Testing and Evaluation of Passive Radiation Detection Equipment for Homeland Security

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Abstract

This article is concerned with test and evaluation methods for passive radiation detection equipment used in homeland security applications. The different types of equipment used in these applications are briefly reviewed and then test and evaluation methods discussed. The primary emphasis is on the test and evaluation standards developed by the American National Standards Institute's N42 committees. Commonalities among the standards are reviewed as well as examples of unique aspects for specific equipment types. Throughout, sample test configurations and results from testing and evaluation at Oak Ridge National Laboratory are given. The article concludes with a brief discussion of typical tests and evaluations not covered by the N42 standards and some examples of test and evaluation that involve the end users of the equipment.

Introduction

There is a need to monitor public gatherings, streams of commerce, etc. for illicit radioactive materials that could be used to fashion devices intended to cause harm, or to detect such devices when they are transported or deployed. These monitoring and detection applications are usually referred to as "homeland security" applications and they are described in more detail in (McDonald, Coursey, and Carter 2004) and (Kouzes 2005).

Two broad classes of equipment are currently deployed in homeland security radioactive material detection—active interrogation and passive. Active interrogation equipment uses either photon or neutron beams to stimulate nuclear reactions in fissile materials, and the products of these reactions are detected (Gozani 2009). Passive equipment is designed to detect and measure the radiation emitted by radioactive materials in the absence of any stimuli. In this paper, we will discuss testing and evaluation of passive radiation detection equipment for homeland security applications.

Homeland security applications present at least three unique challenges in comparison with traditional (e.g., contamination control or occupational safety) passive radioactive material detection applications: First, since most of the equipment is used in a stand-off mode, at some distance away, and the radioactive material to be detected may be shielded by container walls, etc., the demands on instrument sensitivity are higher than traditional applications, where contact measurements can often be made. Secondly, only the gamma-ray and neutron emissions from the radioactive material can typically be used for detection, as any alpha or beta particles emitted have a very short mean free path, even in air. Finally, there are many lawful materials and persons in the natural background and stream of commerce that will have a radioactive signature due to the presence of naturally occurring radioactive materials, radioactive materials used for industrial purposes, and radioactive materials used in medical treatments. Therefore, it is important to be able to identify, in the field, the actual isotopes present in a radioactive material.

Types of passive detection instruments

The more prevalent types of passive detection instruments developed for homeland security applications are listed in Table 1. Most of these instrument types are designed to detect gamma-rays and/or neutrons, with gamma-ray detection being more common. For those instruments that detect gamma-rays, a further distinction is whether the instrument is spectroscopic. Spectroscopic instruments can generate an energy spectrum of the detected gamma-rays, and analysis of this energy spectrum is the most common technique used in identifying radioactive materials. Spectroscopic variants are commercially available for virtually all the instrument types in Table 1. (Virtually all commercially available Radionuclide Identification Devices (RIDs) are spectroscopic.)

There are many domestic (US) and international manufacturers of the equipment types in Table 1. Often, any single manufacturer will offer several different equipment types and have multiple variants of a given type. One common situation is to offer neutron detection capability as a variant for a gamma-ray detecting instrument.

Table 1: Common types of passive radiation detection equipment used in homeland security applications

Type	Description
Personal Radiation Detector	Body-worn device, detects radioactive material in a limited area around the wearer.
Personal Emergency Radiation Detector	Body-worn device, alerts emergency responders to significant levels of radiation. Usually has lower sensitivity but higher measurement range than a personal radiation detector.
Handheld Search Device	Handheld device used to search for radioactive materials.
Radionuclide Identification Device	Portable device used to identify radioactive materials, will also usually have detection (alarm) capability.
Backpack Radiation Detector	Instrument carried in a backpack or shoulder bag that detects radioactive material in a wide area around the wearer.
Mobile System	Radioactive material detection system transported and

	operated on a vehicular platform (truck, boat, or aircraft).
Radiation Portal Monitor	Large-size, often permanently mounted system that detects radioactive material passing through or nearby.

Testing and evaluation

ANSI N42 standard testing

In 2002, the Department of Homeland Security (DHS) helped organize a consortium of government institutes (primarily the National Institute for Standards and Measurement (NIST)) and national laboratories, instrument manufacturers, and the American National Standards Institute (ANSI) to develop performance and related standards for homeland security radiation detection instruments (Karam 2007, Chiaro 2008). This led to the development (and ongoing maintenance), by ANSI committee N42 of a series of standards for passive radiation detection equipment for homeland security. Working in parallel, the International Electrotechnical Committee (IEC) has also developed (and continues to maintain) a set of standards; but, in the following we will focus on the ANSI standards, which are now maintained in collaboration with the Institute of Electrical and Electronics Engineers (IEEE).

Table 2 lists the standards for passive radiation detection equipment that have been developed. Most of these are available at no cost from IEEE (IEEE 2017) through funding provided by DHS's Domestic Nuclear Detection Office (DNDO). The test and evaluation portion of these standards will define a series of performance or other requirements and then define test methods to evaluate each requirement. Furthermore, the test and evaluation portion of each standard is usually divided into five sections: General, radiological, environmental, electromagnetic, and mechanical. These are discussed in sequence below.

Table 2: IEEE/ANSI N42 standards governing the types of passive radiation detection equipment used in homeland security applications

Standard	Equipment type	Latest revision
N42.32	Personal Radiation Detectors (PRDs)	2016
N42.48	Spectroscopic Personal Radiation Detectors (SPRDs)	2008
N42.49	Personal Emergency Radiation Detectors (PERDs)	2011
N42.33	Handheld Search Devices (gamma-ray)	2006
N42.39	Handheld Search Devices (neutron)	2005
N42.34	Radionuclide Identification Devices (RIDs)	2015
N42.53	Backpack Radiation Detectors (BRDs)	2013
N42.43	Mobile Systems	2016
N42.35	Radiation Portal Monitors (RPMs)	2016
N42.38	Spectroscopic Radiation Portal Monitors (SRPMs)	2015

The general section of a given N42 standard is concerned primarily with the design, basic function, and manufacturer-supplied documentation of the equipment. Most of these general requirements will be evaluated either by inspection or basic operation. The specific requirements vary greatly depending equipment type, but there are some commonalities among the various standards. For example, there is usually a requirement that an instruction manual be supplied that is up-to-date and accessible to a non-expert user. This is evaluated by having a small number (usually three) of users independently review the manual and then perform the equipment's intended function. The standard will also usually define an information set that must be provided by the manufacturer. For example, for gamma-ray detecting equipment the manufacturer is required to state the energy range of gamma-rays that can be detected by the equipment. This is evaluated by reviewing the documentation supplied by the manufacturer. One key design requirement in most standards is that alarm thresholds and other operational parameters only be changeable in a password-protected mode, with basic equipment operation being possible outside this mode.

Other evaluations covered in the general section of the N42 standards in Table 2 typically include the dimensions and weight of the equipment as well as external markings, the format of files produced by the equipment (if any) and how they can be transferred to an external computer or storage device, and alarms or indications that are presented to the user. Depending on the device type, there may be limits or constraints on these, or the standard may simply require that these be recorded.

The radiological section of a given N42 standard is concerned with the radiation detection functionality of the equipment. As was the case with the general section, the details of the radiological section depend strongly on equipment type but again there are commonalities.

Most standards will define a maximum false alarm rate where a false alarm is defined as the equipment indicating the presence of an elevated radiation field when, in fact, the field is only undergoing natural background fluctuations. This is evaluated by operating the equipment in a stable radiation field either for a fixed amount of time or for occupancy-based systems (such as portals) for a fixed number of occupancies. The false alarm tests normally will use statistical inference. For example, if the maximum allowable false alarm rate for a portal is 1 every 1000 occupancies, then a larger number of occupancies (e.g., 5000) will be carried out to determine at some level of certainty (normally 95%) that the true false alarm rate is below the requirement in the standard.

In addition to false alarm, most standards will define alarm/response requirements for the types of radiation the equipment is designed to detect. The test method to verify the alarm requirement will specify or define the radiation intensity at some location on the equipment, either the front face or in some cases the center of the detection element inside the equipment. The radiation intensity is modified by adjusting the activity of the radioactive source used to perform the test and/or the distance of closest approach of the source to the equipment. Usually these tests are carried out with the source and equipment in motion relative to each other, with the speed varying depending on the type of equipment. For example, body-worn or hand-carried equipment is usually evaluated at a relative speed of 0.5 m/s while for vehicle portals the relative speed is usually 2.2 m/s. In most of the N42 standards, the number of trials conducted for the alarm/response tests is between 10 and 60.

For gamma-ray detecting equipment, the alarm/response tests will typically be carried out with different radioactive sources covering a wide energy range. A common minimum set of gamma-ray sources is ^{241}Am (59 keV), ^{137}Cs (664 keV), and ^{60}Co (1174 and 1332 keV). For neutron-detecting equipment, the alarm/response tests will typically be carried out at either a single or a small number of moderation levels. ("Moderation" involves surrounding the neutron source with polymeric material to mimic the effects of people, vehicle interiors, etc. on the energy spectrum of neutrons emitted by a source.)

In all the N42 standards, modifications to most equipment settings between the false alarm and alarm/response tests described above are not allowed. Modification would invalidate the results of both sets of tests.

Equipment designed to identify radioactive materials (SPRDs, RIDS, some BRDs and vehicle systems, SRPMs) are required by the applicable N42 standard to identify a limited set of radioactive sources. These will include industrial sources (e.g., ^{192}Ir, used in radiography), medical sources (e.g., ^{131}I, used in thyroid treatments), naturally occurring radioactive materials (e.g., ^{40}K, present in potassium-rich materials such as certain clays), and special nuclear materials (e.g., ^{235}U, a fissile isotope of uranium). Depending on the equipment type, these evaluations would be carried out either with the source and equipment at a fixed distance or with relative motion between the two. There also is usually a limited number of tests where the equipment is challenged with identifying two different radioactive materials simultaneously. For the identification tests the number of trials is small, typically 10.

Fortunately, from a cost standpoint, the alarm/response and identification tests described above are often amenable to simultaneous testing of multiple systems. Some example setups showing testing of this type are shown in Figure 1 and some representative results obtained during simultaneous radiological testing are shown in Figures 2 and 3.

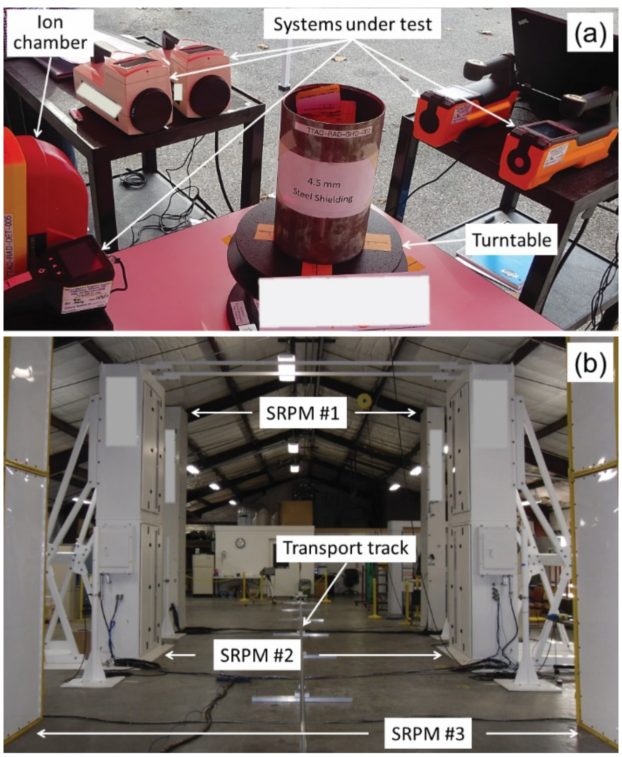

Figure 1: Examples of simultaneous radiological testing on multiple systems. (a) shows several RIDs arrayed around a shielded source. The turntable enables a (time averaged) cylindrically symmetric radiation field and the ion chamber independently assesses the radiation intensity. (b) shows three SRPMs set up around a transport track used to shuttle various source configurations past the SRPMs at a controlled, repeatable speed.

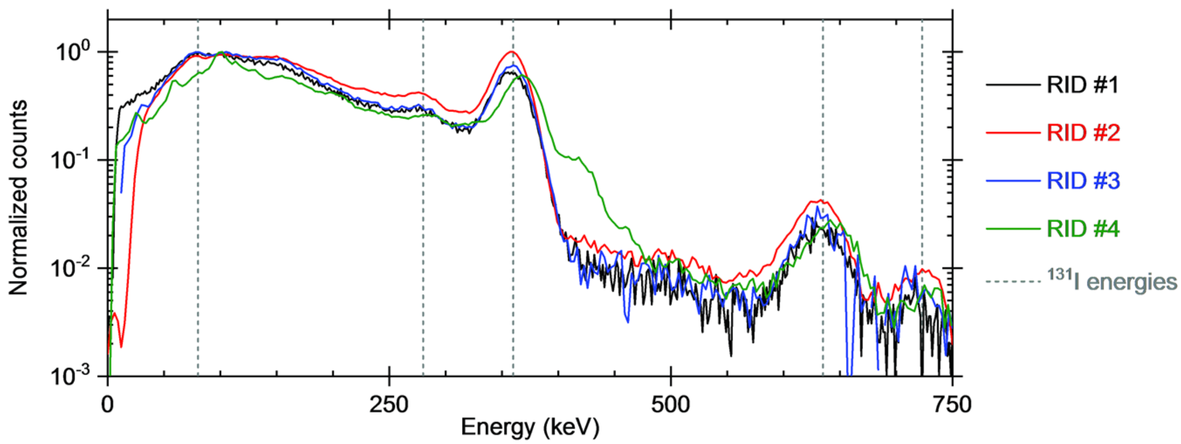

Figure 2: Spectra collected by four different RIDs during simultaneous identification testing with the medical isotope ^{131}I.

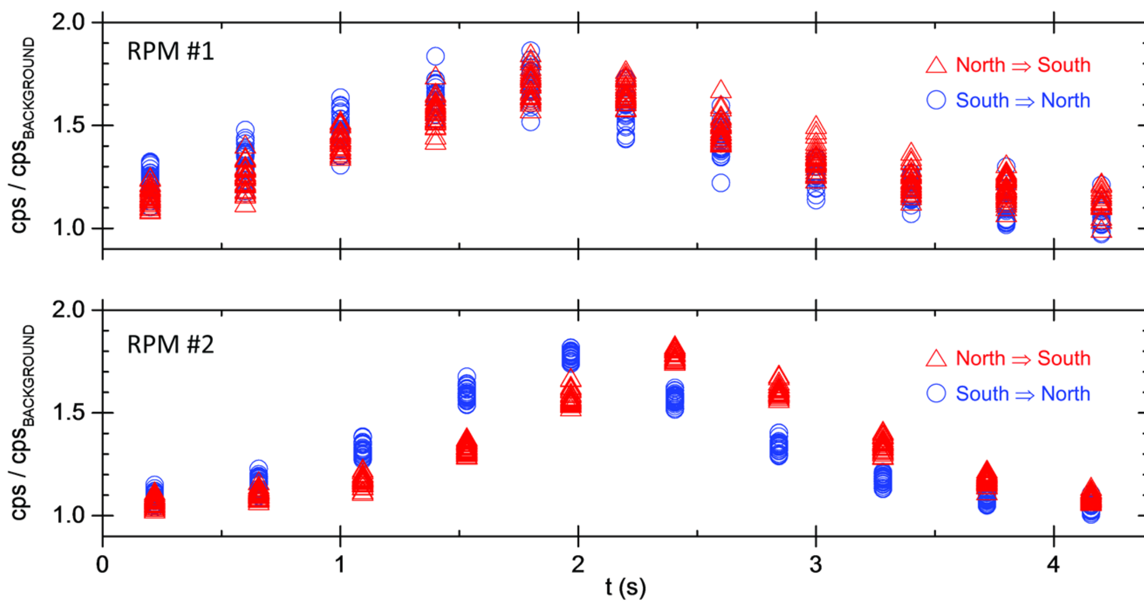

Figure 3: Count data collected by two different RPMs during simultaneous alarm/response testing with ^{137}Cs. 30 passes were made in each direction during the testing. Note the higher variability in the counts / second (cps) recorded by RPM #1 and the stronger asymmetry with direction shown by RPM #2.

Three other types of radiological tests that are nearly ubiquitous in the N42 standards are the over range test for gamma-ray detecting instruments and the gamma rejection and neutrons in the presence of photons tests for neutron detecting instruments. In the over-range test, the equipment is subjected to a radiation field greater, normally 1.5X, than the manufacturer-stated maximum field the equipment is designed to measure. This is to verify first, that the equipment will indeed indicate that the radiation field exceeds the equipment's range and secondly, that the equipment will return to normal operation after removal of the field. In the gamma rejection test, the equipment is subjected to a large gamma-ray field while monitoring the neutron count rate reported by the equipment. This is to ensure that gamma-rays are not falsely reported as neutrons. The neutrons in the presence of photons test is similar, but the gamma-ray field is applied while the equipment is either measuring a neutron source or in some cases the neutron alarm/response capability of the equipment is verified in the presence of the large gamma-ray field.

The final three test sections (environmental, electromagnetic, and mechanical) in the N42 standards are similar in that most of the tests involve stressing the equipment and monitoring for deleterious effect(s) on equipment function. The test section dictates the nature of the stresses applied to the equipment. In most of the tests, equipment function is monitored before, during, and after the application of the stress for evidence of equipment upset or malfunction that would indicate susceptibility. As was the case with false alarm testing, there is a reliance on statistical inference, because the count rate reported by the equipment is often used to diagnose function. In these cases, it can only be ascertained to some level of certainty, less than 100%, that equipment function was not affected by the stress.

In the environmental tests, the equipment is subjected to extremes of temperature (T) and relative humidity (RH) and tested for resistance to spraying water and dust. For the most part, the test methods are similar for all the equipment types in Table 1. Typical T and RH extremes used in testing are for T, -20 ^{o}C to +50 ^{o}C and for RH 93% at 35 ^{o}C. Typical hold times at these extremes are for 16 h. For smaller equipment, thermal shock testing is often specified in the applicable N42 standard to simulate outdoor use shortly after storage in a temperature-controlled building.

The moisture and dust tests subject the equipment to spraying water and powder aerosols. In both these tests, equipment function is monitored before, during, and after the test and the equipment is also opened and inspected for evidence of intrusion after the test. An example of a dust test setup and before, during, and after data from the test are shown in Figures 4 and 5, respectively. As Figure 4 indicates, it is currently acceptable in the N42 standards to do component-level environmental testing on larger equipment. There is growing sentiment to allow whole-system testing only, which will add to the challenges in testing.

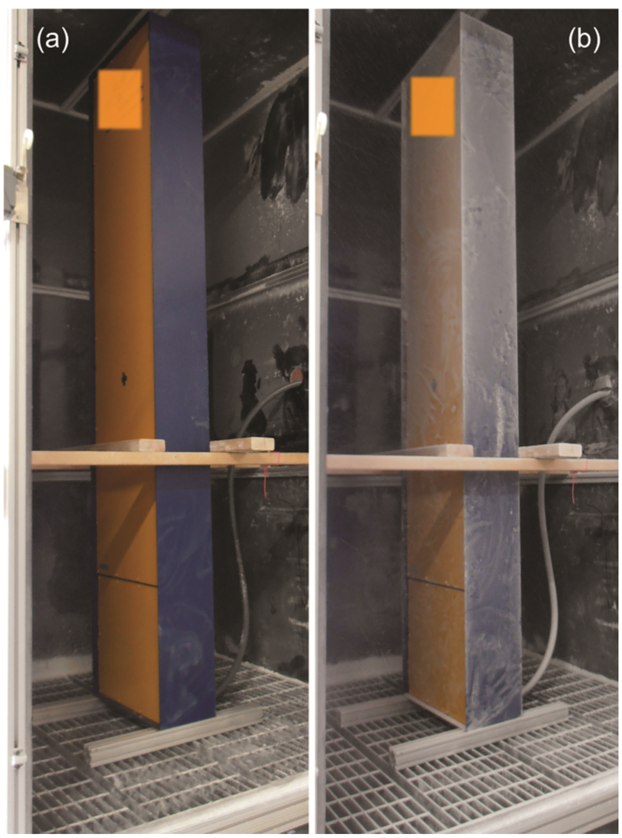

Figure 4: Dust testing of a detection panel from an RPM. (a) shows the panel before the test and (b) shows the panel after one hour of testing.

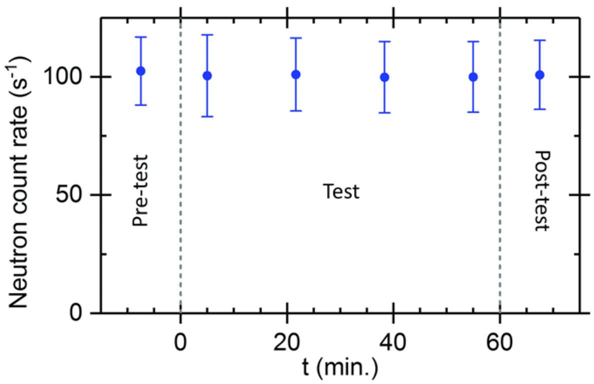

Figure 5: Source-present neutron count data collected during the dust test shown in Figure 4. The error bars represent one standard deviation.

The electromagnetic test section of a given N42 standard is strongly dependent on the type of equipment governed by the standard. For example, AC-powered equipment will have tests designed to stress the equipment with varying supply voltage and frequency, as well as surges applied through the AC power line to simulate lightning strikes on a facility power system. However, as with the radiological test section there are tests that span most equipment types. Examples of these include radiated emissions, radio frequency susceptibility or immunity, electrostatic discharge (ESD), and magnetic fields. Further, as with the environmental tests above, there is an increasing push towards whole-system testing for larger equipment types.

Susceptibility observed during the electromagnetic testing is often quite dramatic. For example, Figure 6 shows the neutron counts from an RPM during ESD testing. The count excursions caused by the ESD pulses applied to the RPM were the same order of magnitude as those induced by a neutron source during alarm/response testing.

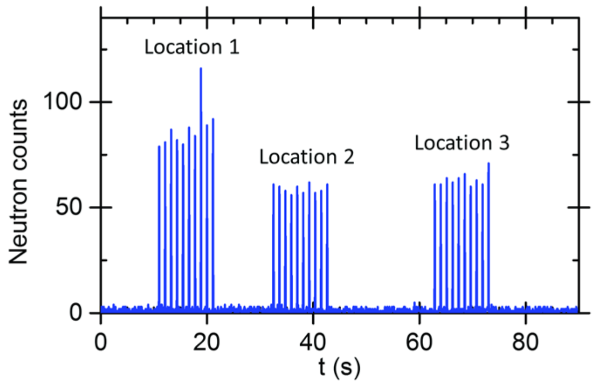

Figure 6: Neutron count data recorded during electrostatic discharge testing of an RPM. The 10 discharges at each location cause false high neutron count indications.

The final test section of the N42 standards to be considered is the mechanical section. As with most of the other test sections, these will vary depending on the type of equipment governed by the standard; but, there are tests that span most equipment types. Vibration and low-intensity impact tests are present in most of the N42 standards. Smaller equipment types will often have requirements on mechanical shock and surviving being dropped from a specific height.

T&E beyond the N42 standards

The N42 tests described above form a minimum set of performance requirements. Often equipment is tested to requirements beyond this minimal set, and in this section three often-encountered additional evaluations will be discussed.

DNDO, working with NIST, has developed Technical Capability Standards (TCS) (DNDO 2017). These standards primarily cover radiological detection performance and are more realistic (and demanding) than the N42 standards. For example, the industrial sources used in TCS testing are high activity (~10 Curie) sources packaged in heavily shielded shipping containers, as would be encountered in the normal stream of commerce. In contrast, the industrial sources used in the N42 testing can be relatively low activity (~10–100 μCurie) unshielded sources. Also, for TCS testing source-to-equipment distances are based on calculated fluence rates for specific gamma-ray energies, whereas for N42 testing source-to-equipment distances are based on measured radiation intensities. The TCS testing involves much more simultaneous radionuclide identification configurations and trials than what is typically called for in the N42 standards, and alarm/response tests for mobile systems are carried out at higher speeds (up to 13.4 m/s in the mobile systems TCS vs. up to 2.2 m/s in N42.43).

A second type of additional evaluation is the use of specific source configurations beyond those in the N42 and technical capability standards. Some threat-informed source configurations are classified and cannot be described in the standards since the standards are available to the public. Testing with these types of configurations would be conducted in a classified setting. There may also be unclassified source configurations that correspond to a specific application.

The third type of frequently-encountered additional testing is testing for a specific operating environment. Operation on water is an archetypical example. The United States Coast Guard deploys radiological detection equipment in marine environments, both near and far from shore. The radiological background far from shore is quite different than on land (due to the absence of ^{40}K) and the equipment may be subject to salt spray as well as immersion. Therefore, evaluation of equipment intended for use in this environment requires testing beyond that in the N42 standards. Unique evaluations are also needed for radiological detection equipment deployed underground in caves, mines, or tunnels.

Involving the users

Most of the evaluations discussed above are carried out by test personnel at DOE national laboratories or specialized test facilities. Intended users of the equipment are often involved in the evaluation as well. Two examples are given below.

DNDO typically conducts operational tests before introduction of new detection equipment or concepts of operation. These tests are used to determine the effectiveness and suitability of systems or components when used by end users in the actual operational environment. They are also used to refine and verify operational procedures, and uncover any conflicts with existing equipment or systems. As an example of the latter, it was discovered during a Coast Guard operational test that certain vessel locations of new detection equipment were susceptible to electromagnetic interference from a radio system on the vessel.

Another example of involving end users is the System Assessment and Validation for Emergency Responders (SAVER) (DHS 2017) program, funded by DHS's Science and Technology office. This program evaluates many types of equipment used by first responders, including radiation detection equipment.

In a SAVER evaluation, a focus group of first responders with expertise in a given equipment type will first establish required equipment features, criteria for evaluation, and test scenarios for that equipment type. A market survey is then conducted to determine which products on the market meet the focus group requirements. Finally, the focus group conducts a hands-on assessment of the products that meet the requirements, including their use in the test scenarios.

Several reports are typically issued from a SAVER evaluation, such as the result of the market survey, detailed technical and assessment reports, summary reports, and highlights.

Although access to some of these is restricted, many are made publicly available. An example of the latter is a summary report on BRDs from 2013 (SAVER 2013).

Conclusion

Through a collaborative effort involving DHS, national institutes and laboratories, and instrument manufacturers, a series of test and evaluation standards for passive radiation detection equipment has been developed and maintained. The standards cover the design, radiological detection performance, and susceptibility to environmental, electromagnetic, and mechanical stresses of the equipment. Evaluations that go beyond these standards often involve unique or classified radiological source combinations or evaluating the equipment for use in a specialized operating environment. Two cases where end users participate in test and evaluation are operational testing and the SAVER program.

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Endnote

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