Published in final edited form as:

J Test Eval. 2018 ; 46: . doi:10.1520/JTE20170349.

Testing the Image Quality of Cabinet X-ray Systems for Security Screening: The Revised ASTM F792 Standard

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Abstract

ASTM F792, *Standard Practice for Evaluating the Imaging Performance of Security X-ray Systems*, provides test objects and methods for measuring the imaging performance of cabinet X-ray systems used at security checkpoints. The standard is widely used, with many thousands of ASTM F792 test objects utilized throughout the world. The last major revision of the standard was more than 15 years ago (2001), and since that time, several deficiencies have been noted when using the standard for testing modern systems employing multiple-view and multiple-energy configurations. Accordingly, the present work describes a new revision of the ASTM F792 standard realized as a trifurcation into three parts, each with its own separate test object and associated test method. The three parts of the standard are intended for routine testing, human-perception testing, and objective technical testing, and represent a major update to this venerable standard.

Keywords

X-ray imaging; security screening; image quality; standards; objective metrics; imaging metrology; security imaging; dual-energy X-ray; radiography; ASTM F792

Introduction and History

In response to a series of armed hijackings during the 1960s and 1970s, aviation security measures were greatly increased in the US and throughout the world. This led the Federal Aviation Administration (FAA, whose security role is now provided by the Transportation Security Administration) to mandate in 1972 that all passengers and carry-on baggage be screened by a metal detector or searched by hand. In response to further bombings, the FAA introduced the universal screening rule in 1974, which led to more widespread adoption of X-ray systems for the screening of carry-on baggage. By the late 1970s, these X-ray systems had evolved into digital devices using either linescan or flying spot technology. At the behest of the FAA, ASTM F12.60, Subcommittee on Controlled Access Security, Search, and Screening Equipment, was established to develop standards for security X-ray systems and metal detectors. This led to the development of ASTM F792, *Standard Practice for*

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Evaluating the Imaging Performance of Security X-ray Systems, in 1982 [1], which provided a standard method for evaluating the imaging performance of security X-ray systems with tunnel apertures up to 1 m by 1 m. Over subsequent decades, as imaging technology has improved and the threat environment has evolved, the standard underwent several major revisions. In this article, we describe the most recent revision of the standard, completed in 2017, the first major revision since 2001 [2].

In aviation security, image quality testing methodologies are often divided into two categories: threat-based test methods and technical performance test methods. Threat-based testing emulates real threats that might be encountered, such as simulated explosive devices in baggage, and determines their probability of detection with different equipment. Technical performance tests seek to describe image quality in terms of a set of metrics describing the capability of the system—e.g., the thickness of steel through which a usable image (of an underlying lead shape) can still be produced. Both testing methodologies are widely used and essential in aviation security. While threat-based testing directly measures the effectiveness of a system at performing the specific task it is intended for, such testing is slow, extremely expensive to undertake, and the results are generally classified. Threat-based tests must also evolve as existing threats change and new threats emerge. Technical performance testing provides complementary benefits to threat-based methods. Technical performance tests can be implemented much more quickly and cheaply than threat-based testing and are, therefore, widely used for quality assurance and site-acceptance testing. Moreover, technical performance tests provide quantifiable and reproducible measures of performance, whereas threat-based methods only provide statistics of threat detection. Because technical performance methods and results are generally unclassified, they are often codified into national and international standards and even referenced in legislation [3].

Early versions of the ASTM F792 test object consisted of sinusoidal wires under an aluminum step wedge (see Fig. 1). The test object would be imaged using the X-ray system, and the image would be shown to the evaluator, who was then required to judge which wire segments were visible under which steps. As such, the test results reflected more than just the intrinsic quality of the X-ray image, being also dependent on factors such as display quality and ambient lighting conditions. The test results also depended on the judgement of the individual undertaking the test, which will vary from person to person. The design of the test emphasized two important aspects of the system's image quality: penetration and wire detection. Testing these aspects in combination, by measuring the detectability of wires under different thicknesses of blocking material, is common in the field of security X-ray imaging and is generally referred to as useful penetration testing. Such testing remains important for modern systems, and elements of these early ASTM F792 test objects informed the design of the test object in the current revision.

Before the revision described in this article, the most recent major revision of ASTM F792 was completed in 2001. That revision significantly increased the capabilities of the standard, effectively increasing the number of tests from two to nine (see the layout in Fig. 2). Tests 1 and 2 were inspired by the previous revisions of the standard (i.e., sinusoidal wires under an aluminum step wedge). Test 3 was a traditional spatial resolution test, in which the system's ability to resolve closely separated wires was tested. Test 4, known as the simple penetration

test, tested the system's ability to detect lead numerals through increasing thicknesses of steel. Test 5 tested the ability to detect thin sheets of plastic, simulating plastic sheet explosives. Test 6 was inspired by the so-called penetrameter tests of non-destructive testing, also known as image quality indicators (IQIs). This tested the system's ability to detect small changes in the thickness of metal and plastic materials. Tests 7, 8, and 9 tested the system's materials discrimination ability. The standard underwent minor revision in 2008 to become the most recent revision of the standard (ASTM F792-08) before the one described in this article [4].

In the remainder of this article, we will describe the most recent revision to the ASTM F792 standard, in which major improvements were made to most of the tests.

The 2017 Revision of the ASTM F792 Standard

An ASTM F792 working group noted the diverse needs of the testing community and sought to address these needs by devising additional tests to be included in ASTM F792. Rather than including all these tests in one larger test object, a decision was made to divide the standard into three parts, replacing the single test object of ASTM F792-08 with three separate test objects (see Fig. 3). Each part is designed to provide the necessary measurement tools for a particular application in which the testing of imaging performance is necessary. The three parts are:

- Part RT: Methods for routine and periodic verification of system operation and function
- Part HP: Methods based on human evaluation of image quality
- Part OE: Methods based on automated objective evaluation of image quality

ASTMF792-RT

Part RT describes the test object and test methods used for routine testing (RT) and periodic evaluation of an X-ray system. It had been noted by some members of the ASTM F792 working group that test objects from older versions of the standard, particularly ASTM F792-88, were still in use and being sold commercially. This indicated an unmet need for a smaller, cheaper version of the ASTM F792 test object that could be used for daily quality assurance testing, which motivated the development of the ASTM F792-RT test object. The ASTM F792-88 test object was used as the starting point for the design of the RT test object, hence the visual similarity between them (see Figs. 4 and 1). To reflect the capabilities of modern systems, the step thicknesses and wire gauges were updated. Part RT, like Part HP, relies on human perception, but uses a smaller test object with fewer tests that can be evaluated more quickly. The RT is intended for performing periodic checks on X-ray system operation and is not intended to provide quantitative information on the performance of the system. The RT would be used by evaluators in the field for routine testing to verify X-ray system operation. The results of the Part RT test also can be used to identify trends in system imaging performance over time, thereby indicating whether the X-ray system is operating properly or more thorough diagnostic testing is necessary, such as that which could be provided by Parts HP or OE.

ASTM F792-HP

Part HP comprises the test methods and associated test object that rely on human perception (thus the designation “HP”) to measure the imaging performance of an X-ray system. This test object replaces and serves the same purpose as the previous revision of this standard, namely, site acceptance testing, performance comparison by users, etc. Just like its predecessor, results are generated based on human judgements of feature visibility. Numerous improvements were made to Part HP compared with its predecessor, including the addition of new tests as well as updates to make the standard more relevant for testing modern, advanced-technology systems.

Tests 1, 2, and 4 underwent minor changes to ensure they remained relevant for testing modern systems (see Fig. 5). The wire gauges used in Tests 1 and 2 were adjusted to make the tests slightly more difficult. The step thicknesses were also adjusted, and the number of steps was increased from three to five to accommodate the evolution of the imaging capability of commercial X-ray systems. The step thicknesses were also adjusted to correspond to whole numbers when measured in metric units. Test 4, the simple penetration test, was insufficiently challenging, as several commercially-available X-ray systems could image the numerals behind the thickest step (34 mm). In this revision of the standard, therefore, the maximum step thickness was increased to 40 mm.

The remaining tests underwent more significant revisions that will be described in the remainder of this section.

Test 3, the spatial resolution test, is scored by judging the visibility of a set of narrowly spaced line pairs. The spacing of the line-pairs was adjusted to 2.0, 1.5, 1.0, and 0.5 mm (from 2, 1.6, 1.3, and 1 mm), to challenge those systems that could resolve the finest line-pairs of ASTM F792-08. The construction method was also changed to make the finely spaced patterns easier to construct. Previously, each line pair gauge of the test piece was fabricated with four copper wires at precise separations from one another (see Fig. 6). The wires were held in place using glue, with the appropriate separation being maintained by custom spacers. The new test piece is constructed by cutting rectangular slots into a thin sheet of steel. The slots can be cut to high precision using electrical discharge machining, laser cutting, or photoetching. This design also has the advantage of providing a uniform thickness for every line-pair spacing, whereas the wire pattern in ASTM F792-08 presented a change in thickness (diameter) that varied with spacing, which had the effect of making narrower segments or spacings appear relatively lighter in the image (thus confounding spatial resolution with contrast in the test).

Test 5 measures the ability of a system to detect thin organic materials. Detecting thin organic materials is an important capability of bulk explosive detection systems, because plastic explosives are sometimes cast into thin sheets. The ASTM F792-08 Test 5 test piece consisted of a polyoxymethylene (POM) step wedge with thicknesses of 1, 3, and 5 mm, and the test method called for the evaluator to record the thickness of the thinnest step that could be seen. Many modern checkpoint systems can detect all the steps, so the test was unable to properly measure the thin organic imaging ability of these systems or track changes in

performance. Consequently, the new test piece incorporates five steps with a minimum step thickness of 0.25 mm. An extra dimension of sensitivity was included by adding hole-type IQI tests with three different radii. For each hole size, the evaluator reports the thinnest plastic for which the hole can be detected. In this way, the test determines the thinnest plastic that a system can detect over a given area (hole size).

Test 6 of ASTM F792-08 was inspired by the IQI-type tests used by the non-destructive testing (NDT) community. The test consisted of a series of disk-shaped recesses of various sizes cut into different thicknesses of steel and plastic. Because Test 5 now incorporates a hole-type organic IQI test, the new Test 6 piece concentrates on detection in steel. Tests 5 and 6 are intended to be complementary, in the sense that they test opposite ends of the intensity (or transmission) scale. Test 5 involves detection of features in low intensity regions, and Test 6 involves detection of features in high intensity regions. Checkpoint X-ray systems produce images that are generally of lower quality than NDT systems and, as a result, the existing Test 6 was far too challenging: of the 12 steel hole-type IQIs on the test object, no more than two were visible in the images produced by the most widely used checkpoint systems. In the new standard, the basic philosophy of detecting circular holes through blocking material remain unchanged, but the test was updated to better reflect the performance of current systems. Holes of diameters 2, 5, and 10 mm in a 0.1-mm-thick steel sheet must be detected through steel blocking material of 0.5, 1, 2, and 5 mm. The evaluator must report the amount of blocking material through which the 0.1 mm thick hole can be detected over a given area (hole size).

Tests 7, 8, and 9 measure the materials discrimination capabilities of a system. In previous versions of the standard, these tests had major shortcomings, and so they were replaced with more-comprehensive materials discrimination tests. For example, in the old Test 7, the evaluator is asked to judge if they can differentiate between a piece of steel and a piece of plastic. The test is perhaps the easiest materials discrimination test one could devise for an X-ray imaging system, and it is easily passed by all modern systems with materials discrimination. By overlaying plastic and steel components, the old Tests 8 and 9 provided a somewhat wider coverage of materials characteristics like effective atomic number, but strictly speaking, were not designed to take full advantage of possibilities for finer discrimination with regard to this and other parameters of interest to materials discrimination. The ability to differentiate between different materials is an important capability of checkpoint systems, and so a method was devised to test this ability more thoroughly in ASTM F792-HP.

ASTM F792 is often applied to systems that use multi-energy methods to colorize images based on materials information. These systems do not have the ability to determine the composition of materials that are made up of multiple elements; they instead determine an effective atomic number (or equivalent) that most closely corresponds to the attenuation of the mixed material. Modern (multi-energy) checkpoint systems, therefore, compute two pieces of information about each pixel:

- The level of transmission is measured based on the number of X rays that reach the detector. The transmission reflects the composition, density, and thickness of

all the material on the path between the X-ray source and the detector pixel. The transmission is represented by the lightness of the pixel.

- The estimated effective atomic number (or equivalent) is obtained for every pixel in the image. The value reflects the elemental composition of all the material that lies on a path between the X-ray source and the pixel. The estimated effective atomic number for a particular pixel is represented with color, in particular, its hue.

The new materials discrimination test is constructed so that these two independent variables are varied in a controlled and independent way, to systematically probe the response of the system with respect to attenuation and effective atomic number. A test piece was constructed with a grid of 7 by 3 attenuators, where the effective atomic number is varied in the horizontal axis and the transmission is varied in the vertical axis.

Test 7, the materials discrimination test, asks the evaluator to judge, for a particular row in Fig. 7, “do neighboring squares in a row have different colors (hues)?” This classic type of materials discrimination test gives information about whether the system has the capability to distinguish between columns of the grid with slightly different effective-Z values. The test should be scored using the central 10 mm by 10 mm portion of each square.

Test 8, the materials misclassification test, asks if a given material is classified consistently for different thicknesses. The ratio of steel to plastic is kept constant in each column, while the total thickness increases from bottom to top. The effective Z, and hence the hue, should therefore be the same for every square in a column. We shall define a column to have a materials misclassification when two or more squares appear to have significantly different hues.

Test 9, the organic differentiation test, asks the evaluator to judge whether the system can differentiate between the four different plastic blocks based on their material composition. The four blocks are made of high-density polyethylene (HDPE), polymethyl methacrylate (PMMA), polyoxymethylene (POM), and polytetrafluoroethylene (PTFE) and have thicknesses chosen so that they attenuate the beam by an approximately equal amount. The evaluator must assess which of the blocks in the images have a perceptibly different hue.

ASTM F792-OE

In recent years, there has been a trend in X-ray security standards toward objective evaluation, where tests are evaluated by an objective algorithm, and the role of human judgement is removed [5]. Part OE continues this trend in that the images are objectively evaluated (thus the designation “OE”) using standard numerical algorithms such that differences in human subjectivity or experience do not affect the scoring. Part OE describes a test object, test methods, and algorithms that can be used to compute values for a set of image quality metrics and serves to provide an automated means for assessing the intrinsic technical performance of an X-ray imaging system. The tests would be performed by a knowledgeable and experienced technician and could be used for site acceptance testing, performance comparison by users, and technical performance evaluation. An image of the

test object is shown in Fig. 8. The following six tests are described in the standard: Test 1, steel differentiation; Test 2, useful penetration; Test 3, organic boundary signal-to-noise ratio (BSNR); Test 4, spatial resolution; Test 5, dynamic range; Test 6, noise equivalent quanta.

Development of part OE was begun using the IEEE/ANSI N42.55-2013 standard, *American National Standard for the Performance of Portable Transmission X-ray Systems for Use in Improvised Explosive Device and Hazardous Device Identification*, as a starting point [6]. That standard is intended for testing portable transmission X-ray imaging systems, such as those used by bomb squads, and includes a set of objective test methods and metrics for quantifying the image quality of those systems. The six tests in ASTM F792-OE were all adapted from tests in IEEE/ANSI N42.55, with the notable exception of the useful penetration test.

One important capability that an X-ray system can have is the ability to detect changes in the thickness of an object. A thickness difference between two regions can manifest in an X-ray image as a difference in brightness (i.e., contrast), assuming the system has sufficient sensitivity to detect that thickness difference. In ASTM F792-OE, the contrast at a boundary between two regions is quantified using a concept known as the BSNR which was originally introduced in IEEE/ANSI N42.55. The BSNR measures the ability of an X-ray system to consistently measure a contrast between two regions across multiple images. In ASTM F792-OE, the BSNR of a particular boundary requires eight images of the boundary: four taken with the long axis of the test object parallel to the belt direction and four with the long axis of the test object perpendicular to the belt direction. The detectability S of the boundary in image i is computed using:

$$S_i = 1 - \frac{\overline{B_{-,i}}}{\overline{B_{+,i}}} \quad (1)$$

Here, $\overline{B_{-,i}}$ is the mean pixel value from a region of interest (ROI) from the thicker side of the boundary. $\overline{B_{+,i}}$ is the mean pixel value from a ROI from the thinner side of the boundary. Computing the mean $\bar{S}$ and sample standard deviation σ_S of the set of S_i values from the eight images, the BSNR is then:

$$BSNR = \frac{\bar{S}}{\sigma_S} \quad (2)$$

Test 1 of ASTM F792-OE is the steel differentiation test, which measures the ability of a system to differentiate between different thicknesses of steel. To a certain extent, the test is threat-inspired and mimics the capabilities required to detect large metallic weapons such as knives or guns when hidden behind shielding material. The test uses the steel step wedge to determine the thickest step that can be discerned from adjacent steps. A step is considered discerned from adjacent steps if the BSNR is greater than five at both its boundaries. The thicknesses of the steps of the step wedge are 1, 2, 4, 6, 8, 12, 16, 20, 24, 32, and 36 mm.

Test 2 is the so-called useful penetration test, which measures the ability of a system to detect wires under steel blocking material. This is an important capability of security X-ray imaging systems, and ASTM F792-OE is the first standard to provide a method for measuring useful penetration that is fully objective (i.e., does not rely on subjective human judgements of wire visibility). A detailed description of the method has previously been given by Glover and Hudson [7], so only a brief summary will be given here.

For each step of the step wedge, an ROI is selected that contains all the wires under that step. A Radon transform is applied to the ROI, as shown in Fig. 9, and the angle of the slanted wires can then be accurately determined based on the column location of the minimum (darkest) pixel value. The wire profile function (WPF) can be determined by taking the column of the Radon-transformed image corresponding to this angle. A wire is said to be visible if its signature in the WPF is different from the background value at a defined level of statistical significance. Example results of applying these statistical tests are shown at the bottom of Fig. 9, where all six wires created a signal that differed significantly from background, and hence, all six wires were considered “detected.”

In the ASTM F792-OE useful penetration test, this method is used to determine the visibility of 20, 24, and 30 AWG wires under each step of the step wedge. For each wire gauge, the evaluator should report the thickest step under which the wire can be detected.

Test 3 is the organic BSNR test, which measures the ability of the X-ray system to image thin pieces of a low atomic number material and distinguish thickness changes as contrast in the image. The test is motivated by the same concerns as the thin organic imaging test of ASTM F792-HP, namely, to detect sheet explosives and other thin organic threats. The test measures the BSNR of a POM step with a thickness of 1.5 mm on one side of the boundary and 3 mm on the other. The evaluator should report the BSNR achieved by the system under test, with higher values corresponding to greater and more consistent contrast for thin organic materials.

Test 4 is the spatial resolution test. While there are numerous methods for measuring spatial resolution, in ASTM F792-OE the spatial resolution is characterized by estimating the modulation transfer function (MTF) by super-sampling the edge of a lead foil [8]. Following the ISO 12233-2000, *Photography—Electronic Still-Picture Cameras—Resolution Measurements*, standard [9], an image is taken of a sharp edge slanted at 5° with respect to the pixel grid. The standard provides a method for aligning and combining the edge-spread function from each row so that it is super-sampled to a step size of one-quarter of a pixel. The line-spread function is calculated by taking the first difference of the edge spread function and then the MTF is calculated by taking the normalized magnitude of the discrete Fourier transform of the line-spread function. In ASTM F792-OE, the MTF is determined in two axes, perpendicular and parallel to the belt direction. In addition to measuring and reporting the full MTF curve, the evaluator must also report the frequency, expressed in line-pairs per millimeter, at which the MTF drops to 0.2.

Test 5 measures the dynamic range of the system. Dynamic range is conventionally defined as the ratio of largest usable signal to the smallest usable signal, and in F792-OE, the largest

signal is taken to be the maximum pixel value. To determine the smallest usable signal, ROIs are selected under each of the steps of the step wedge to determine which of the steps is the darkest. The smallest usable signal is taken to be equal to the standard deviation of the ROI from the darkest step. While this value will generally be larger than the smallest grayscale gradation, any single-pixel signal that is smaller than this would be lost in the noise. The evaluator must report the ratio of largest to the smallest usable signal as the dynamic range.

Test 6 characterizes the noise properties of the imaging system using the NEQ test, which quantifies the noise as a function of frequency. NEQ and related concepts have been in use since the 1940s [10] and 1950s [11] and have been applied in numerous imaging subfields. NEQ quantifies noise in a manner that reflects a fundamental noise source for any imaging system, the discrete (i.e., quantum) nature of light. A brief description of its use in ASTM F792-OE follows:

Consider an ideal detector exposed to an average of N X-ray photons per second in every pixel. Because of the random and discrete nature of light, the number of photons arriving at the detector each second can be modelled as a Poisson process, characterized by a signal mean of N and standard deviation of $\sqrt{N}$. For a uniformly illuminated detector, it is generally assumed that the standard deviation of repeated measurements of a pixel can be approximated by the standard deviation of many neighboring pixels (i.e., the system is assumed to be ergodic). The signal-to-noise ratio (SNR) of such an idealized detector can be calculated as follows:

$$SNR = \frac{N}{\sqrt{N}} = \sqrt{N} \quad (3)$$

The noise levels observed in real-world detectors should be expected to be larger than this, because of contributions from Fano processes, electronic noise, and numerous other detector-specific effects. The observed SNR is therefore always less than one would expect purely from Poisson statistics.

The observed signal-to-noise ratio $SNR_{observed}$ in a real-world detector can be related to the hypothetical number of photons that would give the equivalent SNR in an idealized detector. This value is generally referred to as the NEQ.

$$\sqrt{NEQ} = SNR_{observed} \quad (4)$$

This type of description, in which the information content of an image is quantified in terms of an effective number of absorbed quanta has been referred to as the Rose approach [12].

The NEQ test in ASTM F792-OE follows a similar measurement procedure to that used in the security X-ray computed tomography image quality standard [13], in which the frequency dependent NEQ is calculated using the following relation:

$$NEQ = \frac{S_{out}^2 MTF^2}{NPS} \quad (5)$$

where S_{out} is the mean pixel value and NPS is the noise power spectrum. The NPS is calculated based on eight images where the test object is not in place. The evaluator must report the full NEQ curve measured in directions both the parallel and perpendicular to belt direction. The evaluator must also report values of the NEQ at a frequency of 0.4 cycles per millimeter.

Conclusions

The ASTM F792 standard provides test methods for measuring the imaging performance of cabinet X-ray systems used at security checkpoints. In 2017, the standard underwent a major revision that included a trifurcation, resulting in three test objects, each with an associated test method. The revision represents a major update to this venerable standard. Part RT provides a fast, cheap test object for routine testing, meeting a testing need that was previously filled by a withdrawn standard. Part HP is a major update to the test object described in the previous two revisions of ASTM F792. Several changes were made to the difficulty levels of the tests to help ensure that ASTM F792-HP is appropriate for testing modern cabinet X-ray systems. The materials discrimination tests underwent a major overhaul and now provide much more detailed testing results. Part OE provides a test object and test method for objective testing of cabinet X-ray systems, in which image analysis and scoring of tests is done using standard numerical algorithms, thereby avoiding uncertainties in test results attributable to human subjectivity or judgment.

ACKNOWLEDGMENTS

Jack Glover acknowledges support from the U.S. Department of Commerce, National Institute of Standards and Technology under the financial assistance award 70NANB15H015.

This work is supported in part by the Science and Technology Directorate of the U.S. Department of Homeland Security under IAA HSHQPM-15-T-00021.

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FIG. 1.

The design of the test object described in the 1988 version of ASTM F792.

FIG. 2.

The layout of the ASTM F792 test object underwent a major change in the 2001 revision of the standard, which described nine separate tests.

FIG. 3.

A rendering of the three test objects described in the most recent revision of the ASTM F792 standard.

FIG. 4.

A rendered image of the ASTM F792-RT test object. The aluminum step wedge has a maximum thickness of 20 mm and the wires were chosen to be 24, 27, 30, 33, and 36 American Wire Gauge (AWG).

J Test Eval. Author manuscript; available in PMC 2019 May 13.

FIG. 6.
Alterations to the design of Test 3.

FIG. 7.

The materials discrimination grid is shown. The effective Z is varied from left to right and the transmission is varied in the vertical axis. Only the color of the 21 interior-most squares should be considered, as the remainder of the area is partly obscured by a steel masking grid. The label “Al” indicates where an aluminum sample would appear if it were included in the test object.

FIG. 8.

A diagram of the ASTM F792-OE test object is shown. Arrows indicate which pieces of the test object are used to compute the useful penetration, organic BSNR, spatial resolution, and steel differentiation metrics. The dynamic range is computed based on the regions of the image with the highest and lowest pixel values. The Noise Equivalent Quanta (NEQ) metric is computed based on a noise image where the test object is not present in the image.

FIG. 9.

Top image: the ROI from an X-ray image of a prototype test object showing six wires oriented about 5° from the vertical. Middle image: the Radon transform of the ROI minus its median pixel value. The column with the minimum value is highlighted. This column corresponds to a θ value of about 5° , i.e., the angle of the wires when the test object is aligned along the image grid. This column of data is referred to as the wire profile function, plotted at the bottom of the image. The points in green (light gray in print) were used as the background region. The points plotted in red (dark gray in print) were found to differ significantly from background, while the points in black did not differ significantly from background.