# Operationally Focused Data Analytics for Optimizing Radiation Portal Monitor–Based Nuclear Smuggling Detection Systems at Global Ports of Entry

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## ABSTRACT

The National Nuclear Security Administration's Office of Nuclear Smuggling Detection and Deterrence has deployed a fleet of radiation portal monitors (RPMs) across the world at global ports of entry including seaports, airports, and land border crossings. These RPMs are integrated into radiation detection systems (RDS) that also include fixed cameras, optical character recognition (OCR) systems, primary scanning systems (e.g., X-ray or gamma-ray), and secondary scanning systems (e.g., spectroscopic radiation portal monitors, portable radiation detection systems). The data from these sensing technologies is collected at the Central Alarm Station (CAS) where servers and computers reside to control and operate the system. Operators utilize the data collected by the CAS and declared cargo information to make decisions on how to respond to an alarm.

This work explores the use of CAS-located data, looking at both the sensor data streams and operator inputs, to perform analysis which supports customs and border protection agencies to improve training capability and operational effectiveness. We focus on analyzing site level effectiveness and behavior by rolling up CAS-located data collected from individual occurrences. To-date, more than 15 sites (e.g., seaports, airports, border crossings) have been analyzed in this manner with the goal of understanding system operations to verify effectiveness and recommend potential improvements. This work first aims to provide background information on relevant CAS-located data sources and our current operational system analytics process including example results. After summarizing our current analytic techniques, we discuss how the future data analytics systems can provide key benefits to improving operational performance while minimizing the burden these detection systems place on operators.

## INTRODUCTION

Radiation detection systems (RDS) are used in scanning vehicles, containers, trains, and people to detect nuclear and radiological materials. Radiation detection systems are deployed all over the world including at seaports, airports, and land border crossings in a global effort to detect and deter smuggling of illicit nuclear materials [1]. Thousands of radiation portal monitors (RPMs) within a RDS have been deployed throughout the world through an extensive US Department of Energy program originally known as the Second Line of Defense [1],[2]. The operation and sustainment of these radiation detection systems is directly supported in various facets by the National Nuclear Security Administration's Office of Nuclear Smuggling Detection and Deterrence.

Prior analysis has used technical central alarm station (CAS) data to understand the human operational factors of CAS operators [3]. In [3], the concept of Radiation Alarm Adjudication Data Analysis and Reporting (RAADAR) was introduced with examples of visual data elements including an alarm disposition tree map and a CAS operator response pie chart. We also documented the link between rolled up, visualized CAS data and targeted, individual alarm analysis. To date, this topic does not appear to be well represented in the broader scientific literature. For example, in [4], a risk-based screening framework was developed to optimize how to use threshold-based policies in screening cargo containers. They present two linear programming models and examine the effects of a threshold-based policy on the overall system. Many scientific papers leverage various mathematical models in a similar fashion. Other work showed that the RPM is susceptible to environmental effects including rain [5]. We acknowledge the impact of these scientific efforts and note the lack of available analysis that focuses on human operational factors and their role in the successful operation of RDS within the global supply chain.

This paper is organized into the following sections: the background and methods sections provide context to understand how RAADAR has evolved in comparison to [3], the results section provides examples of RAADAR analysis, and finally, the discussion and conclusion sections summarize the current state of RAADAR and possible ways to expand the analysis in the future.

## BACKGROUND

A functional radiation detection system allows operators to detect and verify the presence of illicit nuclear material that traverses the operational area. To achieve this outcome, it is important that the radiation detection system (RDS) operates as designed and that the standard operating procedure (SOP) facilitates the interdiction of smuggled nuclear material. The RDS includes many components such as RPMs, secondary inspection equipment, the CAS, and SOPs.

An RPM contains passive non-spectroscopic gamma and neutron detectors and relays detector data to the CAS. The RDS also includes fixed camera systems. Alarms and faults within the RPM are sent to the CAS for operator review. Secondary inspection equipment is used to scan conveyances which alarm during primary scanning. During secondary inspections, radioisotope identification devices (RID) are used to determine which radioactive isotopes are present within an alarming conveyance. Secondary inspection equipment may consist of handheld or backpack-based RIDs up to large, drive-thru spectroscopic portal monitors (SPM). SPMs contain spectroscopic radiation detectors that can be used identify isotopes present within the scanned conveyance.

The CAS collects data from various sensing modalities to provide a powerful interface for site operators that facilitates proper response efforts when RPM alarms occur. Operators use the CAS to determine which conveyances should be held back for secondary inspection and to record alarm adjudications. The SOP is a critical element of an RDS that captures the human factor and accounts for how the operators should respond to all the sensor data that is presented to them in the CAS. In [3], we noted that the effective use of an RDS is dependent on human operators' ability to utilize

RDS technology in various deployment scenarios. Figure 1 outlines subsystems that feed data into the CAS. This data is leveraged for assessing the operational effectiveness of a site.

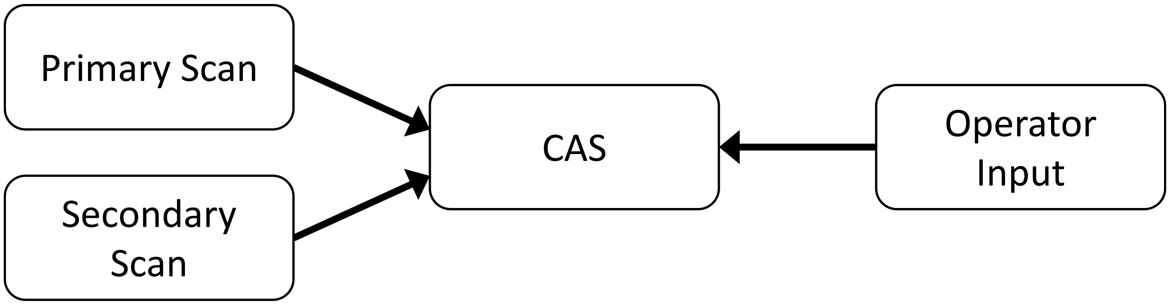


Figure 1. The CAS collects data from various subsystems.

During RAADAR analysis, these data are accessed and analyzed to gain insight into the day-to-day operation of the site for the purpose of providing data-backed, actionable recommendations to improve operations. As shown in Figure 1, various subsystems feed data to the CAS, so is important to have efficient methods for analyzing this data. Also noteworthy is the amount of data present on the CAS. We found it is necessary to automate parts of the analysis to draw the best conclusions from the data. The RAADAR process has evolved from [3] to include more automation and streamlined results. As discussed in the methods section, the RAADAR Tool software application has been developed, which streamlines this analysis, and automated algorithms are used to detect the presence of non-intrusive inspection (NII) or improper background updating in alarms [6].

## METHODS

In this section, we discuss how RAADAR analysis has evolved and improved over the past 5–6 years compared to [3]. This process flow is outlined in Figure 2. The first step is to determine if the RAADAR analysis will be performed on-site or remotely. For a remote analysis, the CAS server must first be backed up. This process is dependent on the type of CAS operating at the site and can range from making a backup of a PostgreSQL database to imaging the entire CAS server. Next, the CAS backup is transported either physically or virtually back to a remote location. Once the CAS data has been received, a virtual CAS can be set up. This is typically done by setting up a virtual machine for each unique CAS. Once the virtual machine is set up, the proceeding steps in the RAADAR process flow are identical for on-site and remote analysis.

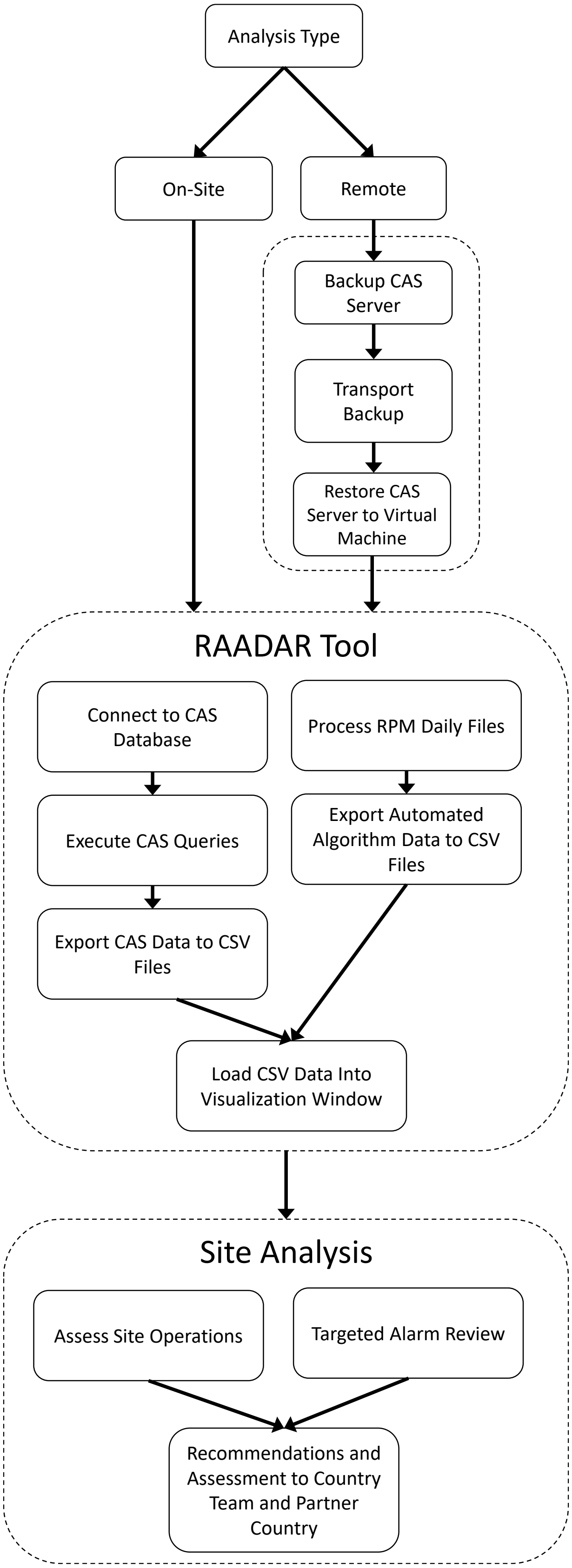
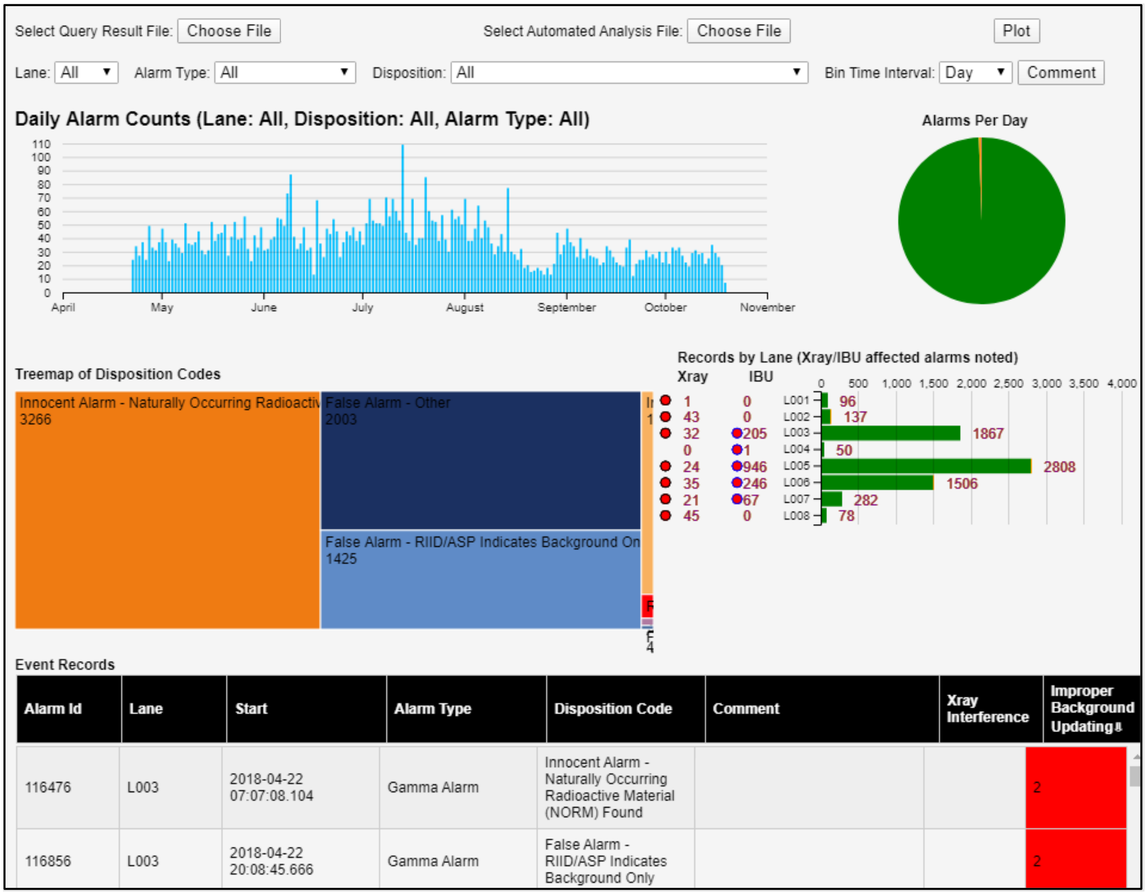


Figure 2. RAADAR process flow diagram that includes both on-site and remote analysis.

The RAADAR Tool is utilized either at the physical CAS (during an on-site analysis) or remotely (using the virtual machine) to connect to the CAS database and extract relevant data about alarms and faults. The RAADAR Tool also contains a visualization window, shown in Figure 3, that provides a fully interactive interface that is used to summarize and filter alarm records. As shown in Figure 2, the RAADAR Tool is also used to process the RPM daily files using automated algorithms that scan the gamma background data for potential interference from NII systems or improper background updating that occurs when vehicles are tailgating near the RPM. Figure 4 provides an example of the automated peak detection algorithm where transient peaks in the gamma background are flagged [6]. These peaks are most likely due to NII interference, which often comes from X-ray scanning systems in the vicinity of the RPM. As shown in Figure 3, alarm records in the visualization window are flagged for possible NII interference and improper background updating.



Lane: All

Alarm Type: All

Disposition: All

Bin Time Interval: Day

Event Records

| Alarm Id | Lane | Start | Alarm Type | Disposition Code | Comment | Xray Interference | Improper Background Updating |
|---|---|---|---|---|---|---|---|
| 116476 | L003 | 2018-04-22 07:07:08.104 | Gamma Alarm | Innocent Alarm - Naturally Occurring Radioactive Material (NORM) Found | | | 2 |
| 116856 | L003 | 2018-04-22 20:08:45.666 | Gamma Alarm | False Alarm - RIID/ASP Indicates Background Only | | | 2 |

Figure 3. RAADAR Tool main visualization window.

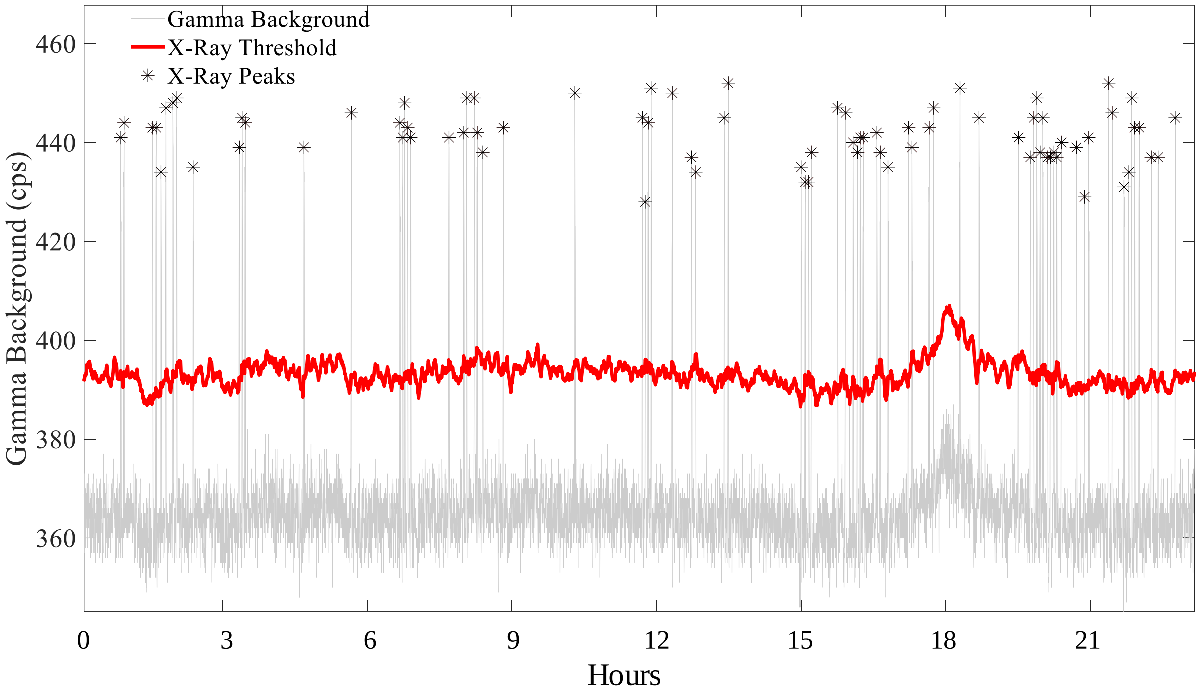


Figure 4. X-ray peaks in the raw gamma background signal (shown in gray) are detected by the peak detection algorithm and noted as stars. The gamma background X-ray threshold is shown in red and uses a 4-minute mean gamma background signal to filter out all X-ray peaks.

## RESULTS

Though the results of this type of analysis are often tailored to the specific needs of each site, key trends have emerged. The first trend is that even though sites may use the same equipment and operators may receive the same training, actual operation of the CAS can vary substantially from site to site. An example of this variability is how operators disposition alarms. In Figure 5, operators at site A have determined that many of the alarms should be dispositioned as false alarms (e.g., due to NII or improper background updating) while also having many alarming occupancies due to shipments of naturally occurring radioactive material (NORM). Sites B and C scan similar traffic and commodities to site A but have noticeably different distributions. Site B has determined that most alarms should be marked *Other*, whereas Site C has determined that most alarms should be marked as a real alarm. Even when cargo is declared as NORM, there may be reasons why the operators would disposition the alarm as either *Other* or as a real alarm and not as *Innocent Alarm—NORM*. The point of the analysis is not to determine if these records are right or wrong; the point is to highlight if this disposition is consistent with the SOPs and the training received. It is helpful to review the site's SOPs for these distributions of alarm categorizations to understand if alarms are being adjudicated properly and whether additional operator training is needed to optimize site operation.

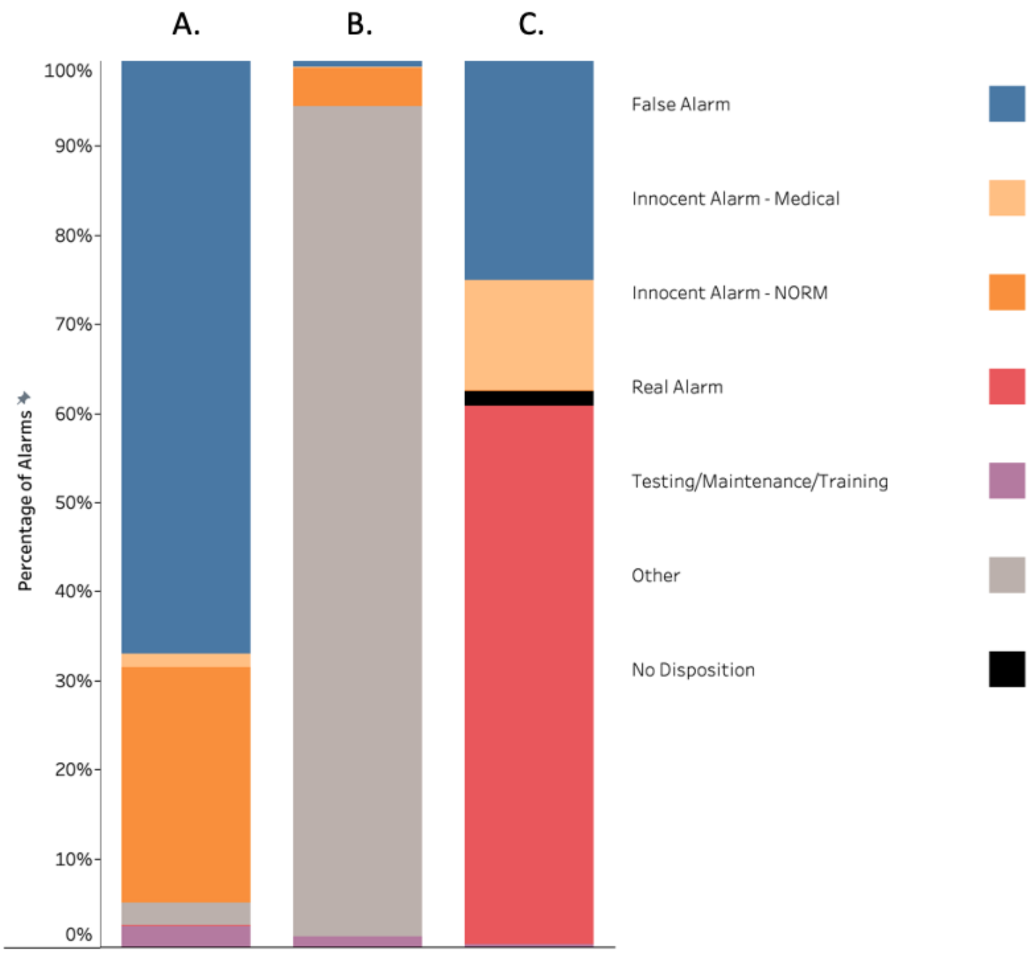


Figure 5. The distribution of disposition codes varies from site to site. Site A, Site B, and Site C use different approaches to dispositioning alarms even though they likely see similar commodities in their cargo traffic.

Another common result of analyzing data for improving RDS operations is that data-backed recommendations often improve operators' decisions to conduct secondary inspections. In several instances, the automated algorithms have been able to quantify the degree to which traffic flow problems cause false alarms at the RPM due to improper background updating. An example of improper background updating is shown in Figure 6. The occupancy begins with a truck already occupying the RPM. This can artificially suppress the calculated gamma background and cause a false alarm as the truck exits the RPM. Quantifying the problem can provide the justification needed for changing parameters in either the CAS, the RPM, or both to reduce the number of false alarms. At one site, the site-level false alarm rate was reduced by 50% while at another, the false alarm rate was reduced by 90%. In another example, automated analysis of operator comments helped to quantify the problem of alarming conveyances skipping secondary inspection. Again, the quantitative analysis justified changing SOPs. As a result, additional signage was installed at the site to discourage drivers from skipping secondary inspections, and the rate of skipped secondaries was reduced by half.

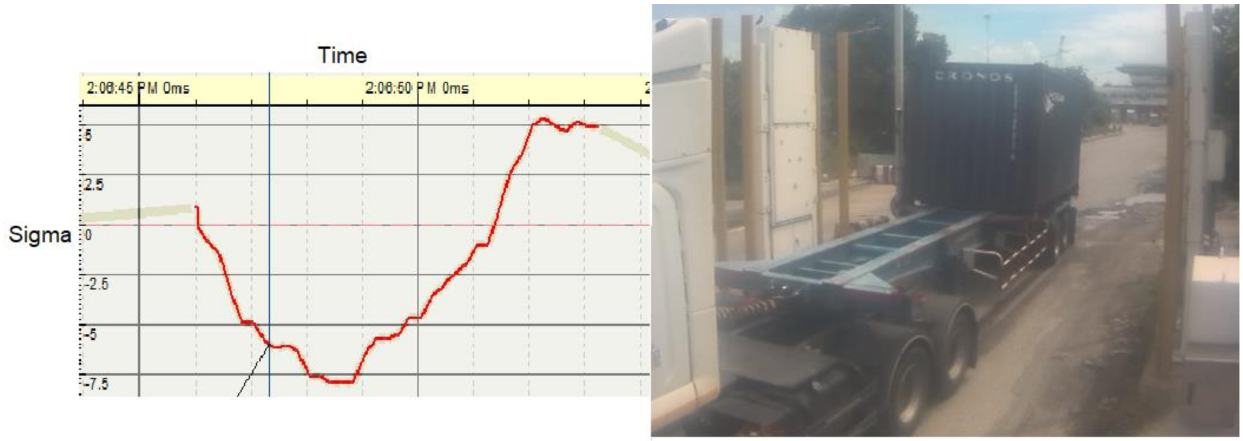


Figure 6. Improper background updating caused by a truck stopping at the RPM. In this case, the open flatbed section contributed to the first occupancy ending, allowing a second occupancy to begin without the truck exiting the RPM.

In Figure 7, data from a site with both RPMs and an SPM was analyzed. Analyzing the data from the RPM CAS and SPM CAS allowed us to track alarming occupancies from primary through secondary scanning. It was discovered that most scans did not alarm at the SPM. Closer inspection of operator comments revealed trucks would sometimes be allowed to pass through the SPM more than once. It is possible that the truck was traveling too fast during the first scan and required a second scan. In some cases, a second scan was used to verify results from the first scan. Analysis of the SPM data provided insight about how the SPM was used for site-level secondary inspections.

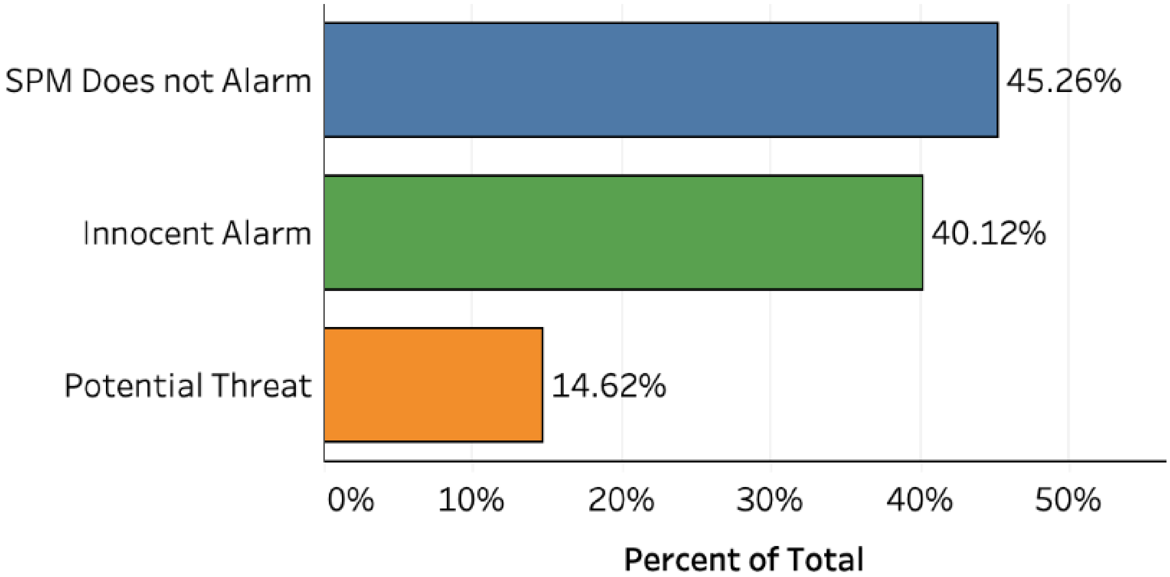


Figure 7. The SPM shows roughly the same number of records for nonalarming occupancies as it does records marked *Innocent Alarm due to NORM*. Roughly 15% of the scans reported a potential threat that requires further investigation.

## DISCUSSION

Findings from the RAADAR analysis often include actionable steps that can be taken to further optimize site operations. There have been numerous examples in the past 5–6 years where RAADAR analysis has led to positive changes in the site operations. This includes one instance where the false alarm rate was reduced by 90% by mitigating alarms due to improper background updating. At another site, as a direct result of the RAADAR analysis, additional training was provided to operators which resulted in a noticeable improvement in the secondary inspection rate. For other sites, RAADAR analysis confirmed that site operations were already being conducted at a high level, and there were few, if any, improvements that needed to be made. In these examples, RAADAR provides data-backed evidence of how well site operations are being conducted. Having an accurate assessment of the site operations, whatever state that may be, has proven to be critically important to understanding what support is needed to ensure sustainability of the RDS.

Improvements to the analysis methods used to conduct a RAADAR, including the development of the RAADAR Tool and leveraging automated algorithms, have also been critical to significantly speeding up the time required for a RAADAR analysis while also opening new elements to the analysis – including the automated detection of NII and improper background updating within alarming occupancies. Using a combination of data, including RPM CAS alarm records, SPM CAS alarm records, and automated algorithms, a more complete picture of day-to-day and minute-to-minute site operations can be created. The accuracy of this picture has proved to be powerful in our efforts to first assess and understand site operations and then provide recommendations for improvements and actionable steps that can be taken to further optimize site operations and improve overall sustainment of the RDS.

## CONCLUSION

It is up to site operators to use the radiation detection system in a way that is conducive to detecting special nuclear material. Operational-focused analysis of the CAS provides actionable insights that help make that possible. In the five years since this type of analysis was first performed, several analytical methods have been employed to expand the number and quality of insights that can be obtained from the CAS data. Additionally, the RAADAR Tool plays a crucial role in streamlining and automating analysis.

The CAS contains a wealth of information from which to draw conclusions about site operations. Current analytical approaches should continue to be improved in the future, and new techniques should be added. Future additions to CAS data analysis may include computer vision, which would allow for automated analysis of camera images; analyzing data from relocatable portal monitors; incorporating other data such as humidity and temperature; and integrating more algorithms from the RPM daily file processor to search for other anomalies in the data stream including failing RPM components.

## ACKNOWLEDGMENTS

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