Lifecycle Management of Nuclear Security Radiation Detection Systems: Testing and Evaluation

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1 Abstract

The lifecycle of radiation detection systems functioning within a State's Nuclear Security Detection Architecture encompasses all activities associated with acquisition, deployment, and eventual disposal. Throughout a system's lifecycle, testing and evaluation activities are needed to ensure requirements are continually met, as underscored by recent experiences.

This paper provides:

1. A discussion of reasons why testing should be part of the radiation detection equipment lifecycle before, during, and after acquisition.
2. A general process for determining applicable evaluation methods.
3. A discussion of issues related to integrating testing and evaluation into procurement and operational processes and mitigation strategies.

2 Introduction

Radiation detection systems are critical assets that serve a State's national security and safety interests. A radiation detection system includes the radiation detection equipment and the communications, monitoring, and other resources required to detect radioactive or nuclear material that is being illicitly trafficked outside of regulatory control. This equipment includes radiation portal monitors (RPMs), radioisotope identification devices (RIDs), personal radiation detectors (PRDs), and survey instruments. This paper presents common issues that impact performance evaluation throughout the lifecycle of a radiation detection system.

3 Procurement Testing and Evaluation

In general, a successful procurement will include a needs assessment, development of requirements that address those needs, and an evaluation of available solutions that satisfy the requirements. Once a solution has been identified, the initial deployment and acceptance of the system may involve an iterative process of test and evaluation followed by configuration and parameter adjustments to optimize the system for each unique deployment environment.

It should be noted that each requirement that is included in a request for proposals or specification should be specific and measurable so that the ability of prospective systems to satisfy those requirements can be validated. When developing requirements, the relative importance and total number of different requirements should be considered. An excessive number of requirements will be challenging for any vendor to meet, and compliance will become increasingly challenging to verify. Testing and evaluation are used to assess compliance with performance requirements, in particular those requirements deemed to be of highest importance.

Performance requirements include a system's ability to detect and possibly identify a minimal amount of radioactive material under certain conditions. The performance requirements should be informed by both the safety and security concerns of the organization and the operational realities associated with using and maintaining the equipment. In some cases, there may be a legal or regulatory minimum basis for requirements, while in other cases the procuring organization may have full discretion to write and adopt requirements. The International Electrotechnical Commission (IEC), Institute of Electrical and Electronics Engineers (IEEE), and American National Standards Institute (ANSI) organizations have developed standards for radiation detection equipment that provide performance requirements and methods of testing for radiation detection equipment. The United States Department of Homeland Security has also produced Technical Capability Standards that augment the special nuclear material detection and identification requirements found in ANSI standards. Each of the standards may be considered as general guidelines but are unlikely to identically match requirements laid out by a specific country.

3.1 Verify General Performance

Testing done by the Nuclear Smuggling Detection and Deterrence (NSDD) Science and Engineering Team (SET) has revealed that equipment with the same hardware component specifications and advertised features frequently have vastly different performance capabilities across vendors and even different models produced by the same vendor. If an organization bases their requirements solely on the common features and hardware specifications that are shared by systems that could potentially suit their needs, there exists the risk that low-quality vendors will produce the successful bid. An example would be requirements that focus primarily on the size, shape, and construction of a radiation portal monitor's detectors but do not include any requirements and verification of detector sensitivity. In this case, a low-quality vendor could win the procurement by creating a low-cost system that complies with all the physical dimension and construction requirements but does not exhibit sufficient sensitivity to threat sources. The sensitivity of instruments to various threat sources can differ by orders of magnitude. This situation is analogous to a vehicle manufacturer choosing between speedometers with ± error of 1 kph, 10 kph, or 100 kph. If advertised capabilities are not performance tested, low-quality vendors are not burdened by the engineering costs associated with designing, and manufacturing a system that will continually be able to meet the performance needs of the organization.

3.2 Verify Fit to Purpose

Equipment should be tested against realistic operational conditions with representative threat sources to determine if the equipment performs as advertised. Depending on the target market of competing vendors, the radiation detection system algorithms may be more geared towards radiation safety versus the generally more challenging mission of nuclear security (detecting small quantities of weakly radioactive nuclear materials). The algorithms used by certain vendors have in some cases been optimized for only detecting high activity sources out of regulatory control in scrap metal or other shipments, instead of the more difficult task of identifying highly enriched uranium in commerce. Vendors that only provide test data showing that their equipment can reliably detect highly radioactive high-energy sources cannot reliably state that the instrument will be able to reliably detect the lower-energy gammas from relatively low-activity highly enriched uranium (HEU).

For this reason, organizations should prioritize validation of instrument performance against threat sources that are representative of the different threat materials of concern. For gamma detectors this may include the use of HEU or low energy gamma sources such as cobalt-57 and higher energy gamma sources such as cesium 137 and cobalt 60. Neutron detectors should be tested with sources that have neutron energies similar to those produced by neutron-emitting materials of concern. These scenarios, as directed by the standards, may involve moderated and unmoderated as well as shielded and unshielded test configurations. Only by performing these sorts of tests can an organization be assured that an instrument can serve its most critical functions.

3.3 Verify Specific Needs

Frequently organizations release a request for proposals or other bid solicitations that require complete compliance with a particular standard such as "*IEC 62484:2020 Radiation protection instrumentation - Spectrometric radiation portal monitors (SRPMs) used for the detection and identification of illicit trafficking of radioactive material*." It is often not required for a submitting vendor to produce an independent test report that shows that the equipment has passed every method of test contained in the standard. In fact, most equipment has never been tested against all the applicable methods of test and would not be able to satisfy all of the requirements of the applicable standards if tested. In many cases, compliance with all metrics within a standard is not actually necessary to satisfy the needs of a procuring organization. Organizations should prioritize the requirements that directly serve the needs of the end user. Procuring agencies may receive higher quality submissions from responsive bidders if they only select and if needed modify the subset of the requirements from the relevant standards that are most likely to impact critical functions instead of demanding compliance with the entire standard. This strategy will also reduce the burden associated with test and evaluation activities that validate the performance requirements. For instance, it is unlikely that a radiation portal monitor will need to be able to withstand both -30 °C and +55 °C temperatures once it is deployed. A radiation portal monitor that is deployed in either of those extreme environments should however have some validation that it will be able to reliably operate at the expected performance level.

3.4 Operator Testing and Feedback

An instrument might meet every single specified requirement related to sensitivity, cost, and availability of spare parts, but, in the end, Front Line Officers (FLOs) need to feel comfortable and satisfied when using the equipment. While FLOs will not be interested in participating in performance testing to see which RPM can detect the smallest amount of HEU, it can be valuable to ask a limited set of FLOs for operational feedback on final candidates under consideration for procurement. Seemingly inconsequential details like button placement, screen brightness or user interface complexity may have a significant impact on how effectively the new equipment will be integrated into operations. An otherwise perfect instrument that is heavily disliked by FLOs is unlikely to be used effectively, if at all.

3.5 Validate Integration with Existing Systems

When adding a new instrument to an existing radiation detection system, compatibility with the existing architecture is paramount. For example, a new radioisotope identification device (RID) under consideration may be the best RID in every way, but perhaps its spectra are incompatible with the central alarm station (CAS) software that the procuring organization uses at all radiation portal monitor (RPM) sites. Making the CAS compatible with the new RID may require an expensive software update. A different RID under consideration might not have scored quite as well as the first RID, but still passed all critical requirements, and it also is compatible with the current CAS software. A procuring organization would then need to weigh the respective benefits and drawbacks of the CAS compatibility and the RID performance.

While most testing can occur physically removed from any actual deployment site, a pilot of a single system at an actual deployment system can help identify any final points of consideration before finalizing a larger procurement of equipment. It is prudent to identify potentially significant compatibility issues early in the procurement and "procurement testing" process, and not during "acceptance testing" after potentially large quantities of equipment have already been procured.

Any systems that outright failed previous testing need not be included in validation testing. However, satisfactory performance testing results are no guarantor for passing validation tests.

3.6 Acceptance Testing

Any serious vendor is likely to provide one of their higher performing units for procurement testing, and it would behoove the vendor to ensure that the delivered unit is free of faults. When a vendor has been selected as the tender winner and a batch of equipment has been procured, the vendor may provide factory acceptance testing reports for each delivered unit, but it is prudent to implement some form of acceptance testing for each delivered system, as quality control, shipping, and installation of equipment provide ample opportunities for something to not fully meet contractual expectations. Simple visual inspections and performance checks formalized as part of acceptance testing can be an uncomplicated way to identify any flaws or issues while the vendor still may be financially responsible for addressing said issues.

Beyond financial considerations, acceptance testing also presents an ideal opportunity to optimize settings and verify compliance with any requirements. For RPMs, meeting a certain requirement may depend on a variety of factors, such as pillar spacing, average background radiation count rates, and RPM settings. For configurable RPMs, post-installation acceptance testing is an ideal time to optimize settings, such as alarm thresholds, to ensure that detection goals are met, and nuisance and false alarm rates are minimized, while considering the specific conditions for the installed RPM. The presence of high natural background or the presence of non-intrusive inspection equipment are common examples of factors that may require site-specific RPM settings adjustments. Preemptively addressing likely issues during acceptance testing will minimize later frustrations for FLOs.

Finally, even though each individual procured piece of equipment may have passed quality control and have been optimized for the local deployed environment, procured equipment is likely to be part of an overall system. Acceptance testing should therefore also include checks on how procured and installed equipment functions as part of the system. For example, are alarms and faults from the RPM being properly transmitted to the Central Alarm Station, and are files being named following a desired convention?

4 Operational Testing and Evaluation

During the operational phase, testing and evaluation activities enable an organization to continually monitor and optimize the system's performance and determine when corrective maintenance activities are needed. Testing and evaluation are needed to compare an instrument's performance over time and after maintenance procedures have been executed or parameters have been changed.

Despite best efforts during procurement and acceptance testing, operational testing and evaluation are necessary for two key reasons: components fail over time requiring corrective maintenance, and site conditions may change over time thus invalidating any assumptions made during acceptance testing. Common changes to site conditions can include the installation of non-intrusive inspection equipment in the vicinity of radiation detection system, or any construction or repaving that may significantly alter the background radiation levels measured by the radiation detection system.

4.1 Basic Functional Tests

The most basic form of operational testing and evaluation are periodic checks that confirm that a system is still functioning. These checks may be as simple as passing a radiation source by the instrument and confirming that the source was detected, and all appropriate alarm functionality is still in working order. Some systems may have status of health warnings, but the reliability of such features can vary between vendors and products and should not completely replace the need for occasional basic functional tests.

Basic functional checks are a low intensity but high frequency activity to catch potential maintenance issues in an expeditious manner. A typical maintenance schedule may involve a subject matter expert inspecting a piece of equipment annually in-depth, which means that a potential problem could go unnoticed for an unacceptably long time in the absence of basic functional checks.

For handheld radiation detection equipment, a basic functional check may be a daily or weekly check to see if the instrument alarms on and correctly identifies a weak radiation check source.

4.2 Performance Testing

More detailed evaluations of the systems are used to determine if the components are still functioning within an acceptable performance envelope. These more rigorous tests are generally warranted on a less frequent basis and are used to determine if the system still maintains the sensitivity required by the organization. For example, RPM detector efficiencies may worsen over time due to aging and degradation of the detector material. Periodic efficiency measurements can be compared to some established minimum efficiency that still meets established requirements. Performance testing could involve annual efficiency measurements to determine when a detector needs to be repaired or replaced. As performance testing is more time intensive than basic functional fests, the frequency of performance testing is expected to be much lower.

4.3 Data Analysis

Additional evaluation techniques involve analyzing the system's data logs to determine the status of health and identify preventative and corrective maintenance procedures that need to be implemented. This form of operational monitoring ensures that the organization's equipment continues to function as specified and may save the organization unnecessary costs associated with downtime or repeated alarms caused by malfunctioning components. Continual monitoring of equipment performance may help an organization plan for component and system replacement. Some vendors may offer data analysis tools or services as part of the procurement or as an additional add-on service. Addressing a desire for such functionality is often best addressed in the requirements development and procurement stage, as opposed to finding or developing a data analysis approach retroactively for deployed systems.

4.4 Environmental and Component Condition Monitoring

Independent external and integrated onboard sensors can provide instantaneous and long-term reports on exposure to environmental conditions, usage statistics, and component degradation for radiation detection equipment.

Environmental datalogging sensors can capture temperature, humidity, and air pressure data. This data can be used to identify issues that will reduce the performance of the radiation detection system. For instance, radiation detection systems that are positioned in hot temperature areas with direct exposure to the sun may experience thermal loading that will significantly increase the temperature of internal components. This increase in temperature may exceed the maximum operating temperature for the equipment and reduce the ability to detect threat material. Hot temperatures, low temperatures, and humidity have been shown to cause permanent damage to components of some equipment models. Organizations that utilize environmental monitoring solutions can in some cases intervene in time to prevent lasting damage from occurring or determine the cause of existing damage and rectify the problem before additional pieces of equipment are affected. Environmental monitoring may be a built-in feature of some instruments or can be achieved through the independent installation of environmental datalogging sensors, though the transfer, collection, and analysis of that data may create additional operational burdens.

Component degradation over time came be tracked using integrated sensors or periodic non-invasive procedures. Integrated sensors are useful for monitoring changes in light transmission and electronics that have direct effect on the reliability and sensitivity of the radiation detection system. These sensors if well implemented can save the organization substantial maintenance costs by automating many evaluation procedures.

5 Common Concerns

Many procuring agencies face similar challenges associated with implementing testing and evaluation activities. Initial steps should include planning for testing in advance and not as an afterthought. Defining a realistic scope for testing is crucial as well. For performance testing, an initial market survey should narrow down the list of systems under consideration to a manageable number relative to available testing resources. There are a variety of mitigation strategies available to overcome common challenges.

5.1 Testing with Limited Resources

One of the most common questions is how can an organization with limited resources ensure procured equipment is appropriately evaluated? First, ensure that testing scope is limited to critical pieces of information needed for informed procurement decisions and that every effort is taken to down-select in advance as much as possible to the shortest possible list of procurement finalists. NSDD will often conduct a market survey of dozens of options of a particular type of instrument, then NSDD will filter the very long market survey list down to a more manageable list of instruments based upon easily verifiable factors most important to NSDD, and then NSDD will test those instruments against criteria that are both deemed highly important to NSDD and that are also not easily known or verifiable without proper testing. NSDD cannot afford to test every instrument against every requirement, so needs must be prioritized and balanced against available resources. On request, NSDD can share market survey results with procuring agencies considering their own procurements.

5.2 Third Party Testing

During a procurement, a practical method for reducing the burden associated with testing and evaluation is to reuse applicable test data from evaluations conducted by other organizations. Time and money can certainly be saved by the procuring organization if a reputable third party has previously conducted the same test that is necessary to evaluate an instrument's ability to perform against a certain requirement and that test data can be utilized. Some of the factors that influence whether the test data can be utilized include the integrity of the testing organization, specifics of how the test was executed and the information provided in the test report. NSDD, the European Commission's Joint Research Centre, the International Atomic Energy Agency, or other national or international organizations that evaluate and procure large amounts of radiation detection systems may have already tested an instrument a procuring organization is considering for procurement.

5.3 Collaborative and Contract Testing

Alternatively, an organization may save time and money by requesting that a third party test the systems under consideration. This strategy can be advantageous if multiple organizations combine resources to create a test dataset that can be used by a larger group. An organization may benefit from contracting a university or laboratory that is already equipped and qualified to conduct the required tests.

5.4 Third Party Vetting

The organization will need to determine if the tests were or could be executed by the third party sufficiently match the organization's requirements. Reputable third-party testing organization will not be beholden to any vendors or have a vested interest and a particular outcome. For instance, organizations should be cautious about test laboratories that have a business model that relies on receiving testing contracts by simply continuing to provide vendors with positive test results. Other test entities may also have a requirement to provide positive test results to domestic vendors if it is in the national interest. Each of these considerations should be evaluated by the organization before accepting test results into their evaluation process. Though a procuring organization may rely on a non-certified lab to test equipment, the organization needs to do some form of due diligence to ensure the test facility can conduct the test and deliver accurate results. NIST has provided a checklist and requirements (Moore & Pibida) for laboratories that perform "testing of radiation detection instruments used in homeland security applications."

5.5 Acquiring Systems to Test

The organization issuing the procurement documents may require the responsive bidders to loan the test facility example equipment that will be subjected to non-destructive tests. If the equipment cannot be transferred to the test facility, the organization may require the responsive bidders to provide test results from a reputable third party.

5.6 Leveraging Tools

Software tools can leverage very limited measurements to simulate a much larger number of test cases. Infinite real measurement test cases are infinitely resource intensive, but utilizing computer tools and simulations can provide significant quantities of information at a fraction of the cost of actual testing measurements. Additionally, organizations can estimate the Minimum Detectable Quantity (MDQ) of radiation portal monitors for specific radioactive materials under the operational conditions by with the free Minimum Detectable Quantity and Alarm Threshold Estimating Tool (MDQ-ATET) (Blessinger & Harris, 2020) that the IAEA has produced and released. However, without validation or a sound understanding of the limitations and constraints of modeling and computer tools, the quality and value of any produced results may be highly questionable. Simple off the shelf tools such as a remote-controlled camera slider can be used to perform the same task as more expensive specialized linear motion system as shown in Figure 1.

Figure 1. Remote control camera slider being used as a linear motion device for dynamic response tests of relocatable RPMs.

5.7 Contractual Constraints

Some organizations have reported that certain vendors may contractually require the organization to utilize specific maintenance service providers and restrict access to hardware and software components that are necessary to conduct operational testing of the radiation detection equipment. These contracts can impede the organization from determining if the system is able to continually detect the threat materials of concern. If the organization is unable to fully understand and monitor the affect that maintenance activities have on system performance, it may be impossible to ever have confidence in the detection system. For this reason, contracts should be avoided that restrict access to the components required to accurately evaluate system performance.

These types of considerations can be used to help narrow down the number of vendors and equipment under consideration, and limited resources should not be squandered on testing systems that can be excluded from consideration for reasons such as above.

6 Conclusion

This paper described and outlined categories of testing and evaluation that should be considered a part of the procurement and operation of radiation detection systems to ensure that the systems meet an organization’s needs. It is understood that procuring agencies’ capacity to test equipment varies and therefore emphasis should be placed on defining testing requirements that are achievable by the procuring organization, and several suggestions are made to maximize the testing and evaluation when limited resources are available.

7 References

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