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EVALUATING THE SENSITIVITY OF RADIONUCLIDE DETECTORS FOR CONDUCTING A MARITIME ON-BOARD SEARCH USING MONTE CARLO SIMULATION IMPLEMENTED IN AVERT®

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Evaluating the Sensitivity of Radionuclide Detectors for Conducting a Maritime On-Board Search using Monte Carlo Simulation Implemented in AVERT®

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Summary

The sensitivity of two specific types of radionuclide detectors for conducting an on-board search in the maritime environment was evaluated using Monte Carlo simulation implemented in AVERT®. AVERT®, short for the Automated Vulnerability Evaluation for Risk of Terrorism, is personal computer based vulnerability assessment software developed by the ARES Corporation.

The sensitivity of two specific types of radionuclide detectors for conducting an on-board search in the maritime environment was evaluated using Monte Carlo simulation. The detectors, a RadPack and also a Personal Radiation Detector (PRD), were chosen from the class of Human Portable Radiation Detection Systems (HPRDS). Human Portable Radiation Detection Systems (HPRDS) serve multiple purposes. In the maritime environment, there is a need to detect, localize, characterize, and identify radiological/nuclear (RN) material or weapons.

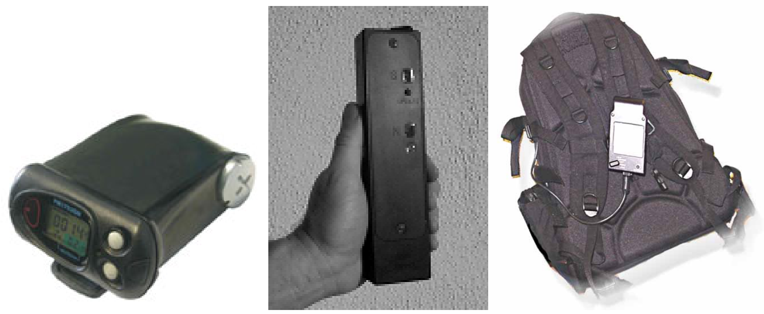
The RadPack is a commercially available broad-area search device used for gamma and also for neutron detection. The PRD is chiefly used as a personal radiation protection device. It is also used to detect contraband radionuclides and to localize radionuclide sources. Neither device has the capacity to characterize or identify radionuclides.

The principal aim of this study was to investigate the sensitivity of both the RadPack and the PRD while being used under controlled conditions in a simulated maritime environment for detecting hidden RN contraband. The detection distance varies by the source strength and the shielding present. The characterization parameters of the source are not indicated in this report so the results summarized are relative. The Monte Carlo simulation results indicate the probability of detection of the RN source at certain distances from the detector which is a function of transverse speed and instrument sensitivity for the specified RN source.

Introduction

The RadPack and PRDs (Figure 1) are commercially available devices for detecting radionuclides. The RadPack resembles a backpack and is a broad-area search device constructed from a cluster of Cesium Iodide detectors used to survey for gamma sources and a number of Helium-3 tubes used for neutron detection. The PRD is chiefly used as a personal radiation protection device but is also used to detect contraband radionuclides and localize radionuclide sources.

A maritime background radiation program (MBRP) conducted by the Savannah River National Laboratory (SRNL), Aiken, SC, characterized and documented the gamma and neutron backgrounds aboard several classes of ships over 300 gross tons. These classes included container ships, roll-on roll-off (RoRo) vessels, bulk cargo carriers, and passenger ferries. The MBRP characterization of the maritime background radiation provides a realistic basis upon which the effectiveness of instruments, alarm thresholds, and search practices can be assessed and compared. As a result, sufficient information was available to perform a computer-based Monte Carlo simulation of the RadPack performance in a maritime environment in order to assess its capability of detecting an RN source in the presence of natural background radiation.



PRD-1 **PRD-2** **RadPack**

Radiation Detection Equipment
Figure 1

In particular, the static alarm distance capability of both the RadPack and PRD under typical maritime background conditions was available from the SRNL/MBRP. The static alarm distance is the maximum distance from a radiological source to a stationary radiation detector when it alarms. This distance corresponds to a stand-still confirmatory measurement performed once a radiological source has been detected and localized.

This information was used in a computer based Monte Carlo simulation of the devices for conducting a search on board a ship called the Bijin (Figure 2).

The Bijin, of Flag State Panama, is a RoRo ship used to carry wheeled cargo such as automobiles, trucks, semi-trailer trucks, trailers or railroad cars. It has built-in ramps which allow the cargo to be efficiently "rolled on" and "rolled off" the vessel when in port.

In order to detect an RN source, a search for the source is usually conducted by walking an HPRDS device through accessible parts of a vessel. The results in this simulation are based on the RadPack carried at different distances from the RN source while varying transverse speeds and instrument sensitivities. The PRD is also compared with the RadPack varying transversal speeds with the fixed distance. The sensitivity and usage parameters of any HPRDS detector can be evaluated using a similar Monte Carlo simulation.

The Bijin
Figure 2

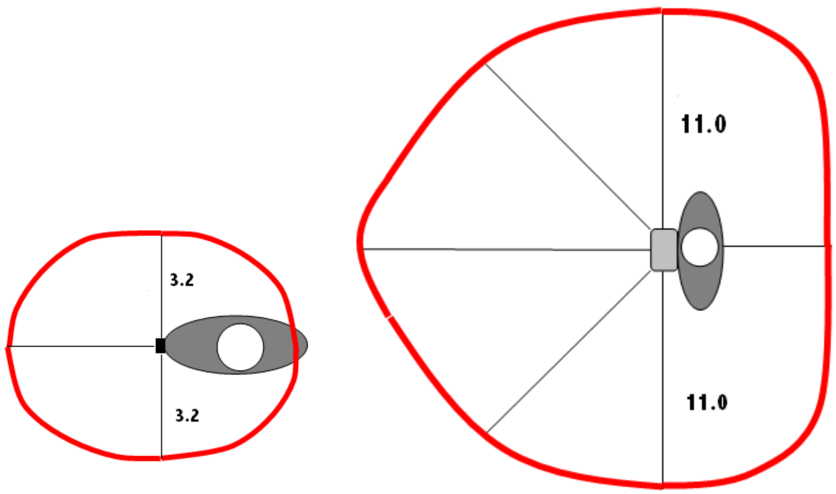
Detector Sensitivity

The RadPack is a broad-area radiation search instrument that can detect both gamma and neutron radiation but does not have an isotope identification feature. Upon power-up the RadPack sets alarm levels based on the prevailing background radiation, so no calibration is required. The RadPack has no data storage or downloading capabilities. The PRD is chiefly used as a personal radiation protection device and can also be used to detect contraband radionuclides and localize radionuclide sources. Neither the RadPack nor the PRD has the capacity to characterize or identify radionuclides.

The vessel size, design and materials of construction (e.g., ballast, engine, control gauges, etc.) contribute to the background conditions which might affect the ability of a HPRDS device to detect an RN source. A broad-area search along a linear transect such as a corridor is generally enhanced when the static alarm distance, the maximum distance between a stationary detector and a source that will result in an alarm, is maximized perpendicular to the search path. However, a walk-by is more likely whereas the source could be at a 45 deg angle to the walking path. As such, the maximum range of the RadPack on a walk-by would be about 30% less than a direct path toward the source (Figure 3).

The effectiveness of an instrument in performing a search also depends on many human factors in addition to detection capability. However, many of the human factors associated with these instruments are known and have been documented in prior research by SRNL and Sandia National Laboratories (SNL).

The measurement profile of static alarm distances for gamma-ray detection by the PRD or RadPack varies by the angle between the source and the detector and is affected by the presence of an operator. These distances characterize the sensitivity of the detector to alarm relative to its orientation to and distance from a source. The alarm distance for the RN material used in the simulation at each side of the PRD is 3.2 units and 11 units for the RadPack (Figure 3).



PRD **RadPack**

Overhead View of Static Alarm Distance for the PRD and RadPack with an Operator in a Simulated Maritime Background

(Coded Distance Units)
Figure 3

Monte Carlo Simulation: Walk-By

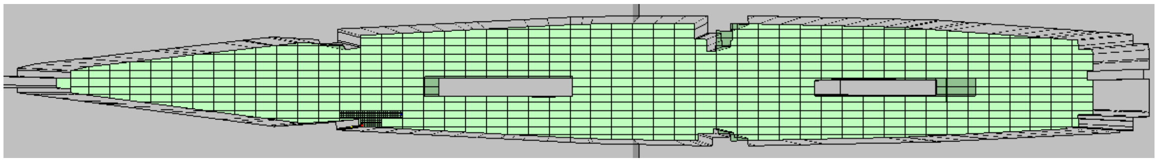
The Automated Vulnerability Evaluation for Risk of Terrorism(1) (AVERT®) personal computer based software developed by the ARES Corporation was used to implement the Monte Carlo simulation. The results were summarized and displayed using the JMP® statistical software(2).

The parameters in the first case included the distance of the source to the RadPack, its transverse speed and sensitivity. Two different distances were considered in the simulation. The first was at 10.4 units from the patrol path and the second was 8.4 units. The maximum range of the RadPack for a walk-by is 11 units (Figure 3).

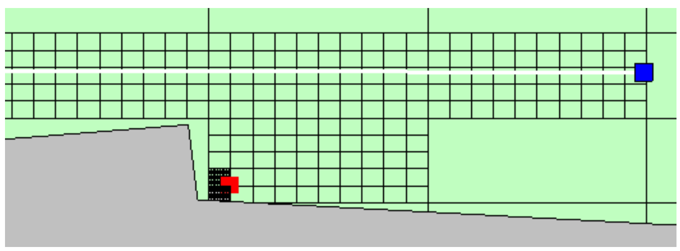
At 11+ units the probability of detecting the source is zero. The probability of detecting the source at a distance of zero (P(d)) from the RadPack with a 2 second integration time was set at 0.90, 0.95 and 0.995 in different simulation runs to assess the impact of varying sensitivities. The type and strength of the source, various types of shielding and absorbers interposed between the source and detector where held fixed in this simulation.

The maximum detection range of the RadPack for the specified RN source (undisclosed in this report) was taken to be the side-ways static alarm distance of 11 units. This distance is the maximum distance between the source and a stationary detector when the detector alarms. As viewed in Figure 3, this distance varies by the position of the detector relative to the source and whether an operator is present.

This case investigated the instruments' performance during a computer simulated search with different RadPack sensitivities for searching Deck J of the Bijin (Figure 4). The location of the RN source used in the simulation is displayed in Figure 5.



Bijin: Deck J
Figure 4

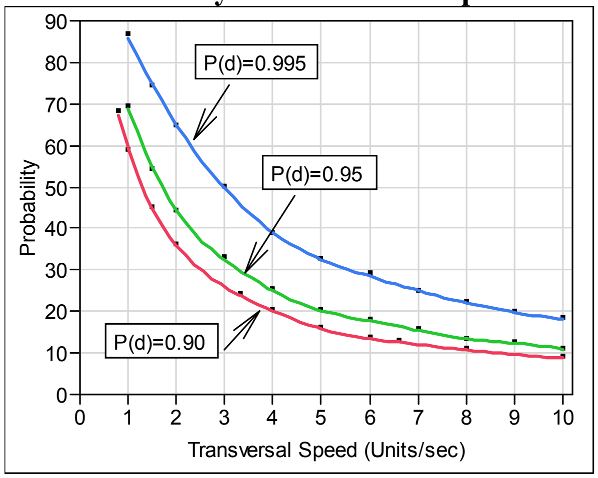


Bijin: Deck J Shaded Area in Figure 4
Patrol: Colored Blue; Source: Colored Red
Figure 5

Two distributions were used in the simulations: the Zero probability distribution and the Normal distribution. The Zero distribution is a single, constant value. This constant value might be used when the input data is very certain with almost no variability, or when there is such limited data that no meaningful estimation of standard deviation can be made. The Normal distribution is characterized by its mean and standard deviation. It has been found to be a very good model for many continuous distributions that occur in real situations. All normal distributions are symmetric. The distribution is often referred to as Gaussian or "bell shaped."

The Monte Carlo simulation has shown that altering the transversal speed can have a substantial impact on the probability of detecting an RN source (Figure 6). The gain in sensitivity seems to be somewhat linear when reducing the transversal speed from 10 units/sec to 5 units/sec while an exponential gain in sensitivity is attained transversal speed from say 5 units/sec to 2 units/sec.

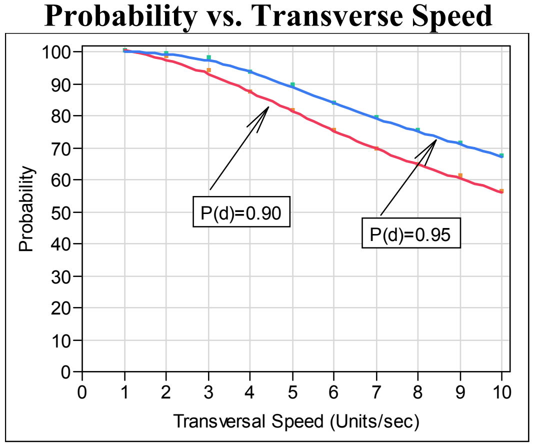
Probability vs. Transverse Speed



RadPack: Zero Dist for all Parameters
Detection Range: 11, Minimum Distance 10.4
Integration Time 2 sec, P(d)=0.90, 0.95 and 0.995
Figure 6

Obviously walking closer to the source would have a substantial effect on the ability of detecting the RN source. In Figure 6, the source was placed at about 3/4 of the maximum range of the RadPack. The probability of detection of the RN source for a transverse speed of 6 units/sec is 75% as opposed to 13% when the source is at 95% of the maximum range and P(d)=0.90. One could recommend that the area being scanned be at least within 75% of the maximum range of the detector with a transversal speed of no more than 5 units/sec. These parameters would attain a detection probability of at least 90% for the given RN source.

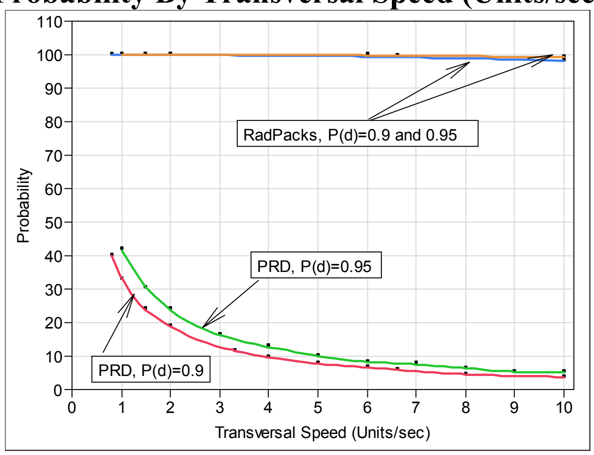
Probability vs. Transverse Speed



RadPack: Zero Dist for all Parameters
Detection Range: 11, Minimum Distance 8.4
Integration Time 2 sec, P(d)=0.90, 0.95
Figure 7

The detection capability of the PRD and RadPack is displayed in Figure 8 for different transversal speeds when the minimal distance between the detection device and RN source is 2.9 units. The capability of the PRD is not comparable to the RadPack regardless of the transversal speed. Even though reducing the transversal speed has a large impact on the detection capability of the PRD, it does not come close to that of the RadPack which is nearly 100% for a separation distance of 2.9 units.

Probability By Transversal Speed (Units/sec)



RadPack vs. PRD ***Zero Dist for all Parameters***
RadPack Detection Range: 11, PRD Detection Range: 3.2
Minimum Distance 2.9
Integration Time 2 sec, P(d)=0.90, 0.95
Figure 8

The Monte Carlo simulations for each plot points in Figures 6, 7 and 8 and also for Exhibits 1 and 2 (below) were bases on 10,000 samples. The Monte Carlo simulation code allows for the impact of the uncertainty in the parameters to be evaluated.

Exhibit 1
Zero Dist for all Parameters
Detection Rate: 1.151, Detection Range: 11, Minimum Distance 8.4
Integration Time 2 sec, P(d)=0.90

Trans Speed=6.62 units/sec		Trans Speed=3.31 units/sec	
Mean	7.24	Mean	14.06
Std Dev	0.49	Std Dev	0.86
upper 95% Mean	7.25	upper 95% Mean	14.08
lower 95% Mean	7.22	lower 95% Mean	14.05
N detects out of 10,000	7117	N detects out of 10,000	9181

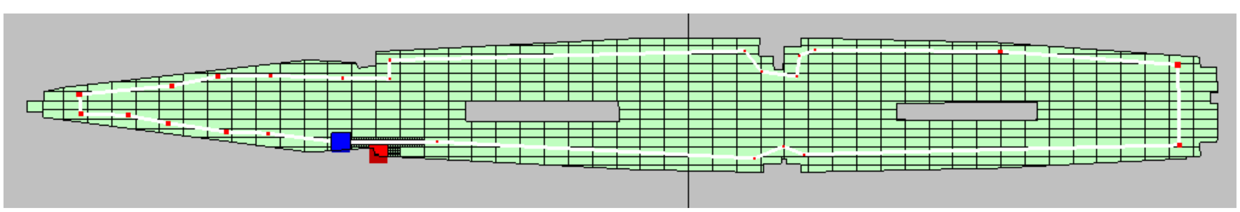
Exhibit 2
Normal Dist with 10% Perturbation for Detection Rate: 1.151, Detection Range: 11 and Transversal Speed**,**
Fixed Parameters: Minimum Distance 8.4
Mean Detection Rate Based on: Integration Time 2 sec and P(d)=0.90

Trans Speed~ N(6.62, Rel std dev=10%)		Trans Speed~ N(3.31, Rel std dev=10%)	
Mean	7.26	Mean	14.13
Std Dev	0.93	Std Dev	1.71
upper 95% Mean	7.28	upper 95% Mean	14.17
lower 95% Mean	7.24	lower 95% Mean	14.10
N detects out of 10,000	7203	N detects out of 10,000	9142

Comparing Exhibit 1 and 2, it can be seen that a 10% perturbation in the input parameters while assuming Normal distributions resulted in essentially no change in the probability of detection (about 71% for a transversal speed of 6.62 units/sec and 91% for a transversal speed of 3.31 units/sec). However, a two fold increase in spread of the time to detection distribution was apparent for both transversal speeds.

Monte Carlo Simulation: Expanded Route

The patrol route was expanded to cover the outer corridor of the deck (Figure 9). Only one pass-by of the RadPack for each sample was permitted in the Monte Carlo simulation. The simulation was based on the detection rate distributed as N(1.151, 0.1151), detection range distributed as N(11, 1.1) and transversal speed distributed at N(6.62, 0.662). The integration time of the RadPack was 2 seconds with a probability of detection near the device (P(d)) of 0.9. The simulation result (Exhibit 3) was a 52% probability of detecting the RN source at a minimum distance of 9.4 units. The time to detection of the RN source, when detected, was approximately 6 minutes:30 seconds (Exhibit 3) with the guard starting at his displayed position. The guard would have to circle the deck about 5 times to attain at least a 95% probability of detection. This would take about and 32 minutes when the guard is traveling clockwise at 6.62 units/sec.

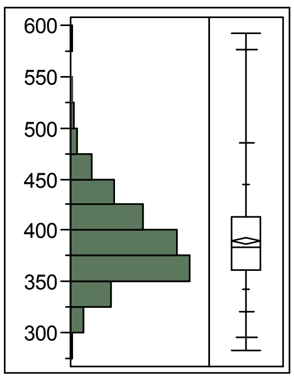


Bijin: Deck J with Expanded Patrol Path
Figure 9

Exhibit 3
Normal Dist with 10% Perturbation for Detection Rate: 1.151, Detection Range: 11 and Transversal Speed 6.62**,**
Fixed Parameters: Minimum Distance 9.4 units
Mean Detection Rate Based on: Integration Time 2 sec and P(d)=0.90
Moments (Time to detect)

Distributions Total Seconds to Detect
(One Walk-By with RadPack)

Distributions
Total Seconds



Quantiles (Seconds)

100.0%	maximum	592
99.5%		577
97.5%		485
90.0%		444
75.0%	quartile	413
50.0%	median	383
25.0%	quartile	361
10.0%		343
2.5%		320
0.5%		295
0.0%	minimum	283

Moments (Seconds)

Mean	389.52
Std Dev	42.27
Std Err Mean	1.86
upper 95% Mean	393.18
lower 95% Mean	385.86
N detects out of 1,000	515

Conclusions and Recommendations

The search parameters associated with human portable radiation detection systems (HPRDS) equipment can be tuned using a Monte Carlo simulation in conjunction with the AVERT® software. The parameters under the user's control include transverse speed, distance, and repetition along the screening path.

The Monte Carlo simulation has shown that altering the transversal speed can have a substantial impact on the probability of detecting an RN source. The gain in sensitivity seems to be somewhat linear when reducing the transversal speed from 10 units/sec to 5 units/sec while an exponential gain in sensitivity is attained when transversal speed is reduced from say 5 units/sec to 2 units/sec (Figure 6). The HPRDS user should know the integration time of the equipment and should recognize that slowing down the screening is especially important when conditions or indicators suggest a need for enhanced sensitivity.

Obviously walking closer to the source has a substantial effect on the ability of detecting the RN source. The probability of detection of the RN source for a transverse speed of 6 units/sec is 75% as opposed to 13% when the source is at 95% of the maximum range and P(d)=0.90. One could recommend that HPRDS users must know the maximum range of their detection equipment and should make every effort to scan an area at least within 75% of the maximum range. These parameters would attain a stationary detection probability of at least 90% for the given RN source.

In addition, multiple walk-bys should be conducted until the probability of detection is acceptable for detecting an RN source of given strength. In the Monte Carlo simulation of an expanded route search using the RadPack there was only a 52% probability of detecting the RN source at the minimum distance in a single pass of the deck. The guard would have to circle the deck about 5 times to attain at least a 95% probability of detection. This would take about and 32 minutes per deck. Additional studies are recommended to provide risk reduction and Conduct of Operations (CONOPS) guidelines for determining how long to detain a vessel and how many boarding team members should be used to clear the vessel before release.

The simulation results can be persuasive in advocating the development of new generation of HPRDS equipment that can be programmed to provide recommendations for variables under the user's control that can help pragmatically attain the desired probability of detection for a particular area of concern or interest.

References

(1) AVERT® Professional Version 4.1-3445, ARES Corporation, Burlingame, CA 94010

(2) JMP® Version 7.0.2, SAS Institute, Cary, NC