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Figure of Merit for Evaluating the Performance of Radionuclide Identification in Portal Monitors and Handheld Devices

Ronald M. Keyser[1], **Neil A. Webster**[2], **Michael D. Belbot**[2],
and Timothy R. Twomey[1]
[1]ORTEC, 801 South Illinois Avenue, Oak Ridge, TN 37831 USA
[2]Thermo Fisher, One Thermo Fisher Way, Oakwood Village, OH 44146 USA

Email: ron.keyser@ametek.com, neil.webster@thermofisher.com

Abstract:

The instruments used in the control of illicit trafficking of radioactive materials, either in radiation portal monitors, hand held radiation identifiers, or search systems, are constructed in widely different ways with widely varying detector materials and analysis software. However, within the various groupings (e.g., portal monitors), all instruments are expected to solve the same problem, that is, to detect and identify any radioactive material present according to the prescribed investigation methods (CONOPS). The best way to compare performance of the instruments is with a numerical score or Figure of Merit (FOM). The FOM must quantify the performance of the instrument with respect to false positives (FP) and false negatives (FN). The minimization of FN for certain radionuclides (e.g., SNM) is more important than the minimization of FN for non-threat nuclides (e.g., low amounts of NORM). Likewise, the minimization of FP for SNM is also more important than allowing false reporting of the common NORM nuclides. The performance depends on the details of the testing, so the CONOPS must also be included in the statement of the FOM. We have developed a FOM based on the number of true positives (TP), the number of false important positives (FIP), the number of FP, the number of true positives for SNM (TPSNM), and the number of false positives for SNM (FPSNM). This formula rates the overall performance with extra weight given to FP and FN for SNM. An Example will be shown for testing of both a NaI and HPGE portal monitors in different modes, nuclides, and shielding.

Keywords: FOM, Figure of Merit, HPGe, NaI, illicit trafficking, detection limit

1. Introduction

The need to increase nuclear security and monitor radioactivity in the environment has resulted in the development of many different solutions designed to solve the same problem, that is, detect small amounts of specific nuclides in an essentially uncontrolled measurement situation with high reliability and minimal inconvenience or interruption of progress to the people or objects being monitored. Typically, the time for measurements is short, perhaps less than a minute. Mixtures of nuclides are expected as well as people who have recently had nuclear medicine procedures. For the majority of the users of these monitoring systems, it is not possible to perform testing of the available systems to determine the efficacy of a system in the expected conditions at the monitoring point. To aid the users in the evaluation of systems, others have developed scoring methods for reporting performance [1]. In this work, we describe a scoring system (Figure of Merit or FOM) which is intended to result in a simple numerical score for each system in a prescribed test.

Each test is the data collection, analysis, and reporting that results in either a negative (no activity) or a positive (activity) result. There is one set of results per test which is the list, if any, of nuclides found during the test. A test can be repeated and the FOM reported on the average score of all the tests. In this work, each test was repeated 32 times.

The result of the test consists of True Positives (TPs) and False Positives (FPs). A TP with a confidence level above a threshold will create an alarm. Other conditions causing alarms are incorrect time of measurement or speed, excessive gross count rate (high dose rate), or system malfunction. In addition, the term “nuisance alarm” has been used to describe the reporting of any nuclide that is actually present, but whose presence is not of concern. An example is ^{40}K in kitty litter. Another possible report is “irrelevant TP” where the nuclide is present in the background and may be reported by some sensitive devices or long counting times and not reported in other conditions.

A TP is the reporting of a nuclide being detected when the nuclide is actually present in the test situation. A FP is the reporting of a nuclide being detected when the nuclide is not present. A FN is failure to report a nuclide, when the nuclide is actually present in the test situation. However, some TPs and FPs are more important than others. For example, a positive report of plutonium detection is more serious than a report of ^{40}K or other Naturally Occurring Radioactive Material (NORM).

In this FOM formula, the nuclides are divided into categories: Special Nuclear Material (SNM), Important, and Other. Different weighting factors are assigned to each category.

The main purpose of the instrument is to maximize number of TPs. In any monitoring situation, FPs causing an alarm must be minimized because each FP requires an investigation and resolution of the alarm. In this calculation of the FOM, the FPs for some nuclides are given more weight than FPs for other nuclides. Likewise, FNs must also be minimized because this is a failure of the monitoring system to perform its primary function.

The FOM is normalized by dividing by the value of the FOM for a perfect score and scaled by 10. That is, the weighted score for all the possible TPs in the test. This gives the best score as 10, but with no lower limit as FPs have negative factors.

The intent is that a high FOM will mean that the monitor is performing better in the stated test conditions than a monitor with a lower FOM. Here “better” includes all factors, including interruption to flow of traffic because of the need to resolve FPs as well as the ability to detect the nuclides present in a variety of conditions.

Two different special situations are important: mixtures of nuclides (including spoofing, where a mixture of nuclides is used to mimic the response in the detector of a specific nuclide) and masking of one nuclide by a large amount of another nuclide or nuclides. The performance when multiple nuclides are in the test mixture is accounted for in the scoring as the combination of TPs and FNs. The masking situation is different in that the masking nuclide(s) could be NORM, which is often detected in many common materials. To account for masking, nuclides can have multiple alarm thresholds. This will allow small quantities of the nuclide to pass without

Table I

SNM	**Important**	**Other**
^{233}U	^{57}Co	^{18}F
^{235}U	^{60}Co	^{67}Ga
^{237}Np	^{133}Ba	^{51}Cr
Pu (^{239}Pu)	^{137}Cs	^{75}Se
Elevated uranium	^{192}Ir	^{89}Sr
U^{232}/Th^{228}	^{204}Tl	^{99m}Tc
SNM	^{241}Am	^{103}Pd
		^{111}In
		^{123}I
		^{125}I
		^{131}I
		^{153}Sm
		^{201}Tl
		^{133}Xe
		Natural
		^{40}K
		*^{226}Ra
		^{232}Th and daughters
		^{238}U and daughters

alarm (not counted as either TP or FN), but should cause an alarm if the level is above the higher threshold (should be TP). If the test condition contains a high level of a “masking nuclide”, the result is a TP if the detected level of the nuclide is above the threshold and a FN if the nuclide is not reported (i.e., no alarm). For these tests, “high NORM” is defined as the emissions from 5 tonnes of KCl stacked uniformly on the entire bottom of a single 8 x 8 x 20 foot CONEX container.

To properly compare the performance of different systems, the details of the test conditions (CONOPS) must be included with the FOM. For example, in freight vehicle portal monitors, the transit speed is important as it determines the length of time for data collection from the container passing through the monitor.

Table I shows the categories, the nuclides in each category, and the weighting factors for the test results shown later. In the situation where a table entry (e.g., Elevated uranium) is reported as a result of the detection of a specific isotope (i.e., ^{235}U) only one result is included in the FOM. In this example, however, if elevated uranium was reported with no other uranium isotope reported, it would be counted as a TP or FP according to the test situation.

Table II shows the weighting factors for the different results.

Table II Weighting Factors

SNM		Important		Other	
TPs	FPs	TPi	FPi	TPo	FPo
4	-4	3	-3	1	-1

The FOM is calculated as shown in the equation below:

$$FOM = 10 * \frac{\sum_{SNM\ found} TPs + \sum_{SNM\ not} FPs + \sum_{Imp} TPi + \sum_{Imp\ not} FPi + \sum_{O} TPo + \sum_{O\ not} FPo}{\sum_{SNM\ Actual} TPs + \sum_{Imp\ actual} TPi + \sum_{O\ actual} TPo}$$

2. Equipment and Setup

The test results shown are based on the ORTEC Detective SNM Portal and the Thermo ARIS-1024 Portal. The ORTEC portal consists of two columns of 4 detectors each. The HPGe detectors are IDMs, as shown in Fig. 1. The Thermo portal consists of two columns each with 8 large volume NaI detectors. The NaI detector module is shown in Fig. 2.

Figure 1 Interchangeable Detector Module (IDM)

Figure 2 NaI detector module

A complete description of the ORTEC portal is given in [2].

One ORTEC monitor is installed (October 2009) at the Anthony, New Mexico Port of Entry and a second one is installed (April 2009) at the Thermo Fisher facility in Oakwood Village, Ohio. The New Mexico portal is in operation on commercial truck traffic on Interstate 10 as a secondary portal. The ORTEC portal is in operation as a test facility with controlled sources, shielding, and NORM. The following discussion applies to both units, but the results are only from the test facility. Figure 3 shows the New Mexico installation.

The Thermo ARIS-1024 is installed and operational in many places. The tests were conducted on the ARIS-1024 installed at the Thermo Fisher portal test facility in Oakwood Village, Ohio. Figure 4 shows the ARIS-1024 in a typical setup.

The tests consisted of three different nuclides (^{57}Co, ^{133}Ba, and ^{137}Cs) mounted, one at a time, in a standard 26 ft box body truck, with and without shielding and NORM. The truck was driven at 8 kph through the portal. Tests with these nuclides, various shielding thicknesses, and with and without NORM were performed.

Figure 3 Installed HPGe Portal at Anthony, New Mexico

The truck occupancies for this testing were determined by optical entry and exit sensors positioned about 4 m apart and centered on the detector position. Independent sensors were used for each portal.

The two portals have the same horizontal spacing (about 5 m) and are installed along the same traffic lane. In this way the same test vehicle could driven past both portals at a constant speed in rapid succession to obtain results that were as comparable as possible.

Figure 4. Typical installation of ARIS-1024 portal monitor.

2.1 Source and attenuators

For the example here, ^{133}Ba was selected. This source closely resembles Pu-239, an SNM material. The sources used were point sources. The sources were mounted in a wooden frame. The attenuators were 3.2 mm thick steel plates which could be combined to give total thicknesses of 0.32 to 10 cm. The attenuators were placed so as to shield the complete field of view on both sides of the portal from the source. The ^{133}Ba source was 148 µCi, as prescribed in ANSI N42.38.

The NORM was placed evenly on the floor of the cargo section of the truck to give an increased background, but was piled low enough so that it did not block the direct path for gamma rays between the sources and the detectors. The NORM was commercial water softener salt substitute or potassium chloride. About 3 tonne of KCl in 18 kg bags on pallets were in the truck.

3. Results

The ^{133}Ba source was placed in the truck and driven through the portals at about 8 kph 32 times for each thickness of steel shielding. The shielding thicknesses were from 1.27 to 4.5 cm. The nuclides detected were recorded and the FOM calculated for each shielding thickness using the nuclides in Table I and the factors in Table II.

To show the efficacy of the FOM method, the results of only the true positives, that is, only the detection of ^{133}Ba is shown in Fig. 4, where the FOM (TP) is plotted as a function of steel shielding thickness. In this case, only ^{133}Ba is accepted as a TP Important. FPs are not included in this calculation of the FOM.

Figure 5 shows the ARIS-1024 portal does detect ^{133}Ba in the pass through mode for shielding up to 4.1 cm, then the detection drops off. The reduction in the FOM at 3.8 cm is possibly due to a detector failure. The failure was reported by the software.

The HPGe results in Fig. 5 show a steady decline in detection from 100% at a thickness of 2.5 cm to no detection at 4.5 cm. The 3.8 cm data point is also (see ARIS-1024) lower than expected so there may be some unknown factor affecting the detection. The average speed for this point is within the range of average speeds for all the other points.

Figure 6 shows the full FOM, from the equation above, for the same set of tests. Note that the vertical axis ranges from -15 to +15.

In this figure, the ARIS-1024 results show the impact of including the reporting of nuclides not in the truck, that is, FPs. The ARIS-1024 reported FPs for both SNM and Other nuclides.

The HPGe results (full FOM) are similar to the TP only FOM results, indicating a much lower number of FPs. The improvement is largely due to the better energy resolution.

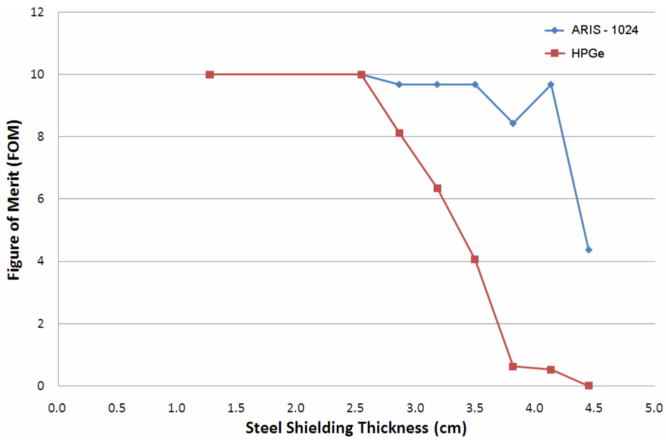

Figure 5. Plot of FOM vs Steel Shielding Thickness for Two Portal Monitors showing results for True Positives only.

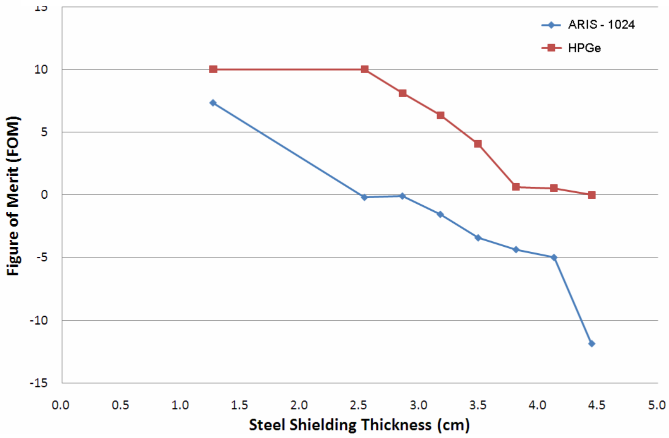

Figure 6. Plot of FOM vs Steel Shielding Thickness for Two Portal Monitors showing results of the FOM as defined.

4. Conclusions

The FOM described in this paper has been shown to provide data that assists in the choice of instrumentation to meet specific security monitoring requirements. This FOM accounts not only for the positive detection of nuclides present, but also the false reporting of nuclides not present, making it useful in the comparison of differing systems designed to solve the same problem. It also provides a useful indication of the extent to which the efficacy of a given system will be impacted by FPs, which must be investigated before the shipment can be released. This FOM applies to any monitoring test comparison, not just portal monitors, because it only uses the results reported by the instrument. In using the FOM, the complete details of the test situation must be given and be as consistent as possible for the different instruments. Future work will include work with different radionuclides and measurement scenarios. These data will assist in the correct choice of instruments for different performance needs.

5. References

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