the wires/line-pairs, and reinserting the bolts; and finally rescanning the test object with the re-orientated tests.

As a result, the Australian test objects are capable of finer measurements with the wire based spatial resolution test because of the additional number of wires used, as well as the measuring resolution in both air and behind three steps of steel. For line-pair gauge measurements, the ANSI test object is capable of finer measurements in air because it has two more line-pairs than the XIQ-2 test object, but the latter allows the user to make these measurements behind steel, which the ANSI test object does not provide. In addition, the Australian test object displays the line-pair gauges in a diagonal orientation, which the ANSI test object does not offer. Thus, the Australian test object has a little more diversity in its capabilities.

5.5.3.2 Contrast Sensitivity

The Australian test objects have five tests for contrast sensitivity (see Tests 2, 3, 4, 5, and 7). Tests 2, 3, and 5 use organic material and are slight variations of each other (e.g., Tests 2 and 3 are taken in air), with Test 5 being a three-dimensional matrix of polyethylene and Delrin, with the third dimension being thicknesses of each material. In addition, Test 4 uses steel and is a three-dimensional step wedge increasing in thickness from left-to-right and from top-to-bottom. Lastly, Test 7 is composed of five different organic and metal materials with each material having three thicknesses. The ANSI test object does not have any contrast sensitivity tests.

5.5.3.3 Penetration

Test 9 of the Australian test object, XIQ-2, contains five steps (with each step consisting of five 5mm plates for a total of 25mm of steel per step) on one side of a 10mm plate (to which everything is attached) and 20 plates of steel, each being 5mm thick on the other side of the base plate. With each steel plate being 5mm thick, the test object affords a fine gradient of thickness for the penetration test. Therefore, Test 9 can range from 10mm (.39”) up to 235mm (9.25”) of steel.

In comparison, the ANSI N42.46-2008 test object ranges from .125” (3.2mm) to 14” (355.6mm) of steel in .125” (3.2mm) increments. As a result, the ANSI test object provides the possibility of slightly more granular measurements.

The ANSI test object has one desired feature associated with its penetration test that the Australian test object does not currently have. The ANSI test object has a kite that can be rotated, whereas the kite in XIQ-2 is fixed. The purpose of the rotatable kite is that it requires the user to record the orientation of the kite being either pointing up, right, left, or down. If the user does not correctly identify the orientation of the kite, then it can be surmised that he or she cannot distinguish the kite under all of the penetration steps. This provides more accuracy to the observed measurements.

5.5.4 Issues Encountered with the Australian Test Objects

After a very few scans, the test engineers soon realized that the wires of Test 1 that were not protected by steel (i.e., wires in air) were susceptible to damage from the X-ray system’s lead curtains. The problem occurs when the lead curtains are dragged across the wires causing the wires to be pulled out of the securing frame. Fortunately, none of the wires broke from scanning, and the test engineers were able to re-secure them. It is recommended that the wires be protected by either placing vertical steel plates on each side of the wires in air or place a thin Perspex (i.e., Plexiglas) shield on both sides of the wires to protect them from being destroyed. Obviously, the wires would not be truly observed in air, but the Perspex should not significantly affect the measurement.

5.5.5 Scoring Spreadsheet

The Australians provided an automated scoring spreadsheet to be used when scoring the system’s X-ray image. They provided both a hardcopy, which could be printed out, filled in, and at a later point in time, the data be transferred to the electronic version, as well as an electronic version that could be filled out by clicking on checkboxes. The electronic version is an Excel file that automatically scores the measurements taken by a particular user as checkboxes are clicked on (see Figure 10). The test engineers noted that the basic layout of the scoring template did not align with the scanned image. More specifically, for the line-pair gauges on the scoring template (see Test 6 in Figure 10), the diagonal pairs are on the left-hand side and they are becoming thicker from left to right. On the test object, this is just the opposite; the diagonal pairs are on the right side, becoming thinner from left to right (see Figure 11).

In addition, the top section of the Test 8 scoring template starts with 10mm of steel (marked “10” on the left-hand side of the template), below which is 20mm of steel (the middle section), followed by line-pairs on 30mm of steel (the bottom section). In the X-ray image, the order from top to bottom was 30mm of steel, 20mm of steel, and 10mm of steel, respectively. Thus, the test engineers filling out the template had to be very careful that they were accurately recording what they perceived.

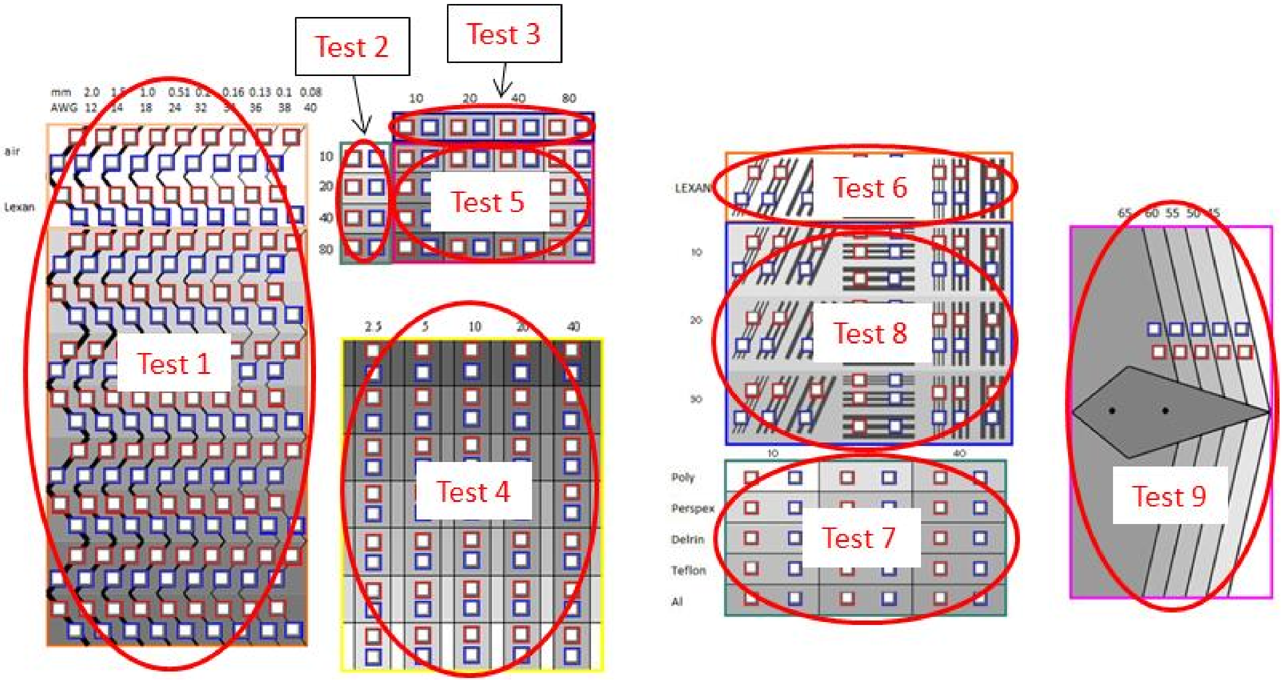

Figure 10. Scoring template for both the paper and electronic versions

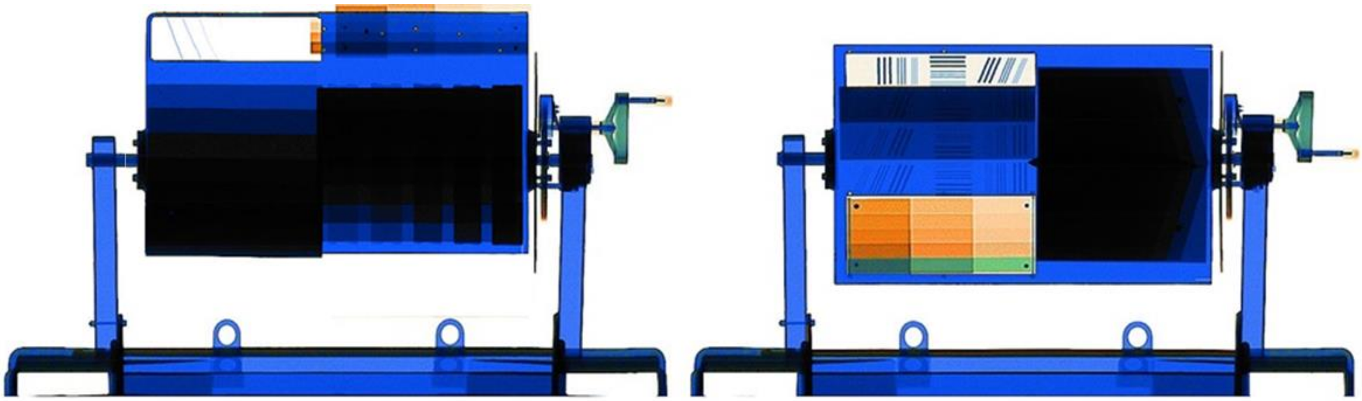

Figure 11. Scanned image of XIQ-1 (left side) and XIQ-2 (right side)

Similarly, the material discrimination test (see Test 7 in Figure 10), which is directly below the line-pair gauges on the scoring template, was reversed left to right, as well. The template shows 10mm, 20mm, and 40mm thicknesses from left to right; however, in the X-ray image, the order is 40mm, 20mm, and 10mm from left to right. These were the only discrepancies between the scoring template and the resultant image of the scanned test objects.

6. CONCLUSIONS

The Australian IQ test objects are well designed and constructed. A human factors assessment showed that they are easy to use, and an individual can capture a significant amount of data (i.e., information from nine different tests) from a single scan of the two objects. In addition, the two-degree incremental adjustments make the task of setting the face of the objects perpendicular to the X-ray beam relatively quick to accomplish. Tailoring the test objects' penetration test was easy to perform. On one side of the test object, four hex nuts had to be removed and 5mm thick steel plates could be added or removed as needed. On the opposite side, two hex nuts secure the kite and the various steel plates that make up the five steps of the step wedge. With thin steel plates on both sides of the test object, fine graduations can be achieved.

When compared to an IQ test object built to the ANSI N42.46-2008 standard, the Australian test objects can provide more precise measurements using its wire based spatial resolution test because it has three more wires than the ANSI test object. Further, the Australian test objects provide users an added benefit of taking measurements in air, as well as behind three different thicknesses of steel. Conversely, the ANSI test object has two additional line-pair gauges than the Australian test objects; however, the ANSI test objects require the user to manually rotate the line-pairs and rescan the test objects.

The penetration test of the ANSI test object contains approximately 4.75" more steel than the Australian test objects, and the ANSI test object contains thinner plates allowing for a more precise measurement. Another desirable feature the ANSI test object has that the Australian test objects do not have is a rotatable kite (or diamond) associated with their penetration test. This ensures that the person scoring the test actually can perceive the kite through the various steps and does not simply believe they are seeing it.

Lastly, the Australian test objects have five different, but related, tests to measure an X-ray machine's contrast sensitivity. They use polyethylene, Perspex, Delrin, Teflon, and aluminum, which provide a good range of Zeff values. The ANSI test object has no tests for contrast sensitivity.

Based on very limited data, it appears that the test objects can be within +/- 12 degrees from perpendicular to the X-ray beam before the measurements begin to degrade. However, the scoring of some tests do not appear to differ throughout the full range of tested angles (i.e., +/- 20 degrees). These tests include Tests 1, 6, and 8, which measure spatial resolution; Tests 2, 3, and 7, which measure contrast sensitivity; and Test 9, which measures X-ray penetration. Since this observation is based on only two test engineers' scores, readers should not base any decisions, policy, or qualification testing on this information. Additional data can be acquired (i.e., scores) if the use of a Smiths emulator can be arranged and additional subjects be made available.

7. REFERENCES

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