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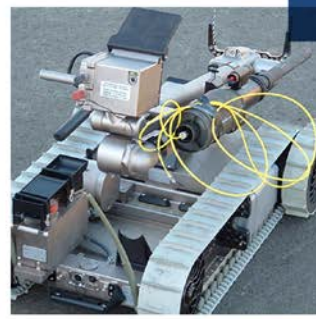

EXPLOSIVES STANDARDS FORUM RECOMMENDATIONS

William G. Billotte
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March 2013

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National Institute of Standards and Technology
U.S. Department of Commerce

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INFORMATION
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NISTIR 7919

Explosives Standards Forum Recommendations

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EXECUTIVE SUMMARY

Federal, state, and local first responders who work with explosives and respond to improvised explosive device (IED) attacks rely on relevant documentary standards to make their jobs safer.[1] Per the International Organization for Standardization (ISO)/International Electrotechnical Commission (IEC) Guide 2:2004, there are eight common types of documentary standards: basic standards, terminology standards, testing standards, product standards, process standards, service standards, interface standards, and standards on data to be provided.[2] Explosives documentary standards that span many of these categories are available (for a cost), but as of September 2012, no explosives standards have been adopted by the U.S. Department of Homeland Security (DHS).[3]

The DHS standards adoption process identifies appropriate and effective national standards that assist federal, state, and local equipment procurement processes, response, training development, and program coordination. Standards adoption assists with the following

- Encouraging and/or mandating that equipment purchased with federal dollars is certified to adopted standards (with exceptions noted when they exist);
- Achieving equipment interoperability;
- Developing training, exercise, and prevention programs;
- Harmonizing homeland security strategies, sharpening operational effectiveness, and maximizing efficiency within DHS and the federal government; and
- Encouraging uniform equipment purchases throughout the federal government based on informed input.[4]

From September 2011 to September 2012, the National Institute of Standards and Technology (NIST) Law Enforcement Standards Office (OLES), sponsored by the DHS Science and Technology Directorate (S&T) Explosives Division, collected recommendations for the adoption and/or development of explosives standards by DHS and identified explosives standards gaps. NIST OLES named this effort the Explosives Standards Forum (ESF).

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[1] Per NISTIR 7614, there are two types of standards: physical measurement and documentary. This effort focuses on documentary standards. (http://gsi.nist.gov/global/docs/pubs/NISTIR_7614.pdf)

[2] See http://www.iso.org/iso/catalogue_detail?csnumber=39976 for more information.

[3] See https://www.rkb.us/contentdetail.cfm?content_id=67919 for a full list of adopted standards to date.

[4] See Explosives Standards Working Group (ESWG) documents and the Adoption of DHS National Standards: https://www.dhs.gov/xlibrary/assets/foia/mgmt_directive_106001_adoption_of_department_of_homeland_security_dhs_national_standards.pdf.

The ESF

- Identified stakeholders in the explosives community, including
  - Numerous federal agencies;
  - State and local responders (primarily represented by the National Bomb Squad Commander Advisory Board [NBSCAB]); and
  - Other subject-matter experts;
- Utilized stakeholder input to create a list of existing standards;
- Pared down the list and evaluated selected standards for DHS adoption;
- Analyzed standards gaps; and
- Produced a report detailing the final recommendations.

On behalf of the federal, state, and local responder community, the ESF is recommending the standards listed in Table 1 for DHS adoption. This recommendation is based on the collected narrative of federal, state, and local stakeholders; the scores collected through a controlled Decision Analysis and Resolution (DAR) process, which is based on the Capability Maturity Model Integration (CMMI) process improvement model;[5] and additional subject-matter expert analysis.

Table 1. Standards Recommended for DHS Adoption

Number	Title
NIJ Standard–0117.0	Public Safety Bomb Suit Standard
ASTM F792-08	Standard Practice for Evaluating the Imaging Performance of Security X-Ray Systems
NIJ Standard–0603.01	Portable X-Ray Systems for Use in Bomb Identification
ANSI N42.44, 2008	American National Standard for the Performance of Checkpoint Cabinet X-Ray Imaging Security Systems
ASTM Series for Robots[a]	
ASTM E2801-11	*Standard Test Method for Evaluating Emergency Response Robot Capabilities: Mobility: Confined Area Obstacles: Gaps*
ASTM E2802-11	*Standard Test Method for Evaluating Emergency Response Robot Capabilities: Mobility: Confined Area Obstacles: Hurdles*
ASTM E2803-11	*Standard Test Method for Evaluating Emergency Response Robot Capabilities: Mobility: Confined Area Obstacles: Inclined Planes*

[5] The DAR process (based on the CMMI model developed by the CMMI Institute, powered by Carnegie Mellon, www.cmmiinstitute.com) is a formalized decision-making process whereas decision criteria are developed, evaluated, and agreed upon at the beginning of a project.

ASTM E2804-11	*Standard Test Method for Evaluating Emergency Response Robot Capabilities: Mobility: Confined Area Obstacles: Stairs/Landings*
ASTM E2826-11	*Standard Test Method for Evaluating Emergency Response Robot Capabilities: Mobility: Confined Area Terrains: Continuous Pitch/Roll Ramps*
ASTM E2827-11	*Standard Test Method for Evaluating Emergency Response Robot Capabilities: Mobility: Confined Area Terrains: Crossing Pitch/Roll Ramps*
ASTM E2828-11	*Standard Test Method for Evaluating Emergency Response Robot Capabilities: Mobility: Confined Area Terrains: Symmetric Stepfields*
ASTM E2829-11	*Standard Test Method for Evaluating Emergency Response Robot Capabilities: Mobility: Maneuvering Tasks: Sustained Speed*
ASTM E2830-11	*Standard Test Method for Evaluating the Mobility Capabilities of Emergency Response Robots Using Towing Tasks: Grasped Sleds*
ASTM Series for Blast Resistant Trash Receptacles[a]	
ASTM E2639-12	*Standard Test Method for Blast Resistance of Trash Receptacles*
ASTM E2740-12	*Standard Specification for Trash Receptacles Subjected to Blast Resistance Testing*
ASTM E2831M-11	*Standard Guide for Deployment of Blast Resistant Trash Receptacles in Crowded Places*

[a] These have been bundled for analysis as one standard as they are complementary components regarding one technology or knowledge area.

State and local ESF stakeholders also highly ranked/recommended the National Guidelines for Bomb Technicians; however, the ESF at large is not recommending it for adoption at this time due to its law enforcement sensitive classification.

The ESF has also identified the following standards gaps.

- **Blasting Equipment.** Participants discussed the variability in the performance of hand-held firing units on the market today. These are critical pieces of equipment used by bomb squads to detonate counter charges to defeat explosive devices. The participants agreed that the standard should specifically address energy output, disposal, and ruggedness, especially against falls and water. (Any research or standards development activity related to this gap should reference the Mine Safety and Health Administration's [MSHA] materials and standards on this topic, which includes 30 Code of Federal Regulations [CFR] 75.0-1 Subpart N.)

- **Homemade Explosives/Continuing Education.** Participants recognized a need for homemade explosives (HME) training standards/courses based on roles, including bomb squads, operations, specialists, explosives workers, and ordnance workers.

- **X-Ray Technology.** Participants stated that x-ray standards should be developed or modified to account for new technology, including back scatter, dual energy, and millimeter wave.

- **Robots and Interoperability.** Participants were encouraged by the development of robot test standards and methods. However, they thought that there was a clear need for robot performance standards. In addition, consideration should be given to the development of standards to address robot interoperability and how robots communicate with one another and the bomb squads to work as a team.

- **Communications.** Standards for electromagnetic communications are not available outside the U.S. Department of Defense (DoD). Participants stated that an Explosive Ordnance Disposal (EOD) communications standard should be considered. The standard would address inter-bomb squad communications, communications between the bomb squad and other responders, and robot/sensor communications. In addition, the standard should address the security of information and intrinsic safety to prevent accidental detonation of an explosive device.

- **Canine Teams Explosives Training.** Participants noted that standards have yet to account for canine explosives detection activities. Test methods for canines are also necessary, and consideration should be given to the human-animal team. Any canine standard should also encompass incident mitigation once the canine has completed its task. Participants agreed that training standards for canine teams are paramount.

- **Explosive Breaching.** There are currently courses on explosive breaching, but there are no accreditation requirements for breaching training. Participants thought that standards for explosive breaching tools and training should be considered.

- **Military Ordnance.** State and local bomb squads are encountering an increasing amount of military ordnance in the U.S. Due to varying processes and procedures for incidents involving recovery of military ordnance. The participants indicated that standards addressing military ordnance response should be implemented.

- **Explosive Containment Vessels and Total Containment Vessels (TCV).** Fully enclosed TCVs were originally designed to contain an explosion but have evolved to include containment of toxic gases and biological or chemical agents. Manufacturers make claims that the vessels can contain repeated explosions and toxic materials, but no standard or testing exists to determine if these claims are true.

- **Development of a Program to Use DHS-NIST-ASTM International Standard Test Methods for Response Robots (E54.08.01).** NBSCAB recommended that E54.08.01 be used as a way to self-train and self-evaluate robot operator proficiency compared to "expert" operator performance captured during the standardization process.

- **Portable Hand-Held Shields/Ballistic Shield Protection.** A standard should be developed for portable hand-held shields carried by special weapons and tactics (SWAT) bomb technicians to protect against fragmentation and blast/shrapnel. This standard could be developed leveraging the work being performed by the National Institute of Justice (NIJ) at the University of Denver. (A representative from the Bureau of Alcohol, Tobacco, Firearms and Explosives [ATF] strongly cautioned that this concept should be analyzed and determined safe before developing a standard.)

This report details the activities of the ESF from September 2011 to September 2012 and includes a detailed approach, documentation of all findings, and final recommendations.

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1.0 OVERVIEW

The National Institute of Standards and Technology (NIST) promotes U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life. Within NIST, the Law Enforcement Standards Office (OLES) directs programs and provides technical advice in a number of areas including criminal justice, public safety, forensic science, interoperable communications, emergency response, and counterterrorism. From September 2011 to August 2012, NIST OLES, sponsored by the Department of Homeland Security Science and Technology Directorate's (DHS S&T) Explosives Division, collected recommendations for the adoption and/or development of explosives standards by the U.S. Department of Homeland Security (DHS) and identified explosives standards gaps. This effort is referred to throughout this report as the Explosives Standards Forum (ESF).

The following sections will describe the ESF's approach, findings, and recommendations.

2.0 APPROACH

The ESF was executed as a collaborative effort between federal, state, and local stakeholders with a common goal to produce a list of recommended standards for DHS adoption and a list of identified standards gaps. The process was purposely inclusive and all input was considered in the final analysis phase. The major steps in the approach are discussed in Sections 2.1 through 2.8. Figure 1 illustrates the approach that the ESF followed.

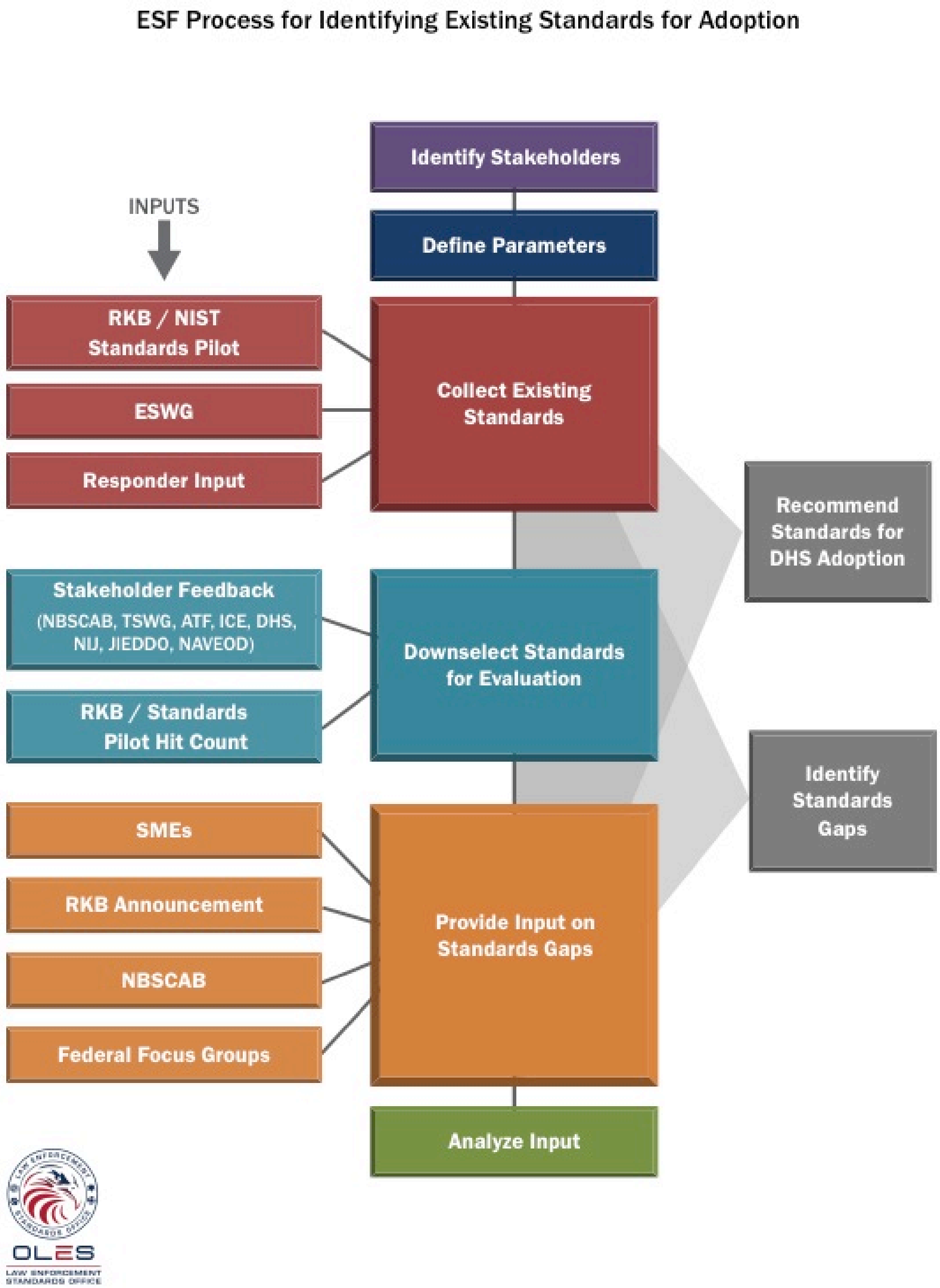

Figure 1. Approach

2.1 Identification of Stakeholders

NIST OLES identified stakeholders in the explosives community at the federal, state, and local levels. Maximum participation and feedback was solicited at all levels of the process from individuals representing the following agencies:

1. Federal representation
    a. Department of Defense (DoD)
        i. Combating Terrorism Technical Support Office (CTTSO) Technical Support Working Group (TSWG)
        ii. Joint Improvised Explosive Device (IED) Defeat Organization (JIEDDO)
        iii. Naval Explosive Ordnance Disposal Technology Division (NAVEODTECHDIV)
    b. U.S. Department of Treasury
        i. Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF)
    c. DHS
        i. Immigration and Customs Enforcement (ICE)
        ii. Federal Protective Services (FPS)
        iii. DHS S&T Explosives Division
        iv. Office of Bombing Prevention (OBP)
    d. U.S. Department of Justice (DOJ)
        i. National Institute of Justice (NIJ), Office of Science and Technology, Operational Technologies Division
        ii. Federal Bureau of Investigation (FBI), Hazardous Device School (HDS)

e. U.S. Department of Commerce

   i. NIST OLES

   ii. NIST Material Measurement Laboratory (MML)

2. State and local representation

   a. National Bomb Squad Commanders Advisory Board (NBSCAB) (feedback by quorum)

   b. Responder Knowledge Base (RKB) community (http://www.rkb.us/)

3. Explosives Standards Working Group (ESWG)[6]

2.2 Define Parameters

The ESF focused solely on explosives documentary standards (and did not address physical standards) for this effort. The ESF set forth the goals of recommending standards for DHS adoption and of recording all standards gaps put forth by stakeholders.

2.3 Research and Identification of Existing Standards

NIST OLES identified 34 existing published explosives standards, which included basic standards, terminology standards, testing standards, product standards, process standards, and service standards. Each source listed in Table 1 provided input. For the full list of identified existing standards, see Appendix B.

[6] The ESWG commenced in 2008 with the goal of providing "all DHS agencies with a forum/platform for collaboration and information exchange with national and international standards development bodies, other federal agencies, state and local government agencies and non-government entities on explosives related standards and conformity assessment measures." The ESWG produced a number of materials and recommendations before it concluded in 2010, and all produced materials were used as inputs to the ESF.

Table 2. Sources of Existing Standards

Source	Synopsis of Input
2009 ESWG	The 2009 ESWG plans, briefings, and documents were evaluated for input into this ESF process.
Federal Stakeholder Feedback	The federal stakeholders identified a list of existing standards.
NBSCAB Feedback	NBSCAB members provided an initial set of standards for consideration during their November 2011 meeting.
RKB	NIST OLES analyzed top-viewed explosives standards for inclusion.
NIST OLES Standards Pilot	An analysis was conducted on findings from the NIST OLES Standards Pilot for explosives standards applicability based on document requests or user feedback. These findings determined key equipment or training issues that the responder community has a strong interest in tracking and necessitated the inclusion of several of the radiographic standards on the evaluation list.[7]

2.4 Down-Selection of Standards for Evaluation

The ESF used stakeholder input (federal, state, and local) and the ranked popularity of the standards on websites such as the RKB and the Standards Pilot platform to pare down the list to a more manageable number of standards for closer evaluation. The downscaled list of 21 standards included those that stakeholders deemed most relevant to the explosives community. The list of standards deemed most relevant for further evaluation is in Table 3. Summaries of these standards are included in Appendix C.

[7] See http://www.nist.gov/manuscript-publication-search.cfm?pub_id=910380.

Table 3. Standards for Additional Analysis

Standard Number and Title
NIJ Standard–0603.01, Portable X-Ray Systems for Use in Bomb Identification
ASTM Series for Robots[a] • ASTM E2801-11, Standard Test Method for Evaluating Emergency Response Robot Capabilities: Mobility: Confined Area Obstacles: Gaps • ASTM E2802-11, Standard Test Method for Evaluating Emergency Response Robot Capabilities: Mobility: Confined Area Obstacles: Hurdles • ASTM E2803-11, Standard Test Method for Evaluating Emergency Response Robot Capabilities: Mobility: Confined Area Obstacles: Inclined Planes • ASTM E2804-11, Standard Test Method for Evaluating Emergency Response Robot Capabilities: Mobility: Confined Area Obstacles: Stairs/Landings • ASTM E2826-11, Standard Test Method for Evaluating Emergency Response Robot Capabilities: Mobility: Confined Area Terrains: Continuous Pitch/Roll Ramps • ASTM E2827-11, Standard Test Method for Evaluating Emergency Response Robot Capabilities: Mobility: Confined Area Terrains: Crossing Pitch/Roll Ramps • ASTM E2828-11, Standard Test Method for Evaluating Emergency Response Robot Capabilities: Mobility: Confined Area Terrains: Symmetric Stepfields • ASTM E2829-11, Standard Test Method for Evaluating Emergency Response Robot Capabilities: Mobility: Maneuvering Tasks: Sustained Speed • ASTM E2830-11, Standard Test Method for Evaluating the Mobility Capabilities of Emergency Response Robots Using Towing Tasks: Grasped Sleds
ASTM E2520-07, Standard Practice for Verifying Minimum Acceptable Performance of Trace Explosive Detectors
ASTM Series for Blast Resistant Trash Receptacles[a] • ASTM E2639-12, Standard Test Method for Blast Resistance of Trash Receptacles • ASTM E2740-12, Standard Specification for Trash Receptacles Subjected to Blast Resistance Testing • ASTM E2831M-11, Standard Guide for Deployment of Blast Resistant Trash Receptacles in Crowded Places
National Guidelines for Bomb Technicians 2012
ASTM F792-08, Standard Practice for Evaluating the Imaging Performance of Security X-Ray Systems
NIJ Standard–0117.00, Public Safety Bomb Suit Standard
ANSI N42.47-2010, American National Standard for Measuring the Imaging Performance of X-Ray and Gamma-Ray Systems for Security Screening of Humans
ANSI N42.44-2008, American National Standard for the Performance of Checkpoint Cabinet X-Ray Imaging Security Systems
ANSI N42.45-2011, American National Standard for Evaluating the Image Quality of X-ray Computed Tomography (CT) Security-Screening Systems
ANSI N42.46-2008, American National Standard for the Determination of the Imaging Performance of X-Ray and Gamma-Ray Systems for Cargo and Vehicle Security Screening

[a] These have been bundled for analysis as one standard as they are complementary components regarding one technology or knowledge area.

2.5 Conduct Federal Stakeholder Focus Groups

The ESF solicited input on 21 standards during two separate federal focus groups (in Washington, DC, and Gaithersburg, MD). The focus groups provided feedback and ratings for each standard against established evaluation criteria utilizing a Decision Analysis and Resolution (DAR) process, based on the Capability Maturity Model Integration (CMMI) model.[8] Prior to the first focus group, specific evaluation criteria were developed based on input from the federal focus group participants and guidance found in DHS Management Directive 10600.1, Adoption of Department of Homeland Security (DHS) National Standards. At the focus group, attendees reviewed and approved the criteria and assigned a specific weight to each related to level of importance. Once the criteria and weights were finalized, attendees rated each standard against the criteria. The same criteria and weightings were used for all federal participant input during the first and second focus groups (see Figure 2). These criteria are listed in Table 4.

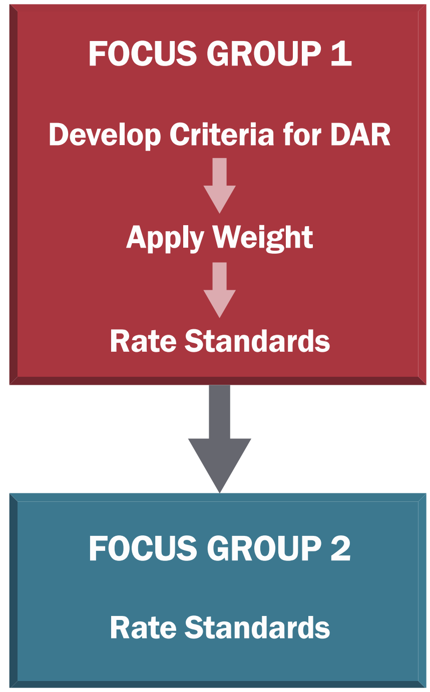

Figure 2. Conduct Focus Groups

Table 4. Standards Evaluation Criteria

Weight	Criteria	Criteria Considerations
20%	Was the standard updated within the last 5 years?	• Is there a process to update the standard?
25%	Is the standard relevant to state/local responders and industry?	• Does the standard promote and develop best practices and operations? • Does it provide guidance in the purchase of effective, safe, quality, necessary, and interoperable equipment and promote confidence in that equipment? • Does it define minimum performance levels/requirements, test methods, specifications, and operation procedures?

[8] The DAR process (based on the CMMI model developed by the CMMI Institute, powered by Carnegie Mellon, www.cmmiinstitute.com) is a formalized decision-making process whereas decision criteria are developed, evaluated, and agreed upon at the beginning of a project.

15%	Is the standard relevant to the federal response community?	• Does the standard assist with the Federal Grants Program? • Does it assist in collaboration and information exchange between the federal and state/local/tribal governments and non-government entities? • Does it promote standardized decisions/operations within DHS by developing clear and unambiguous requirements and performance objectives when assisting with explosives related programs?
20%	Is the standard authored/developed by a reputable and recognized organization using open and transparent procedures?	• Is the standard based on data from reputable institutions? • Is the document based on a consensus procedure? • Were members of the responder community involved in the development of the standard?
15%	Does the standard maximize responder effectiveness and not create any unnecessary burdens?	• Does the standard present clear benefits for safety or performance? • Does it present a reasonable ratio of effectiveness to efficiency?
5%	Is the standard easily accessible?	• Is there a cost associated with obtaining the standard?

The DAR was based on a 100-point scoring scale. The final acceptance criteria received a weighted percentage to total 100 percent, and each standard was scored on a scale of 1 to 5 for its applicability to each of the acceptance criteria. The DAR process accounts for scoring from multiple stakeholders, and the resulting calculations provide an averaged, weighted score for each standard.

2.6 Solicit State and Local Input at NBSCAB Meetings

State and local input was solicited through the National Bomb Squad Commanders Advisory Board (NBSCAB). The NBSCAB's mission is "to act in a leadership role for the bomb squad community, providing guidance and advice on important issues." The NBSCAB focuses on initiatives to improve bomb squad tactics, techniques, procedures, training and equipment. Further, the NBSCAB sets guidelines and standards for the bomb squad community through its role as elected representatives for state and local bomb squads. In addition, numerous federal agencies involved in issues related to state and local bomb squads regularly attend and contribute at the NBSCAB meetings.[9]

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[9] See http://nbscab.org/NBSCAB/nbscab_ex.php for more information.

During the commencement of the ESF, DHS designated the NBSCAB to represent the responder community. The NBSCAB, per its by-laws, provided collective input by quorum to the ESF. The input focused mainly on the specific needs of bomb technicians (local, state, and federal). During the ESF process, NBSCAB reviewed, approved, and recommended standards to be considered for adoption and identified standards to be developed.

2.7 Solicit Additional Input

NIST posted a question on the RKB website (http://www.rkb.us/) to solicit additional input from federal government users.

2.8 Conduct Final Analysis and Produce Scores

The DAR scores were not solely relied upon for final recommendations. Collected narrative was considered as valuable in determining the final recommendation.

The final phase, per the established methodology, included reviewing all inputs from the various stakeholders, producing scores, and determining final suitability for adoption.

3.0 FEEDBACK AND FINDINGS

3.1 Input on Existing Standards for DHS Adoption

This section details input from all solicited sources as related to existing explosives standards recommendations.

3.1.2 Federal Focus Group Input on Existing Standards for DHS Adoption

Both focus groups talked in depth about the existing explosives standards and related topics. Comments were collected without attribution and paraphrased as follows:

- The federal focus group participants favored basic, product, or process standards for DHS adoption. While testing and service standards are valuable in the federal, state, and local responder community, the participants thought that performance standards were more desirable and useful.

- Participants agreed that standards can quickly become expensive for a bomb squad. A federal focus group attendee pointed out that standards in the ASTM Series for Robots are $40.00 each, and the whole series totals $360.00. Participants were unaware of efforts by DHS to provide some standards at no cost to responders and generally thought that most responders were also unaware of this service.

- Participants indicated that they had found most standards related to explosives range from approximately $10.00 to $100.00. They agreed that standards for responders should be free, especially standards that were developed and published utilizing federal dollars. Participants noted that some federal agencies are not able to purchase standards in bulk and thus are not able to take advantage of economies of scale in buying.

- Participants discussed the disconnect between the research and development community and the standards community. For example, a technology may be created or improved, but a standard may not be available to support the new technology. This leaves the responders and researchers unable to evaluate the technology's performance and applicability to the current needs.

- One of the general observations by the participants was that bomb squads are moving toward using teams of robots for incidents. Participants agreed that the major standards issue with robots is communication between the robot and operator, between robots, and between the robot and other sensors.

- Participants stated that the Mine Safety and Health Administration (MSHA) had produced several relevant standards and agreed that these should be readily available to bomb squads.

Standards-specific feedback includes:

- ASTM E2520-07 does not address current threats, but the standard is in the process of being revised.

- NIJ 0603.01 does not account for back scatter or dual energy devices; as a result, the standard does not address all x-ray technologies.

- The National Guidelines for Bomb Technicians falls in the category of a process standard and is a valued resource; however, it is classified as law enforcement sensitive, making it more difficult to obtain and recommend for DHS adoption.

Each federal focus group attendee rated the aforementioned standards per the evaluation criteria. Ratings were added up to produce a score for each standard. Ratings from the two groups were combined. Scores that resulted from the DAR process are shown below, in Table 4.

Table 5. Federal Focus Group DAR Scores

Score	Standard
87%	NIJ Standard-0117.00, Public Safety Bomb Suit Standard
84%	ASTM Series for Blast Resistant Trash Receptacles
83%	ASTM F792-08, Standard Practice for Evaluating the Imaging Performance of Security X-Ray Systems
82%	NIJ Standard-0603.01, Portable X-Ray Systems for Use in Bomb Identification
77%	ANSI N42.44-2008, American National Standard for the Performance of Checkpoint Cabinet X-Ray Imaging Security Systems
76%	National Guidelines for Bomb Technicians 2012
75%	ASTM Series for Robots
64%	ANSI N42.45-2011, American National Standard for Evaluating the Image Quality of X-Ray Computed Tomography (CT) Security-Screening Systems
62%	ANSI N42.46-2008, American National Standard for Determination of the Imaging Performance of X-Ray and Gamma-Ray Systems for Cargo and Vehicle Security Screening
61%	ANSI N42.47-2010, American National Standard for Measuring the Imaging Performance of X-ray and Gamma-ray Systems for Security Screening of Humans
54%	ASTM E2520-07, Standard Practice for Verifying Minimum Acceptable Performance of Trace Explosive Detectors

3.1.3 NBSCAB Input on Existing Standards for DHS Adoption

After discussion, NBSCAB members recommended that DHS adopt the following standards:

1) NIJ Standard-0603.01, Portable X-Ray Systems for Use in Bomb Identification
2) National Guidelines for Bomb Technicians 2012
3) NIJ Standard-0117.00, Public Safety Bomb Suit Standard
4) ASTM Series for Robots

The above standards are up to date, are relevant to the community at large, and maximize responder effectiveness. NBSCAB posed no objection to adoption of the remaining presented standards but opted not to specifically recommend them for adoption because they fall outside NBSCAB's main area of responsibility.

3.1.4 Additional Input

The ESF received no additional input from the federal members of the RKB in regards to explosives standards to adopt or standards gaps that needed to be addressed.

4.0 IDENTIFIED STANDARDS GAPS

4.1 Federal Focus Group-Identified Standards Gaps

Both federal focus groups discussed the need for improvements to existing or the establishment of new standards for the explosives community. The participants thought the following were the highest priority for consideration.

- **Ballistic Shield Protection.** Current standards do not account for ballistic shield protection for bomb squads. Standards specific to portable, hand-held shields for blast, shrapnel, and overpressure protection should be considered. (This gap was combined with the **Portable Hand-Held Shields** gap in the final recommendations).

- **Blasting Equipment.** Participants discussed the variability in the performance of hand-held firing units on the market today. These are critical pieces of equipment used by bomb squads to detonate counter charges to defeat explosive devices. The participants agreed that the standard should specifically address energy output, disposal, and ruggedness, especially against falls and water.

- **Homemade Explosives/Continuing Education.** Participants recognized a need for homemade explosives (HME) training standards/courses based on roles, including bomb squads, operations, specialists, explosives workers, and ordnance workers.

- **X-Ray Technology.** Participants stated that x-ray standards should be developed or modified to account for new technology including back scatter, dual energy, and millimeter wave.

- **Robots and Interoperability.** Participants were encouraged by the development of robot test standards and methods. However, they thought there was a clear need for robot performance standards. In addition, consideration should be given to the development of standards to address robot interoperability and how robots communicate with one another and the bomb squads to work as a team.

- **Communications.** Standards for electromagnetic communication are not available outside DoD. Participants stated that an Explosive Ordnance Disposal (EOD) communications standard should be considered. The standard would address inter-bomb squad communications, communications between the bomb squad and other responders, and robot/sensor communications. In addition, the standard should address the security of information and intrinsic safety to prevent accidental detonation of an explosive device.

- **Canine Teams Explosives Training.** Participants noted that standards have yet to account for canine explosives detection activities. Test methods for canines are also necessary, and consideration should be given to the human-animal team. Any canine standards should also encompass incident mitigation once the canine has completed its task. Participants agreed that training standards for canine teams are paramount.

- **Explosive Breaching.** There are currently courses on explosive breaching, but there are no accreditation requirements for breaching training. Participants thought that standards for explosive breaching tools and training should be considered.

- **Military Ordnance.** State and local bomb squads are encountering an increasing amount of military ordnance in the U.S. Due to varying processes and procedures for incidents involving recovery of military ordnance, the participants indicated that standards addressing military ordnance response should be implemented.

4.2 NBSCAB-Identified Standards Gaps

NBSCAB recommended that standards or programs be developed related to the following explosives issues.

- **Explosive Containment Vessels and Total Containment Vessels (TCV).** Fully enclosed TCVs were originally designed to contain an explosion but have evolved to include containment of toxic gases and biological or chemical agents. Manufacturers make claims that the vessels can contain repeated explosions and toxic materials, but no standard or testing exists to determine if these claims are true.

- **Development of a Program to Use DHS-NIST-ASTM International Standard Test Methods for Response Robots (E54.08.01).** NBSCAB recommended that E54.08.01 be used as a way to self-train and self-evaluate robot operator proficiency compared to "expert" operator performance captured during the standardization process.

- **Portable Hand-Held Shields.** NBSCAB encourages the development of a standard for portable hand-held shields carried by special weapons and tactics (SWAT) bomb technicians to protect against blast/shrapnel. This standard could be developed by leveraging the work being performed by NIJ at the University of Denver.

5.0 FINAL RECOMMENDATION/CONCLUSION

The ESF compared and normalized input from various stakeholders using detailed narrative analysis and formal DAR scores and considered the purpose for DHS adoption. The ESF recommends the following standards for DHS adoption:

Table 6: Standards Recommended for DHS Adoption

Number	Title
NIJ Standard–0117.0	Public Safety Bomb Suit Standard
ASTM F792-08	Standard Practice for Evaluating the Imaging Performance of Security X-Ray Systems
NIJ Standard–0603.01	Portable X-Ray Systems for Use in Bomb Identification
ANSI N42.44, 2008	American National Standard for the Performance of Checkpoint Cabinet X-Ray Imaging Security Systems
ASTM Series for Robots[a]	
ASTM E2801-11	*Standard Test Method for Evaluating Emergency Response Robot Capabilities: Mobility: Confined Area Obstacles: Gaps*
ASTM E2802-11	*Standard Test Method for Evaluating Emergency Response Robot Capabilities: Mobility: Confined Area Obstacles: Hurdles*
ASTM E2803-11	*Standard Test Method for Evaluating Emergency Response Robot Capabilities: Mobility: Confined Area Obstacles: Inclined Planes*
ASTM E2804-11	*Standard Test Method for Evaluating Emergency Response Robot Capabilities: Mobility: Confined Area Obstacles: Stairs/Landings*
ASTM E2826-11	*Standard Test Method for Evaluating Emergency Response Robot Capabilities: Mobility: Confined Area Terrains: Continuous Pitch/Roll Ramps*

ASTM E2827-11	*Standard Test Method for Evaluating Emergency Response Robot Capabilities: Mobility: Confined Area Terrains: Crossing Pitch/Roll Ramps*
ASTM E2828-11	*Standard Test Method for Evaluating Emergency Response Robot Capabilities: Mobility: Confined Area Terrains: Symmetric Stepfields*
ASTM E2829-11	*Standard Test Method for Evaluating Emergency Response Robot Capabilities: Mobility: Maneuvering Tasks: Sustained Speed*
ASTM E2830-11	*Standard Test Method for Evaluating the Mobility Capabilities of Emergency Response Robots Using Towing Tasks: Grasped Sleds*
ASTM Series for Blast Resistant Trash Receptacles[a]	
ASTM E2639-12	*Standard Test Method for Blast Resistance of Trash Receptacles*
ASTM E2740-12	*Standard Specification for Trash Receptacles Subjected to Blast Resistance Testing*
ASTM E2831M-11	*Standard Guide for Deployment of Blast Resistant Trash Receptacles in Crowded Places*

[a] These have been bundled for analysis as one standard as they are complementary components regarding one technology or knowledge area.

These standards were all ranked higher than 70%, and verbal narrative from the stakeholders supported the scores. The National Guidelines for Bomb Technicians was recommended by NBSCAB; however, it was not included due to its law enforcement sensitive classification.

The ESF also identified the following standards gaps.

- **Blasting Equipment.** Participants discussed the variability in the performance of hand-held firing units on the market today. These are critical pieces of equipment used by bomb squads to detonate counter charges to defeat explosive devices. The participants agreed that the standard should specifically address energy output, disposal, and ruggedness, especially against falls and water. (Any research or standards development activity related to this gap should reference the MSHA materials and standards on this topic, which includes 30 Code of Federal Regulation [CFR] 75.0-1 Subpart N).

- **Homemade Explosives/Continuing Education.** Participants recognized a need for homemade explosives (HME) training standards/courses based on roles, including bomb squads, operations, specialists, explosives workers, and ordnance workers.

- **X-Ray Technology.** Participants stated that x-ray standards should be developed or modified to account for new technology, including back scatter, dual energy, and millimeter wave.

- **Robots and Interoperability.** Participants were encouraged by the development of robot test standards and methods. However, they thought there was a clear need for robot performance standards. In addition, consideration should be given to the development of standards to address robot interoperability and how robots communicate with one another and the bomb squads to work as a team.

- **Communications.** Standards for electromagnetic communication are not available outside DoD. Participants stated that an EOD communications standard should be considered. The standard would address inter-bomb squad team communications, communications between bomb squads and other responders, and robot/sensor communications. In addition, the standard should address the security of information and intrinsic safety to prevent accidental detonation of an explosive device.

- **Canine Teams Explosives Training.** Participants noted that standards have yet to account for canine mitigation activities. Test methods for canines are also necessary, and consideration should be given to the human-animal team. Any canine standards should also encompass incident mitigation once the canine has completed its task. Participants agreed that training standards for canine teams are paramount.

- **Explosive Breaching.** There are currently courses on explosive breaching, but there are no accreditation requirements for breaching training. Participants thought that standards for explosive breaching tools and training should be considered.

- **Military Ordnance.** State and local bomb squads are encountering an increasing amount of military ordnance in the U.S. Due to varying processes and procedures for incidents involving recovery of military ordnance, the participants indicated that standards addressing military ordnance response should be implemented.

- **Explosive Containment Vessels and TCVs.** Fully enclosed TCVs were originally designed to contain an explosion but have evolved to include containment of toxic gases and biological or chemical agents. Manufacturers make claims that the vessels can contain repeated explosions and toxic materials, but no standard or testing exists to determine if these claims are true.

- **Development of a Program to Use DHS-NIST-ASTM International Standard Test Methods for Response Robots (E54.08.01).** NBSCAB recommended that E54.08.01 be used as a way to self-train and self-evaluate robot operator proficiency compared to "expert" operator performance captured during the standardization process.

- **Portable Hand-Held Shields/Ballistic Shield Protection.** A standard should be developed for portable hand-held shields carried by SWAT bomb technicians to protect against fragmentation and blast/shrapnel. This standard could be developed by leveraging the work being performed by NIJ at the University of Denver. (A representative from the ATF strongly cautioned that this concept should be analyzed and determined safe before developing a standard.)

APPENDIX A
ACRONYMS/ABBREVIATIONS

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ACRONYMS/ABBREVIATIONS

ANSI	American National Standards Institute
ATF	Bureau of Alcohol, Tobacco, Firearms and Explosives
BSR	Board of Standards Review
CBRN	Chemical, Biological, Radiological, Nuclear
CFR	Code of Federal Regulation
CMMI	Capability Maturity Model Integration
CTTSO	Countering Terrorism Technical Support Office
DAR	Decision Analysis and Resolution
DHS	U.S. Department of Homeland Security
DoD	U.S. Department of Defense
DOJ	U.S. Department of Justice
EOD	Explosive Ordnance Disposal
ESF	Explosives Standards Forum
ESWG	Explosives Standards Working Group
FBI	Federal Bureau of Investigation
FPS	Federal Protective Services
HDS	Hazardous Device School
HME	Homemade Explosives
ICE	Immigration and Customs Enforcement
IEC	International Electrotechnical Commission
IED	Improvised Explosive Device
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
JIEDDO	Joint Improvised Explosive Device Defeat Organization

MSHA	Mine Safety and Health Administration
MML	Material Measurement Laboratory
NAVEOD	Naval Explosive Ordnance Disposal
NBSCAB	National Bomb Squad Commander Advisory Board
NIJ	National Institute of Justice
NIST	National Institute of Standards and Technology
OBP	Office of Bombing Prevention
OLES	Law Enforcement Standards Office
RKB	Responder Knowledge Base (http://www.rkb.us/)
S&T	Science and Technology
SME	Subject Matter Expert
SOP	Standard Operating Procedures
SWAT	Special Weapons and Tactics
TCV	Total Containment Vessel
TSWG	Technical Support Working Group
VBIED	Vehicle-Borne Improvised Explosive Device

APPENDIX B
LIST OF IDENTIFIED EXISTING STANDARDS TO DATE

APPENDIX B

LIST OF IDENTIFIED EXISTING STANDARDS TO DATE

	Number	Title
1		National Guidelines for Bomb Technicians 2012 (Law Enforcement Sensitive)
2		National Strategic Plan for U.S. Bomb Squads
3		ATF Vehicle Bomb Explosion Hazard and Evacuation Distance Tables
4		ATF Federal Explosives Law and Regulations
5		ATF Explosives Tracing Pocket Guide (Law Enforcement Sensitive)
6		ATF Detonator Recognition and Identification Guide
7	2010-1-A	FBI Bomb Data Center Special Bulletin: Model for Bomb Squad SOPs
8		Weapons Technical Intelligence Improvised Explosive Device Lexicon
9	NIJ Standard-0603.01	Portable X-Ray Systems for Use in Bomb Identification
10	NIJ Standard-0117.00	Public Safety Bomb Suit Standard
11	NIJ Standard-0116.00	CBRN Protective Ensemble Standard for Law Enforcement
12	ANSI N42.44-2008	American National Standard for the Performance of Checkpoint Cabinet X-Ray Imaging Security Systems
13	ANSI N42.45-2011	American National Standard for Evaluating the Image Quality of X-ray Computed Tomography (CT) Security-Screening Systems
14	ANSI N42.46-2008	American National Standard for Determination of the Imaging Performance of X-Ray and Gamma-Ray Systems for Cargo and Vehicle Security Screening
15	ANSI N42.47-2010	American National Standard for Measuring the Imaging Performance of X-ray and Gamma-ray Systems for Security Screening of Humans
16	ANSI/IEEE N42.55	Standard for the Performance of Portable X-Ray Systems for Use in Bomb Identification
17	ANSI/IEEE C95.4-2002	IEEE Recommended Practice for Determining Safe Distances from Radio Frequency Transmitting Antennas When Using Electric Blasting Caps During Explosive Operations
18	ASTM F792-08	Standard Practice for Evaluating the Imaging Performance of Security X-Ray Systems
19	ASTM E2740-12	Standard Specification for Trash Receptacles Subjected to Blast Resistance Testing
20	ASTM E2639-12	Standard Test Method for Blast Resistance of Trash Receptacles
21	ASTM E2831M-11	Standard Guide for Deployment of Blast Resistant Trash Receptacles in Crowded Places
22	ASTM E2520-07	Standard Practice for Verifying Minimum Acceptable Performance of Trace Explosive Detectors
23	ASTM E2801-11*	Standard Test Method for Evaluating Emergency Response Robot Capabilities: Mobility: Confined Area Obstacles: Gaps
24	ASTM E2802-11*	Standard Test Method for Evaluating Emergency Response Robot Capabilities: Mobility: Confined Area Obstacles: Hurdles
25	ASTM E2803-11*	Standard Test Method for Evaluating Emergency Response Robot Capabilities: Mobility: Confined Area Obstacles: Inclined Planes

	Number	Title
26	ASTM E2804-11*	Standard Test Method for Evaluating Emergency Response Robot Capabilities: Mobility: Confined Area Obstacles: Stairs/Landings
27	ASTM E2826-11*	Standard Test Method for Evaluating Emergency Response Robot Capabilities: Mobility: Confined Area Terrains: Continuous Pitch/Roll Ramps
28	ASTM E2827-11*	Standard Test Method for Evaluating Emergency Response Robot Capabilities: Mobility: Confined Area Terrains: Crossing Pitch/Roll Ramps
29	ASTM E2828-11*	Standard Test Method for Evaluating Emergency Response Robot Capabilities: Mobility: Confined Area Terrains: Symmetric Stepfields
30	ASTM E2829-11*	Standard Test Method for Evaluating Emergency Response Robot Capabilities: Mobility: Maneuvering Tasks: Sustained Speed
31	ASTM E2830-11*	Standard Test Method for Evaluating the Mobility Capabilities of Emergency Response Robots Using Towing Tasks: Grasped Sleds
32	BSR N42.40-200x	Standard for Evaluation and Performance of High Energy, X-Ray Interrogation Systems for Detection of Contraband of Concern in Homeland Security
33	ISO 16934: 2007	Glass in Building—Explosion-Resistant Security Glazing—Test and Classification by Shock-Tube Loading
34	MIL-D-16191F NOT 1	Detectors, Explosive Vapor

Notes:

Highlighted standards have been bundled into one standard as they are complementary components regarding one technology or knowledge area.

* These standards will also be part of the Vehicle-Borne Improvised Explosive Device (VBIED) Robot Standard that is currently under development.

APPENDIX C
STANDARDS ANALYZED FOR DHS ADOPTION

APPENDIX C
STANDARDS ANALYZED FOR DHS ADOPTION

Subject-matter experts prepared the following summaries and attempted to provide an overview of the standard. Participants at the federal focus groups and NBSCAB were provided the opportunity to read the full standard prior to discussions or rating.

C.1 NIJ Standard-0603.01: Portable X-Ray Systems for Use in Bomb Identification Summary

NIJ Standard-0603.01	
Author	National Institute of Justice
Date Published	December 2007
Audience	Owners, operators, and manufacturers of portable x-ray systems
Title	Portable X-Ray Systems for Use in Bomb Identification
Purpose	The purpose of this standard is to establish performance requirements and testing methods for portable x-ray systems for use in bomb disarming operations. This standard does not apply to cabinet x-ray systems, such as those used for security screening.
Summary	This standard is applicable to battery-powered portable x-ray systems and to optional-powered (battery or AC-mains) portable x-ray systems. The standard includes diagrams of a test pattern (figures 3 and 4) to be used to test the proper functioning of the system. The pattern involves the specific placement of copper and tungsten wire and lead pieces behind a 10-mm piece of steel and a steel wedge, all mounted on a 6-mm-thick piece of acrylic. When testing the image quality of the portable x-ray system, place the test pattern parallel to and 10 mm (±3 mm) in front of the image capture unit, and place the x-ray generator module as far away from the test pattern as recommended by the manufacturer's operational manual for a clear image on the full image capture unit. Activate the system five times and ensure that all of the lead, copper, and tungsten are clearly visible in the resulting five images. Furthermore, the entire image should be clear, within 12 mm of the edge of the image. To test the power capacity of the system, install fresh batteries and perform this test once every 10 minutes. Each image should be completely clear until the system indicates that the battery should be replaced. The portable x-ray system should provide an exposure area of 39.1 cm square when the x-ray generator module is positioned 59 cm (±5 cm) away from the target. To test this, collect nine test patterns and create a 3x3 grid that is 480 mm high and 660 mm wide. With the x-ray generator module positioned 59 cm (±5 cm) away from the target, acquire the image, and ensure that the field of vision is correct and the image is clear. The image acquisition period, which includes any discrete task needed to capture and display the image, should not exceed 240 seconds. This time can be measured with a stopwatch. Because x-ray generator modules may leak radiation, a qualified individual should test the amount of leakage in nine specific locations (figure 2 in the standard). After

	covering the aperture with a 3-mm-thick piece of lead, measure the leakage dose rate at locations 1 m (±5 mm) above, below, right, and left of the x-ray generator module axis, which passes through the center of the machine collinear with the useful x-ray beam. Take these four measurements in the plane of the aperture and the plane of the anode. Finally, measure the dose along the x-ray generator module axis no more than 10 mm away from the rear of the module. These doses should not exceed 1 mSv in 1 hour. The x-ray generator module should fit on a typical photographer's tripod with a ¼-20 UNC thread mount. The batteries required for the system should be easily replaceable or recharged, and the manufacturer should provide a battery tester. If the system includes an x-ray generator tube that is easily replaceable in the field, this should be accomplished with basic or manufacturer-provided tools. The whole portable x-ray system, complete with travel cases and other required accessories should not exceed 50 kg and should work in a temperature range of 0 to 110 degrees F. It should also operate correctly without leaking radiation after being bumped or dropped. To test the bump endurance, apply 100 bumps, each with a peak acceleration of 15 g, to each of the 6 sides of the system. To test drop endurance, place each section of the system in its transport case and drop it from a height of .3 m (±.03 m) on each face and corner. After these actions, the system should continue to operate to the level of the previous tests. The portable x-ray system should have a visual control and display unit for the operator. Buttons on this control unit and other parts of the system should be no smaller than 5 mm across. Although the operator can activate the system through the control unit, the operator should also be able to activate the system remotely and view images at a distance of at least 6 m away. Systems should also feature a delay timer that will postpone exposure by at least 1 minute after activation and a separate timer that postpones activation by 1 minute after powering on remotely. The portable x-ray system should have distinct visual and audible alarms for each of three conditions: (1) the system has been powered on and is ready to emit radiation, (2) the exposure delay timer has been activated and the system is counting down to emit radiation, and (3) the system is actively emitting radiation. Finally, systems that use sensitized media to record images should be key-activated to avoid accidental media exposure, and this key should not be able to be removed while the system is operating.

Reference:

https://www.ncjrs.gov/pdffiles1/nij/218586.pdf

C.2 ASTM Series for Robots

ASTM Series for Robots: E2801-11, E2802-11, E2803-11, E2804-11, E2826-11, E2827-11, E2828-11, E2829-11, E2830-11	
Author	ASTM International
Date Published	2011
Audience	Owners, operators, and manufacturers of emergency response robots
Title	ASTM Series for Robots: Standard Test Method for Evaluating Emergency Response Robot Capabilities for: (1) E2801-11, Mobility: Confined Area Obstacles: Gaps; (2) E2802-11, Mobility: Confined Area Obstacles: Hurdles; (3) E2803-11, Mobility:

	Confined Area Obstacles: Inclined Planes; (4) E2804-11, Mobility: Confined Area Obstacles: Stairs/Landings; (5) E2826-11, Mobility: Confined Area Terrains: Continuous Pitch/Roll Ramps; (6) E2827-11, Mobility: Confined Area Terrains: Crossing Pitch/Roll Ramps; (7) E2828-11, Mobility: Confined Area Terrains: Symmetric Stepfields; (8) E2829-11, Mobility: Maneuvering Tasks: Sustained Speed; (9) E2830-11, Mobility Capabilities of Emergency Response Robots Using Towing Tasks: Grasped Sleds
Purpose	The purpose of these nine standard test methods is to quantitatively evaluate the performance of robots for emergency response applications. These standards are not specifications for a standard robot of any kind.
Summary	These nine robotic standard test methods were developed as a baseline for all emergency response robot applications. A specific set of standard test methods to evaluate response robot capabilities to counter vehicle-borne improvised explosive devices is currently being developed, and that project uses these nine standards as a set of pre-qualifying basic robotic abilities. These test methods measure robot capabilities in mobility/maneuvering, energy/power, sensing, radio communications, manipulation, human-robot interaction, logistics, and safety to provide points of comparison for a variety of robot sizes and configurations prior to testing in more realistic scenarios. Statistically significant robot apparatus/procedures performance data captured within standard test methods measure incremental system improvements, highlight break-through capabilities, and support procurement/deployment decisions. The apparatuses used in these tests use terrains, targets, and tasks that are intentionally abstract and are built with readily available materials to facilitate fabrication by robot developers. This standards development process involved periodic robot requirements workshops, standards committee meetings, and robot evaluation exercises at responder training facilities that gathered emergency responders, robot developers, and test administrators around draft standard test methods and practice deployment scenarios. These events allowed emergency responders to articulate essential robot capabilities, to validate proposed test methods, and to refine performance thresholds and objectives based on objective performance data captured across a class of robots. Emergency responders involved in the process learned about the state of the science in robotic capabilities and helped ensure that the test method apparatuses and procedures addressed their application needs. The events also informed robot developers about the reliability and applicability of their robots for actual deployment scenarios, the ease of use of their robots within the test apparatuses, and the emerging operational requirements. For these test methods, the working definition of a “response robot” is a remotely deployed device intended to perform operational tasks at operational tempos. The robot should serve as an extension of the operator to improve remote situational awareness, to provide a means to project operator intent through the equipped capabilities, to improve effectiveness/efficiency of the mission, and to reduce risk to the operator. During these tests, the robots are operated by a remote “expert” as designated by the developer, and the performance data is collected by staff members. Each robot may attempt each test as many times as necessary to attain a satisfactory result. They may abstain from a particular test method when not applicable or when they may not successfully complete the set of continuous repetitions necessary to get reported in the data. In either case, the test will be marked as “ABSTAINED” to indicate that the manufacturer acknowledged the omission of performance data. These nine standards should be packaged together as a suite of standards for DHS adoption.

Reference:

http://www.astm.org/Standards/E2801.htm

Reference:

http://www.astm.org/Standards/E2802.htm

Reference:

http://www.astm.org/Standards/E2803.htm

Reference:

http://www.astm.org/Standards/E2804.htm

Reference:

http://www.astm.org/Standards/E2826.htm

Reference:

http://www.astm.org/Standards/E2827.htm

Reference:

http://www.astm.org/Standards/E2828.htm

Reference:

http://www.astm.org/Standards/E2829.htm

Reference:

http://www.astm.org/Standards/E2830.htm

C.3 ASTM E2520-07: Standard Practice for Verifying Minimum Acceptable Performance of Trace Explosive Detectors

ASTM E2520-07	
Author	ASTM International
Date Published	2007
Audience	First responders, security screeners, manufacturers/vendors

Title	ASTM E2520-07: Standard Practice for Verifying Minimum Acceptable Performance of Trace Explosive Detectors
Purpose	This practice is intended primarily to assist first responder and security screeners in verifying the minimum acceptable performance of trace explosive detectors used to identify traces of high explosives. The practice can also be used by manufacturers to demonstrate that the equipment is performing properly to a minimum standard.
Summary	This practice is used to demonstrate that detectors used to identify traces of high explosives by use of a test swipe meet a minimum acceptable performance. This practice is used to evaluate the detector response to evaporated residues of low-concentration solution of explosive compounds placed on test swipes. The concentrations of the solutions of explosive have been determined to be sufficient to provide a positive detector alarm signal. This practice uses three explosive compounds—RDX, PETN, and TNT—that are used to represent nitro-based compounds having a range of physical and chemical properties. This practice was developed using ion mobility spectrometry-based trace explosive detectors, but this practice should also be applicable to any explosive detector designed to analyze trace levels of high-explosive compounds collected on swipes. The practice may be used to accomplish several ends: to compare detectors before purchase; as a demonstration by the vendor that the equipment is performing properly to a minimum standard; or for a periodic verification of detector performance after purchase. This practice establishes the minimum performance that is required for a detector to be considered effective and is considered to have "minimum acceptable performance" when it has passed all of the evaluation tests without a failure. This practice outlines the necessary performance evaluation materials (test kits), procedures, analysis of the test swipes, and documentation of the test procedures.

Reference:

http://www.astm.org/Standards/E2520.htm

C.4 ASTM Blast Resistant Receptacle Series

ASTM Series for Blast Resistant Trash Receptacles: E2639-12, E2740-12, E2831M-11	
Author	ASTM International
Date Published	2011, 2012
Audience	Managers with public assembly areas, manufacturers, and test laboratories
Title	ASTM E2639-12: Standard Test Method for Blast Resistance of Trash Receptacles
Purpose	This test method provides a procedure for characterizing the performance of a trash receptacle when an explosive is detonated within the receptacle.
Summary	ASTM E2639 is a test method that provides a procedure for measuring the magnitude of an explosion when the explosion is detonated inside a trash receptacle. The procedure determines the extent and location of fragments produced during the explosion and whether breaches are created in the exterior surfaces of the trash receptacle. An appendix provides guidance for determining the magnitude of blast waves (that is, external overpressures). This test procedure is used to measure two of the main effects of an explosive detonated in a trash receptacle as related to the type and amount of explosive

	charge and the location where the charge is placed in the trash receptacle. The two effects are the release of primary and secondary fragments and physical damage to the trash receptacle. For users having interest in determining overpressures created by detonation, an appendix provides guidance for making such determinations. The test method is conducted in the following manner: • A trash receptacle is placed on a steel plate in the center of an explosive test arena. • An explosive charge is placed at one of four predetermined locations within the receptacle and detonated. • After detonation, the trash receptacle is examined for the presence of breaches (such as cracks, fissures, and holes) in its exterior surface, and the extent and location of fragments produced are recorded. • Note: Users of this standard testing the blast resistance of trash receptacles can, at their own option, measure the magnitude of overpressures created during the explosion. Guidance for performing such measurements is provided in the appendix. This test procedure is applicable to all trash receptacles, including lidded or non-lidded as supplied by the manufacturer. This test procedure is used to generate data for use in developing performance specifications for trash receptacles. (Cont.)

Reference:

http://www.astm.org/Standards/E2639.htm

ASTM Series for Blast Resistant Trash Receptacles (Continued)	
Title	ASTM E2740-12: Standard Specification for Trash Receptacles Subjected to Blast Resistance Testing
Purpose	This specification provides performance requirements for trash receptacles when subjected to the explosive tests described in ASTM E2639.
Summary	The trash receptacle test specimens shall be tested according to the requirements of Test Method E2639. Each test specimen shall be tested separately from the others in the group submitted with the charge at one of three locations. The testing laboratory shall randomly select the individual test specimen for each test from the group submitted. Trash receptacles including accessory components shall be tested as supplied by the manufacturer for in-use service. For example, if the trash receptacle is intended to have a lid in service, it shall be tested with the lid in place. The lid shall be secured to the receptacle as recommended by the manufacturer. The mass of the explosive charge shall be the same for all test specimens in the group submitted. (Cont.)

Reference:

http://www.astm.org/Standards/E2740.htm

ASTM Series for Blast Resistant Trash Receptacles (Continued)	
Title	ASTM E2831M-11: Standard Guide for Deployment of Blast Resistant Trash Receptacles in Crowded Places
Purpose	This standard provides guidance on the deployment of blast resistant trash receptacles because the selection of deployment locations impacts both the mitigation of the effects of an explosion occurring within one as well as the convenience of using the receptacles.
Summary	This guide provides general provisions for the deployment of blast resistant trash receptacles. Each facility or venue has unique features associated with factors such as demographics, location, and functions. The guide identifies key factors that should be considered prior to the receptacle deployment (in interior and exterior locations) and discusses the facilities and venues where the receptacles should be deployed. The importance of a strategy and procedures for the deployment of blast resistant trash receptacles in crowded places cannot be overly emphasized. Trash receptacles in crowded places have been, and continue to be, an attractive repository for explosives. The selection of deployment locations impacts both the mitigation of the effects of an explosion occurring within one as well as the convenience of using the receptacles. The deployment of blast resistant trash receptacles provides a means for decreasing injury and lethality during an explosive event, no matter their location when compared to the protection afforded by ordinary trash receptacles or clear plastic bags. Fragments resulting from explosions create the greatest danger to people, as fragments may travel several hundred meters and still have velocities that could be lethal or injurious. Blast resistant trash receptacles that meet the requirements of ASTM E2740-10 when subjected to internal explosions equal to or less than the force protection rating contain horizontal primary fragments and do not produce secondary fragments. The guide is intended for use by individuals in both the private and public sectors who are considering the purchase and deployment of blast resistant trash receptacles.

Reference:

http://www.astm.org/Standards/E2831.htm

C.5 National Guidelines for Bomb Technicians

National Guidelines for Bomb Technicians 2012	
Author	National Bomb Squad Commanders Advisory Board/Federal Bureau of Investigation
Date Published	March 2010
Audience	U.S. civilian bomb technicians
Title	National Guidelines for Bomb Technicians 2012
Purpose	Law enforcement sensitive
Summary	Law enforcement sensitive

Reference:

http://nbscab.org/NBSCAB/nbscab_ex.php

C.6 ASTM F792-08: Standard Practice for Evaluating the Imaging Performance of Security X-Ray Systems

ASTM F792-08	
Author	ASTM International
Date Published	2008
Audience	X-ray manufacturers and security evaluators
Title	Standard Practice for Evaluating the Imaging Performance of Security X-Ray Systems
Purpose	The purpose of this practice is to establish a method to measure the imaging performance of x-ray systems used for the screening of prohibited items in baggage, packages, cargo, or mail.
Summary	This standard practice establishes a method to measure the imaging performance of x-ray systems used for the screening of prohibited items, such as weapons, explosives, and explosive devices in baggage, packages, cargo, or mail. The practice applies to all x-ray-based screening systems with tunnel apertures up to 1 m wide by 1 m high, including both conventional x-ray systems and explosives detection systems, where the system provides a projection or projection/scatter image for an operator to interpret. The practice is intended for use by manufacturers to assess performance and by evaluators screening x-ray systems to verify performance. The practice is intended to establish whether the system meets the manufacturer's specification or if the system's performance has deteriorated over time. The practice may also be used for manufacturing control, specification acceptance, service evaluation, or regulatory statutes. The practice relies upon the use of a standard ASTM x-ray test object that was developed to assess the system's image quality/performance level in the following nine distinct areas: • Wire Display: To characterize the system's ability to display wires, including details such as gauge and spacing between wires. • Useful Penetration: To determine how well the system can penetrate various thicknesses of aluminum to display wires under the aluminum. • Spatial Resolution: To determine the gauge and spacing between narrowly spaced wires. • Simple Penetration: To determine simple penetration with lead digits placed on top of steel that varies in thickness. • Thin Organic Imaging: Using plastic samples of various thicknesses to characterize the system's ability to image thin organic material. • Image Quality Indicator: Using steel and plastic samples of various thicknesses with flat-bottom holes drilled in them to determine the depth and diameter of the holes and the thickness of the samples. • Organic/Inorganic Differentiation: Ability to determine the difference between steel and plastic samples. • Organic Differentiation: Ability to differentiate between plastic samples that shall have different effective atomic numbers but nominally identical attenuation. • Useful Organic Differentiation: Using samples of plastic placed on top of steel that varies in thickness to determine useful differentiation of materials.

	This practice establishes quantitative and qualitative methods for evaluating the systems but does not establish minimum performance requirements for any particular application. The practice lists the specific testing procedures and outlines numerous evaluation considerations.

Reference:

www.astm.org/Standards/F792.htm

C.7 NIJ Standard–0117.00: Public Safety Bomb Suit Standard

NIJ Standard–0117.00	
Author	U.S. Department of Justice, Standards and Testing Program, Office of Justice Programs, National Institute of Justice
Date Published	March 2012
Audience	Certified public safety bomb technicians
Title	Public Safety Bomb Suit Standard
Purpose	The purpose of this standard is to specify minimum voluntary performance requirements for bomb suits and to outline the associated certification program test methods for assessing that the performance requirements are met. This standard is for bomb suits used by certified public safety bomb technicians while performing hazardous device render safe procedures and assessing potential suspicious items. A second related document (Certification Program Requirements) defines the methods used to test the performance requirements, and a third document (Selection and Application Guide) is available to provide guidance on selecting, procuring, using, and maintaining bomb suits. Since this standard is a performance and testing standard, it provides precise and detailed test methods.
Summary	This standard is a Voluntary Performance Standard with an accompanying Certification Program Requirements document. The standard addresses six key areas: fragmentation, impact, flame, blast overpressure, optics, and ergonomics. Fragmentation, impact, flame, and blast overpressure are hazards that a bomb technician needs protection from when performing render safe procedures. Optics and ergonomics relate to a bomb technician's ability to perform render safe procedures while wearing the bomb suit. The standard balances the protection requirements against the bomb technician's need for mobility, clear vision, and dexterity. Within the six key areas, all bomb suit models shall meet or exceed the applicable performance requirements specified in the categories below. • Ergonomics: Donning/doffing, body mobility • Optics: Distortion, refraction, anti-fogging • Flammability: Outer shell materials and helmets • Electrostatic discharge: Grounding strap requirements • Head protection: Impact, perforation resistance, and retention system • Spine protection: Impact attenuation • Fragmentation: Perforation resistance • Blast integrity: Ability to remain intact when subject to blast overpressure • Drag rescue: Handles to provide drag ability for downed bomb technician • Label durability: Wear and chemical resistance • Optional foot protection slip resistance All bomb suits used when testing against this standard shall be new. The bomb suits shall be designed to protect at least the wearer's head, face, neck,

	thorax/abdomen, pelvis, arms and legs. The suit shall be designed so no protected areas shall become unprotected due to body movement. Bomb suits shall be available in at least three distinct sizes with the following weight restriction requirements: 68 lbs. for the smallest size, 76 lbs. for midrange size, and 85 lbs. for the largest size. No optional accessories shall be required to meet the form, fit, and performance requirements of this standard. If accessories are attached or integrated with the bomb suit, the suit with required accessories installed shall meet all of the form, fit, and performance requirements of this standard. A major area of discussion during this standard's development was the effect of blast overpressure. It was decided that research and data related to blast overpressure effects on the bomb technician wearing the suit was limited and would not be included at the time. The following aspects of blast overpressure will not be addressed until the necessary research is completed: blast head trauma, blast thoracic injuries, blunt thoracic injuries, blunt lower neck trauma, other neck injuries, and blast ear injury. NIJ anticipates publishing addenda or revisions to this standard when the necessary data are available and test methods are defined. This standard only addresses blast overpressure in terms of bomb suit integrity; i.e., the bomb suit's ability to remain intact when subjected to an explosion. Additionally, chemical, biological, radiological, and nuclear protection is not addressed in this standard but will be if additional data becomes available. This standard does not address all safety concerns associated with wearing the bomb suit. The standard does not address search suits or reconnaissance suits or specific protection from projectiles from firearms. Although agencies are advised to require their bomb suit procurements to meet or exceed the most recent version of this standard, this does not necessarily mean that an agency should remove bomb suits that they currently have in use, as a bomb suit that does not meet the current standard may well be better than no bomb suit at all. This standard shall not restrict any supplier or manufacturer from exceeding the requirements of this standard and no manufacturer may claim compliance with only selected portions of the standard. The bomb suit model shall meet all applicable requirements of this standard including the associated Certification Program Requirements.

Reference:

https://www.ncjrs.gov/pdffiles1/nij/227357.pdf

C.8 ANSI N42.47-2010: American National Standard for Measuring the Imaging Performance of X-Ray and Gamma-Ray Systems for Security Screening of Humans

ANSI N42.47-2010	
Author	National Committee on Radiation Instrumentation, American National Standards Institute, Institute of Electrical Electronics Engineers, Inc.
Date Published	August 2010
Audience	X-ray and gamma-ray system manufacturers, potential system users, and other

	interested parties
Title	American National Standard for Measuring the Imaging Performance of X-Ray and Gamma-Ray Systems for Security Screening of Humans
Purpose	This standard applies to security screening systems that utilize x-ray or gamma radiation and are used to inspect people who are not inside vehicles, containers, or enclosures. Specifically, this standard applies to systems used to detect objects carried on or within the body of the individual being exposed. The purpose of this standard is to provide standard methods of measuring and reporting imaging quality characteristics and to establish minimum acceptable performance requirements.
Summary	This document establishes standard test methods and test devices for measuring the imaging performance of x-ray and gamma-ray systems for security screening of humans. Minimum acceptable performance requirements are also provided. The following types of systems are included in the scope of this standard: • Systems designated as fixed, portal, re-locatable, transportable, mobile, or gantry. • Systems employing detection of primary radiation (transmission systems) or scatter radiation (back scatter systems) or a combination of both. • Systems that are primarily imaging but that also may have complementary features, such as material discrimination or automatic active or passive threat alerts. This standard will not address how to test these complementary features. The imaging performance evaluation procedures used for this standard are as follows: • Test Documentation: Documentation shall include testing of environmental conditions, image performance results, background conditions, description of systems tested, and identification of people involved in the test. • Image Quality Measurement Objectives and Scope: The objective of the imaging performance measurement procedures is to provide standardized test methods that enable system manufacturers, potential system users, and other interested parties to establish a consistent indicator of the expected performance of the screening system when used for the inspection of individuals, to provide repeatable and verifiable imaging performance data, and to establish a benchmark that can be used over time to calibrate the system or detect any performance degradation. • Body Phantom and Test Objects: The test objects for each of the image quality tests shall be mounted on a body phantom. The body phantom shall be made of high-density polyethylene. • Location of Testing: At a minimum, all the image quality tests shall be performed at the reference location, which is defined as: (1) the surface of the body phantom and test object combination closest to the radiation source shall be at the optimum operating distance as specified by the manufacturer, and (2) the center of the body phantom shall be in the center of the scan area and at a height 1 m from the ground. • The Spatial Resolution Test: This test measures the ability to display as materials objects separated by a space equal to the object width. • Wire Detection Test: This test determines the minimum diameter of copper wire that can be detected. • Materials Detection on Body Test: This tests the ability to detect objects on the body that are of a density similar to that of the body. • Materials Detection in Air Test: This tests the ability to detect objects hidden in

	clothing on the sides of the body when the image of the objects is not superimposed on the image of the body. • Penetration Test: This measures any degradation of spatial resolution and wire detection with increased body size. This test applies only to transmission systems. This standard has a minimum acceptable imaging performance, which is detailed in a chart in the standard.

Reference:

http://ieeexplore.ieee.org/servlet/opac?punumber=5557723

C.9 ANSI N42.44: Performance of Checkpoint Cabinet X-Ray Imaging Security Systems

ANSI N42.44-2008	
Author	National Committee on Radiation Instrumentation, American National Standards Institute, Institute of Electrical and Electronics Engineers, Inc.
Date Published	November 2008
Audience	X-ray and gamma-ray system manufacturers, potential system users, and other interested parties
Title	American National Standard for the Performance of Checkpoint Cabinet X-Ray Imaging Security Systems
Purpose	Screeners frequently use the images provided by checkpoint x-ray systems to detect weapons and contraband materials as well as to verify manifests (to determine that the contents of a package are what they are purported to be). For these applications, this standard is intended to provide procurers and/or prospective users of checkpoint x-ray systems with test methods that facilitate performance comparisons among systems and the minimum acceptable imaging-performance requirements. Additionally, a variety of factors essential for the safe operation of checkpoint x-ray systems are assembled and standardized in this document.
Summary	This standard specifies minimum requirements and test procedures for x-ray imaging performance, radiation-limitation requirements, and electrical, mechanical, and environmental requirements. This standard addresses technical image-quality performance, not threat-detection performance. The test object used in this document is composed of fixtures for the following nine tests: • Test 1: Wire display; • Test 2: Useful penetration; • Test 3: Spatial resolution; • Test 4: Simple penetration; • Test 5: Thin organic imaging; • Test 6: Image-quality-indicator sensitivity; • Test 7: Organic/inorganic differentiation; • Test 8: Organic differentiation; and

	• Test 9: Useful organic differentiation. The use of non-tinned, solid copper wires is required for Test 1, Test 2, and Test 3 in this standard. The test object shall be placed alone and in its case such that one surface of the case is in contact with the x-ray conveyor belt. The surface in contact with the conveyor belt should be chosen such that the test object is more nearly perpendicular to the x-ray beam axis. Thus, if the x-ray beam is primarily directed vertically upward ("up-shooter"), the case should lie flat; if the x-ray beam is primarily directed horizontally ("side shooter"), the case should be positioned on edge. An exception is permitted for systems in which the x-ray beam is primarily directed vertically downward ("down-shooter"), for which the test object shall be positioned with the bottom surface of the case parallel to the conveyor surface but may be elevated to a height above the conveyor belt of up to one-fourth of the vertical tunnel dimension. In all cases, the test object (in its case) shall be scanned with its long dimension parallel to the direction of the conveyor motion. The case may be positioned laterally (with respect to the direction of the conveyor motion) for optimal performance in any test. In all cases, the placement and orientation of the test object shall be reported in the test procedure with the corresponding test results. The tests specified in this standard may be used for type testing. Type tests are intended to demonstrate that production systems made according to a specific design meet defined performance criteria.

Reference:

http://ieeexplore.ieee.org/servlet/opac?punumber=4667698

C.10 ANSI N42.45: Standard for Evaluating the Image Quality of X-Ray Computed Tomography (CT) Security Screening Systems

ANSI N42.45-2011	
Author	Institute of Electrical and Electronics Engineers, Inc.
Date Published	2011
Audience	Owners, operators, and manufacturers of computed tomography (CT) security-screening systems
Title	American National Standard for Evaluating the Image Quality of X-Ray Computed Tomography (CT) Security-Screening Systems
Purpose	This standard provides test methods for the evaluation of image quality of CT security-screening systems. The quality of data for automated analysis is the primary concern. This standard does not address the system's ability to use this image data to automatically detect explosives or other threat materials, which is typically verified by an appropriate regulatory body.
Summary:	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. This data is 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, evaluation procedures to determine whether a system's automated detection performance is adequate have been developed. Typically, vendors submit a copy of their products, including their software, to the regulator's facility. The regulator runs a wide variety of parcels with threats 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 specific system tested is capable of meeting the required criteria. Normal manufacturing variability, quality control issues, or aging of the equipment may degrade performance compared with what was observed on the article tested by the regulator. Replicating the original test on each machine in question is impractical. Transporting the regulator's threat set to a factory site or to locations where the machines are in use, presents significant security and in some cases safety concerns. This standard seeks to address this issue. The performance testing carried out by the regulators essentially evaluates the combination of the system's ability to produce an image of the parcel along with its automatic analysis of that image data to reach a decision of threat or clear. The second part of this sequence, the analysis, is implemented through software. It should be noted that the regulators generally require that this software be designed so as to not devolve 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 originally approved. This standard specifies a set of methods to apply in assessing CT image quality geared toward security screening. An application of this standard would be in the factory acceptance testing of equipment. The standard could be used to indicate whether the unit offered for sale produces the equivalent image quality as the unit that was tested by the original regulatory agency. This standard does not address image quality presented to the operator. This standard specifies procedures for measuring a wide range of image quality indicators. Below is a list of the eight test procedures: • Object length accuracy • Path length CT value and Zeff • Noise equivalent quanta • CT value consistency • Zeff and CT value uniformity • Streak artifacts • Slice sensitivity profile • Image registration Along with the eight procedures are the accompanying image-quality indicators they measure and the test object they use. Each testing procedure generates a report when executing this standard. The first

	part of the report is manually recorded observations of the test environment. The second part is the result of analysis of test article A, and the third part is from the analysis of test article B.

Reference:

http://ieeexplore.ieee.org/servlet/opac?punumber=5783277

C.11 ANSI N42.46: Determination of the Imaging Performance of X-Ray and Gamma Systems for Cargo and Vehicle Security Screening

ANSI N42.46-2008	
Author	Institute of Electrical and Electronics Engineers, Inc.
Date Published	2008
Audience	Owners, operators, and manufacturers of x-ray and gamma-ray systems for cargo and vehicle security screening
Title	American National Standard for Determination of the Imaging Performance of X-Ray and Gamma-Ray Systems for Cargo and Vehicle Security Screening
Purpose	The purpose of this document is to provide standard, repeatable, and verifiable methods to describe and measure the imaging performance characteristics of x-ray and gamma-ray systems for cargo and vehicle security screening. It is not intended to determine the capability of a security screening system under specific operational inspection conditions.
Summary	This standard is intended to be used to determine the imaging performance of x-ray and gamma-ray systems utilized to inspect loaded or empty vehicles, including personal and commercial vehicles of any type, marine and air cargo containers of any size, railroad cars, and palletized or un-palletized cargo larger than 1 m × 1 m in cross-section. The standard applies to systems that: • Are single or multiple energy, source, or view; • Employ primary (i.e., transmission) and/or scatter (e.g., backscatter) radiation detection; • Detect prohibited and controlled materials and/or verify manifests; and • Serve primarily as imaging systems but that also may have complementary features, such as material discrimination and automatic active or passive threat alerts. This standard does not address how to test these complementary features. The below are the Performance Measurement Procedures that shall be consistent for all systems of similar type or size: • General Requirements: Test objects and measurement procedures may differ to some extent depending on the type of imaging system (e.g., transmission or backscatter) or system size. Test objects and procedures shall be consistent for all systems of similar type or size. • Standard Test Conditions: The tests defined in this standard should be performed on the standard commercial product as provided by the manufacturer.

	• Radiation Field Measurement: The x-ray and gamma-ray systems that are the subject of this standard use ionizing radiation to create an image of cargo and vehicles. For purposes of this standard, the resulting radiation field in and around the system and the radiation dose received by the inspected object also shall be measured as part of the characterization of system performance. • Documentation: All testing environmental conditions, measurements, description of systems, etc. shall be documented, retained, and available for inspection for as long as any systems similar to those tested remain in service. • Image Quality Measurement Objectives and Scope: The objectives are to establish a consistent indicator of the expected performance of the screening system when used for the inspection of cargo and vehicles, to provide repeatable and verifiable imaging performance data, and to establish a benchmark that can be used over time to calibrate the system or to detect any performance degradation. • Test Object Positions: At a minimum, all tests shall be performed at a horizontal and vertical location. • Penetration: The test should measure the maximum thickness of steel through which the orientation of a specified test object can be determined. • Spatial Resolution: The test should measure the minimum separation between the features of a test object for which the individual features can be distinguished • Wire Detection: The test should determine the smallest diameter wires that are visible in the x-ray or gamma-ray image. The test objects and test procedures differ for transmission and backscatter imaging. In both cases, the test measures the minimum diameter copper wire that is visible in the image of a test object scanned in air. • Contrast Sensitivity: The test should measure the minimum increase in steel thickness visible in an x-ray or gamma-ray image. The test objects and procedures differ for transmission and backscatter imaging.

Reference:

http://ieeexplore.ieee.org/servlet/opac?punumber=4606805