AN ABSTRACT OF THE THESIS OF

William L. Duffy for the degree of Master of Science in Radiation Health Physics presented on September 12, 2001. Title: A Method for Predicting Peak Scanning Detection Efficiency of a Cylindrical Sodium Iodide Scintillation Detector.

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Scanning surveys of building surfaces and land areas are performed with radiation detection equipment to identify areas of elevated radioactivity. To quantify the extent and magnitude of the contamination, follow-up radiation surveys and soil sampling are usually required. The ability to accurately quantify discrete locations or "hot particles" of contamination requires a full understanding of the scanning detection efficiency of the instrument being used. A cylindrical sodium iodide detector's scanning detection efficiency was examined theoretically using the Monte Carlo N-Particle Code, version 4b, and examined experimentally using the Marianno Research Sled located in the Department of Nuclear Engineering, Oregon State University. A method is described for predicting instrument scanning detection efficiency for a 1 s observation interval over a range of scanning speeds using a series of static detection efficiency measurements. Testing of the prediction method and accuracy of predicted values was performed by comparison to experimentally determined values of scanning detection efficiency. Additionally, the validity of the predicted scanning detection efficiency values was tested by

quantifying a radioactive source at a number of scanning speeds to quantitatively determine its activity. Activity values determined by scanning the source were compared against an activity value determined a by high purity germanium detection system. Results indicate that the method is both easy to perform and provides statistically accurate scanning detection efficiency values that can be utilized for the quantification of discrete locations or “hot particles” of radioactive contamination.

A Method for Predicting Peak Scanning Detection Efficiency of a Cylindrical Sodium Iodide Scintillation Detector

by

William L. Duffy

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William L. Duffy, Author

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CONTRIBUTING AUTHORS

Captain Kevin G. Hart, United States Army, contributed to the design, data collection, evaluation and review of this work.

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A Method for Predicting Peak Scanning Detection Efficiency of a Cylindrical Sodium Iodide Scintillation Detector

William L. Duffy, Kathryn A. Higley, and Kevin G. Hart

ABSTRACT

Scanning surveys of building surfaces and land areas are performed with radiation detection equipment to identify areas of elevated radioactivity. To quantify the extent and magnitude of the contamination, follow-up radiation surveys and soil sampling are usually required. The ability to accurately quantify discrete locations or "hot particles" of contamination requires a full understanding of the scanning detection efficiency of the instrument being used. A cylindrical sodium iodide detector's scanning detection efficiency was examined theoretically using the Monte Carlo N-Particle Code, version 4b, and examined experimentally using the Marianno Research Sled located in the Department of Nuclear Engineering, Oregon State University. A method is described for predicting instrument scanning detection efficiency for a 1 s observation interval over a range of scanning speeds using a series of static detection efficiency measurements. Testing of the prediction method and accuracy of predicted values was performed by comparison to experimentally determined values of scanning detection efficiency. Additionally, the validity of the predicted scanning detection efficiency values was tested by quantifying a radioactive source at a number of scanning speeds to quantitatively determine its activity. Activity values determined by scanning the source were compared against an activity value determined a by high purity germanium detection system. Results indicate that the method is both easy to perform and provides statistically accurate scanning detection efficiency values that can be utilized for the quantification of discrete locations or “hot particles” of radioactive contamination.

INTRODUCTION

A new specialty within the nuclear industry has developed as various nuclear reactors and nuclear related facilities reach the end of their in-service lives. After ceasing normal operations, these facilities are faced with transitioning into the multifaceted and arduous mode of decontamination and decommissioning (D&D) of potentially contaminated sites. The development of procedures and practices associated with the specialty of D&D has given birth to a myriad of issues that need resolution. One question, in particular, revolves around the most accurate and cost effective method of determining the extent and magnitude of locations of radioactive contamination.

One common method of performing this task is to conduct a moving scan over areas of suspected contamination with sensitive radiation detection equipment. With this application, information regarding the location and size of contaminated areas is determined. A characterization or scoping survey is generally conducted by slowly moving detection equipment over an area to detect areas of elevated radioactivity. One traditional method relies on an operator wearing headphones to interpret the audible output of an instrument to identify the contamination. As the audible output increases in intensity, the operator slows the speed of the scan until a peak count rate is achieved. The operator then stops to mark the location of the contamination. Additional follow-up surveys are then repeated or soil samples are taken in order to verify the results of the initial scan and quantify the amount of radioactive material actually present. Regardless of the follow-up method, additional time and resources are consumed in conducting these surveys.

Recent advances in detection instrumentation technology have allowed for the incorporation of data collectors and positioning systems (Wright et al., 2000; Egidi et al, 2000) in an attempt to decrease the cost and time required to perform surveys of potentially contaminated areas. Most recently, the move is toward utilizing a combination of Global Positioning System (GPS) and data logger technology in conjunction with radiation detectors (Marianno et al., 2001). This allows survey data to be logged with positional data in a fast and accurate scan of an area of suspected contamination. Survey data can then be downloaded for the generation of survey maps that display contaminated locations. While these technologies reduce the time required to perform initial surveys, follow-up methods are still required to determine the quantity of contamination at the mapped locations.

One reason that follow-up surveys are required to determine the magnitude of radioactive contamination is the uncertainty associated with instrument detection efficiency experienced during a scan. For any radiation detection instrument, detection efficiency is dependent upon the properties of the detector, source-detector geometry and the energy of the radiation being detected (Knoll, 1989). In using a specific detector to locate contamination of a known radionuclide, the factors of detector properties and energy of the radiation emitted by the contamination are unvarying. Additionally, during static measurements of instrument detection efficiency the source-detector geometry is unchanging. When a detector is used for scanning a surface however, the source-detector geometry configuration is in a dynamic state. More specifically, the solid angle subtended by the detector at the source position is constantly changing over the path of the scan. Without solid information as to the scanning detection efficiency of the instrument, it is unreasonable to attempt quantification of the amount of radioactivity measured during a scan survey.

A limited amount of research has been conducted with regard to scanning detection efficiency. An early work by Sommers (1975) obtained measured data to test the soundness of theoretical calculations of a surveyor's source detection frequency using Geiger-Mueller (GM) and ion chamber detectors by moving calibrated sources beneath a detector at speeds ranging from 2.4 to 15 cm s^{-1}. With consideration of the ability of a surveyor to detect an audible signal in Sommers' study, it was concluded that source detection frequencies were strongly dependent upon source strength, survey speed and background activity, in addition to the already mentioned factors of instrument detection efficiency.

NUREG-1507 (Abelquist et al., 1998) provides a wealth of comprehensive information regarding detector scanning sensitivity. That report examines both static and scan minimum detectable concentrations (MDCs) for a variety of detector designs under a number of different conditions. NUREG-1507 states that the sensitivity of a radiation detection instrument used in a scanning application is strongly dependent upon the speed at which the scan is conducted, but the report provides no explicit analysis of the effect of scanning speed on an instrument's scanning detection efficiency. Like Sommers' study, a large component of the NUREG-1507 analysis focuses on the ability of a surveyor to distinguish radioactive contamination by means of an audible signal or deflection of a needle on a rate meter.

Abelquist and Brown (1999) describe a method for anticipating contamination levels that surveyors might be expected to detect in scanning. By estimating the increment in an instrument's counting rate that would be necessary to support specified limits on Type I and Type II errors, the result is applied to calculations of MDCs achievable while scanning different areas. Once again, however, Abelquist and Brown take into account the fact that surveyor interpretation of elevated instrument count rates are relied upon to identify radioactively contaminated areas.

Because all of the above research has focused primarily upon the traditional method of performing a scan survey, their applicability to recent technology is limited. Each piece does provide, however, a certain amount of basis for further investigation into scanning detection efficiencies. The following studies, however, prove to be much more insightful with respect to the goal of this research.

Marianno and Higley (2000) performed an in-depth theoretical and experimental analysis of scanning detection efficiency with the Field Instrument for Detecting Low Energy Radiation (FIDLER), taking into account data logging and global positioning technologies. It was demonstrated that scanning detection efficiency is a function of scanning speed, observation interval, signal processing, and contaminant position in relation to the detector. Decreases in scanning detection efficiency of the FIDLER were observed with larger values of scan speed, observation intervals, and depth of cover over a discrete location or "hot particle" of radioactive contamination.

Moss et al. (2000) investigated the effects of scanning speed and different data logger signal processing response times on the scanning detection efficiency of two sodium iodide detectors and two GM detectors. A laborious process was used to develop empirical relationships between the scanning speed and scanning detection efficiency for each of the above instruments to predict scanning detection efficiency as a function of scanning speed. These empirical relationships are specific to the instruments and the signal processing algorithms of the data logging device examined in Moss' study.

The present study was designed to investigate the effects of scanning speed upon the detection efficiency of a cylindrical NaI(Tl) detector subject to no signal processing effects and to develop a method of predicting scanning detection efficiency as a function of scanning speed. Intended for use in the field, this procedure may allow for an expeditious and accurate determination of instrument scanning detection efficiency for "hot particles" of radioactive contamination.

METHODS AND MATERIALS

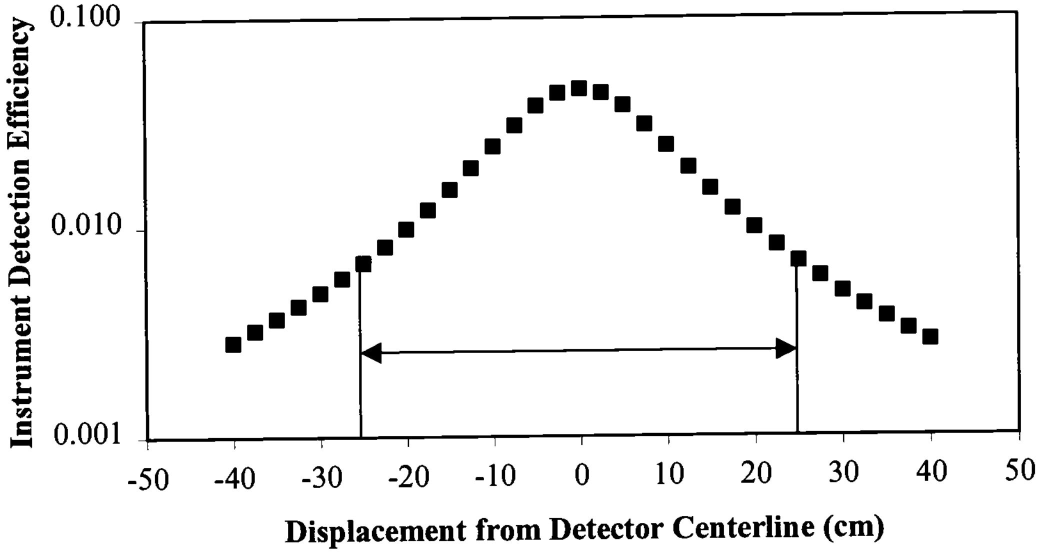
MONTE CARLO SIMULATIONS

Monte Carlo N-Particle Code (MCNP4b) was used to examine theoretically the effectiveness of utilizing a series of static instrument detection efficiency measurements to predict the scan detection efficiency of a NaI(Tl) scintillation detector for point sources. Two separate series of Monte Carlo photon transport simulations were performed using MCNP4b. In both cases, the NaI(Tl) detector was modeled as a sodium iodide crystal of diameter 12.7 cm and thickness 7.62 cm surrounded by a 0.081 cm thick aluminum housing. The detector was placed 7.62 cm above the surface of modeled coral sand with a density of 1.55 g cm^{-3}. Modeled dry air was placed between the surface of the sand and the detector. A simulated ^{137}Cs source was modeled on the surface of the sand according to the two methods described below.

The first series of MCNP4b simulations focused on static measurements of theoretical detection efficiency as a function of lateral displacement from the central axis of the detector. Detection efficiencies were determined in 2.5 cm increments over a total displacement of 80 cm. The ^{137}Cs source was simulated as a point isotropically emitting 661.67 keV photons. Five million particle histories were performed in each simulation at each increment of displacement. Detection efficiency was calculated by dividing the number of full energy photoelectric interactions within the detector by the number of photons emitted by the simulated source. The results of this first series of simulations provide theoretical static instrument detection efficiency as a function of position from the central axis of the detector. Data from this simulation were plotted and used to calculate a predicted value of the peak scanning detection efficiency for a range of scanning speeds as explained below.

To make predictions of scanning detection efficiency for varied scan speeds, the average value of static detection efficiency over a range of displacement equal to a one second observation interval was determined. For example, the predicted scanning detection efficiency for a scan at 60 cm s^{-1} was determined by summing each discrete static detection efficiency value between –30 cm and 30 cm displacement and dividing by the number of discrete values within that region (Figure 1). Predicted values of scanning detection efficiency (ε) as a function of scanning speed were determined for speeds ranging from 20 cm s^{-1} to 80 cm s^{-1}.

The second series of simulations were conducted in a manner similar to those conducted by Marianno et al. (2000) to examine the detection efficiency of the NaI(Tl) detector in a scanning mode at speeds ranging from 20 cm s^{-1} to 80 cm s^{-1}. Because of the difficulty in simulating the motion of a detector over a point source of photons, the relative motion between the detector and the source was simulated using a line source that mimics the movement of the point source under the detector (Figure 2). Under these conditions, the length of the line source is a product of the speed of scan and the length of the observation interval. A count interval of 1 s was used for each scanning simulation performed in this analysis. As



$$\text{Predicted } \varepsilon(\text{speed}) = \frac{\sum_{x=-\text{speed}/2}^{x=\text{speed}/2} \varepsilon(x)}{n} \Rightarrow \varepsilon(60) = \frac{\sum_{x=-30}^{x=30} \varepsilon(x)}{25}$$

Figure 1. Example methodology for predicting scanning detection efficiency as a function of speed for a speed of 60 cm s^{-1}.

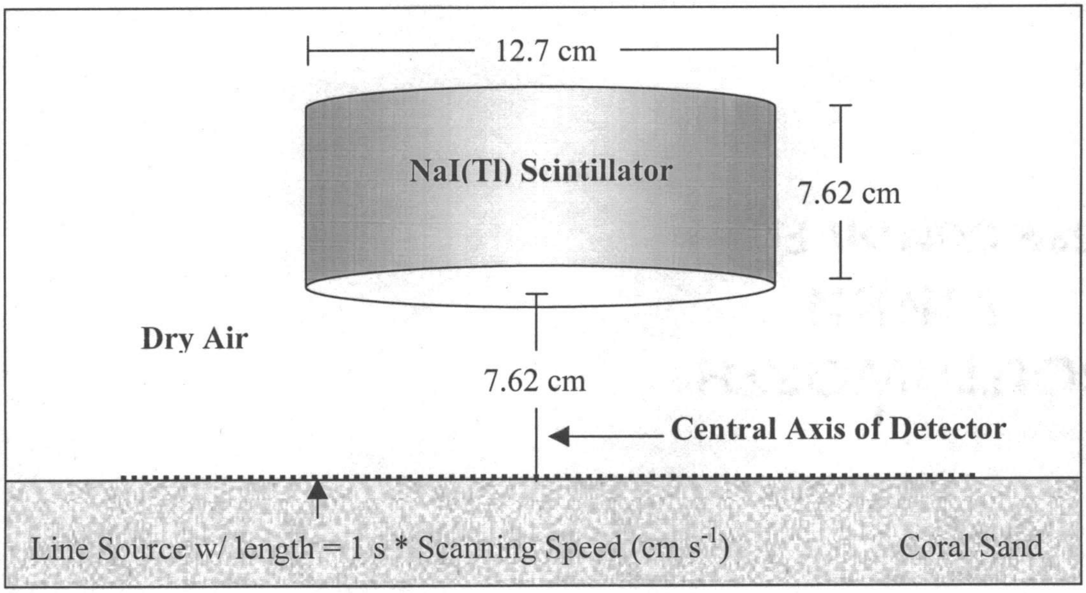


Figure 2. Model geometry for MCNP4b investigation of scanning detection efficiency of a 12.7 cm x 7.62 cm NaI(Tl) scintillator.

in the simulations of static measurements, the source was placed on the surface of the coral-like sand, centered on the central axis of the detector. Photons with energy of 661.67 keV were simulated to originate from the source isotropically and randomly along the length of the line source. Detection efficiency was calculated by dividing the number of full energy photoelectric interactions within the detector by the number of photons emitted by the simulated source. Calculated values of scanning detection efficiency were plotted as a function of scan speed and compared to the predicted values calculated above.

EXPERIMENTAL DESIGN

Experimental Apparatus

In an effort to demonstrate that the method described above is effective for an actual radiation detection system, the researchers assembled a counting system and performed experiments utilizing the Marianno Research Sled (MRS) located at the Department of Nuclear Engineering, Oregon State University (Figure 2). This apparatus constructed by Marianno can repeatedly collect data at different scanning speeds while maintaining constant detection geometry. Designed to be useful for different types of detection equipment, this sled and track system was constructed such that a source placed in the center of the sled can be moved under a test detector to simulate a field survey during which a detector moves directly over a source of radiation.

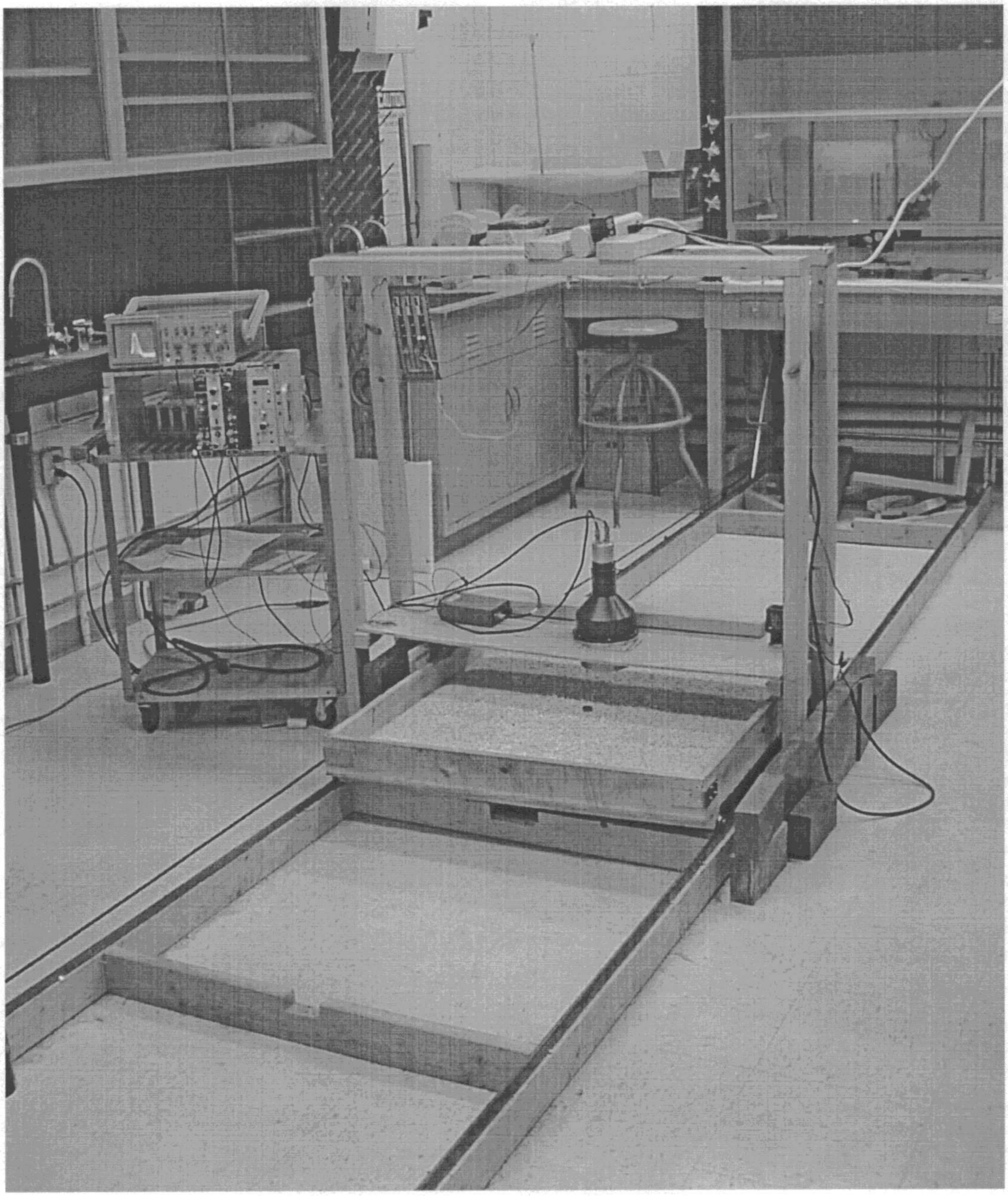


Figure 3. Marianno Research Sled (MRS) located in the Department of Nuclear Engineering, Oregon State University.

The 5.5 m long track system is designed to move a 1 m by 1 m sled via a chain driven by a variable speed 1/6 horsepower DC motor under a detector positioned at the midpoint of the track. The sled frames a 4-inch deep tray containing a 2 cm depth of coral-like sand (density ≈ 1.55 g cm^{-3}). Upon initiation of the motor, the sled accelerates to a constant speed, travels under the detector, and decelerates to a stop after passing under the detector. Using this system, the sled is able to achieve speeds ranging from 10 cm s^{-1} to over 100 cm s^{-1}.

A photo emitter/receiver switch wired to a digital timer measures, to the nearest 0.01 s, the time that the sled was beneath the centerline of the detector. As the leading edge of the sled approaches the detector, a light source is shielded from a phototransistor, actuating the digital timer. Upon the departure of the trailing edge of the sled from beneath the detector, the light source is unshielded from the phototransistor, and the timer ceases. The speed of the cart can be determined by dividing the length of the cart (94.8cm) by the measured time interval.

In order to achieve the desired observation counting interval during scans of varied speeds, an additional apparatus was designed and added to the MRS to operate independent of the timer circuit. An infrared switch was constructed to initiate and terminate detector pulse counting with an infrared light-emitting diode and an infrared sensing transistor. With the infrared switch centered on the midpoint of the detector, pulse counting begins when the infrared light source is shielded from the sensor by a card mounted to the side of the sled as it travels beneath the detector. When the card ceases shielding the infrared light source from the sensor, pulse counting is stopped. For each scan speed examined, the length of the card was chosen to yield a 1 s observation interval. The card was then attached to the side of the sled such that it was centered on the sled and the source, providing an observation interval equal to 0.5 s on the leading and trailing side of the source for a total observation time of 1 s.

Experimental Instrument Detection Efficiency Measurements

A 12.7 cm x 7.62 cm NaI(Tl) scintillation detector connected to a standard Nuclear Instrument Module (NIM) Rack was positioned at the mid-point of the track width and half the length of the track. The vertical position of the detector was set such that the face was 7.62 cm (~ 3 in.) above the surface of the coral sand. A 0.108 MBq ^{137}Cs source was placed in the middle of the sled on the surface of the coral sand. The detector and source were positioned such that the source would pass directly below the central axis of the detector when the sled passed underneath. Initial tests of the NIM System were performed to determine the operating detector bias supply voltage and the energy resolution of the system.

Static detection efficiency examination of the 12.7 cm x 7.62 cm NaI(Tl) scintillator was performed through a series of twenty 300 s observation intervals with the source-detector geometry stated above. The initial measurement was conducted with the 0.108 MBq ^{137}Cs source positioned directly beneath the central axis of the detector, 7.62 cm from its face. Subsequent measurements were performed after repositioning the source at 2.5 cm increments from the central axis of the detector parallel in the direction of sled travel, until a total displacement of 40 cm had been achieved in both the positive and negative directions with respect to the detector center. Total gross counts collected over each observation interval were recorded, and background corrected count rates and static efficiencies at each source position were determined. The corresponding 95% confidence intervals about the value of static efficiency was calculated based on propagating the errors in counting statistics and in the measured source emission rate.

Predictions of scanning detection efficiency for a range of speeds from 20 cm s^{-1} to 80 cm s^{-1} were made using the experimentally determined values of static detection efficiency. Just as conducted with the Monte Carlo simulated values, the prediction was made by determining the average static detection efficiency over a specified lateral displacement. The predicted values of scanning detection efficiency were recorded for comparison to experimentally determined values of scanning detection efficiency over the same range of scanning speeds.

Examination of the scanning detection efficiency of the 12.7 cm x 7.62 cm NaI(Tl) scintillator and NIM system as a function of speed was performed over scan speeds ranging from 20 cm s^{-1} to 80 cm s^{-1}. With the detector positioned as during the static detection efficiency determinations and the source positioned at the middle of the MRS sled, the sled was placed in position to be pulled under the detector. The MRS drive motor was activated, pulling the sled beneath the detector, actuating the photo emitter/receiver switch and timing circuit as well as the infrared counting switch. The drive motor was deactivated after the trailing edge of the sled passed beyond the counting circuit switch. The digital readout of the MRS sled timer and gross counts collected by NIM system within the observation interval were recorded. The sled was then returned to its starting position. Twenty trials were conducted for each scanning speed investigated. Upon completion of these trials for each scanning speed, an average scanning detection efficiency and corresponding 95% confidence interval were calculated based on propagating the errors in counting statistics and in the measured source emission rate.

Quantification Test for ^{137}Cs Source of Unknown Activity

To further verify the validity of the prediction method, a series of trials were conducted to demonstrate the ability of using predicted scanning detection efficiency values to quantify the activity of a point source. A ^{137}Cs button source of unknown activity was placed at the center of the MRS sled. Scanning measurements of the unknown source over the same range of scanning speeds specified above were performed. Ten scanning trials were conducted at each speed, and gross counts collected by the NIM system and digital readout of the MRS timing circuit were recorded.

Using the experimentally determined predicted values of scanning detection efficiency calculated in the previous section, an average value of the unknown point source activity and corresponding 95% confidence interval was determined at each scanning speed. The true value and associated 95% confidence interval of the activity of the ^{137}Cs button source was determined by the Oregon State University TRIGA Reactor Health Physics group through a count performed on a High Purity Germanium (HPGe) detector calibrated by a National Institute of Science and Technology (NIST) traceable mixed nuclide source. The values of source activity determined via scanning were compared to the HPGe detector determined values.

RESULTS AND DISCUSSION

MONTE CARLO SIMULATIONS

Theoretical static detection efficiency as a function of position from the central axis of the detector is plotted in Figure 4. Examination of this plot demonstrates the range of efficiencies that are observed as the central axis of a detector is moved over a point source during a scan. For a scanning application, this plot shows a clear increase in instrument detection efficiency as the detector approaches the point source, until detection efficiency reaches a peak value when the source is directly below the central axis of the detector. As the detector travels away from the source, a corresponding decrease in instrument detection efficiency is observed. This response is symmetrical about the maximum value of detection efficiency for the modeled detector.

The peak scanning detection efficiency, therefore, occurs over an observation interval that encompasses the range of values around the peak of this plotted data. When a detector is moved over a point source in this manner at varied speeds, corresponding variations in observed peak scanning detection efficiency would result. This variation, due to the range of efficiencies experienced in the given scanning observation interval, is a function of scanning speed and the length of the observation interval. As scanning speed is increased, the range of observed efficiencies about the peak widens, thereby decreasing the observed value of peak scanning detection efficiency. Additionally, if a larger observation interval is used

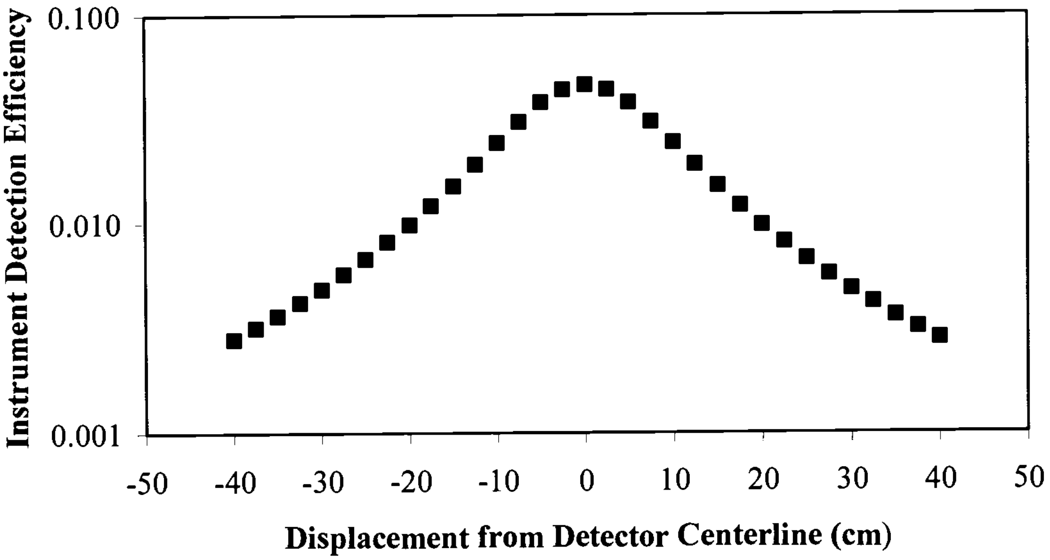


Figure 4. MCNP4b simulated 12.5 cm x 7.62 cm NaI(Tl) scintillator theoretical static detection efficiency for 661.67 keV photons as a function of position from the central axis of the detector.

the same effect occurs. If values of static detection efficiency experienced in an observation interval are known, an accurate prediction of scanning detection efficiency can be made by the method described earlier. These predictions, based on MCNP4b generated data, of peak scanning detection efficiency as a function of scanning speed are displayed in Table 1.

MCNP4b simulated values of theoretical peak scanning instrument detection efficiency are plotted in Figure 5. As stated above, as the speed of the scan is increased there is an observed decline in the value of detection efficiency. The results of these simulations were compared to the values predicted with the static instrument detection efficiency simulations and are displayed in Table 1.

Examination of the values contained in Table 1 favorably reflects the ability of the outlined procedure to accurately predict scanning detection instrument efficiency for a range of speeds from a series of static instrument detection efficiency measurements. The percent difference between each predicted efficiency value and the simulated scanning efficiency value is less than 5 percent.

EXPERIMENTAL INSTRUMENT DETECTION EFFICIENCY MEASUREMENTS

Measured values of static instrument detection efficiency as a function of position from the central axis of the detector and associated 95% confidence intervals are plotted in Figure 6. This plot displays similar characteristics as the plot of theoretical values for the same scenario. The plot represents the series of instrument detection efficiencies that would be experienced over an observation

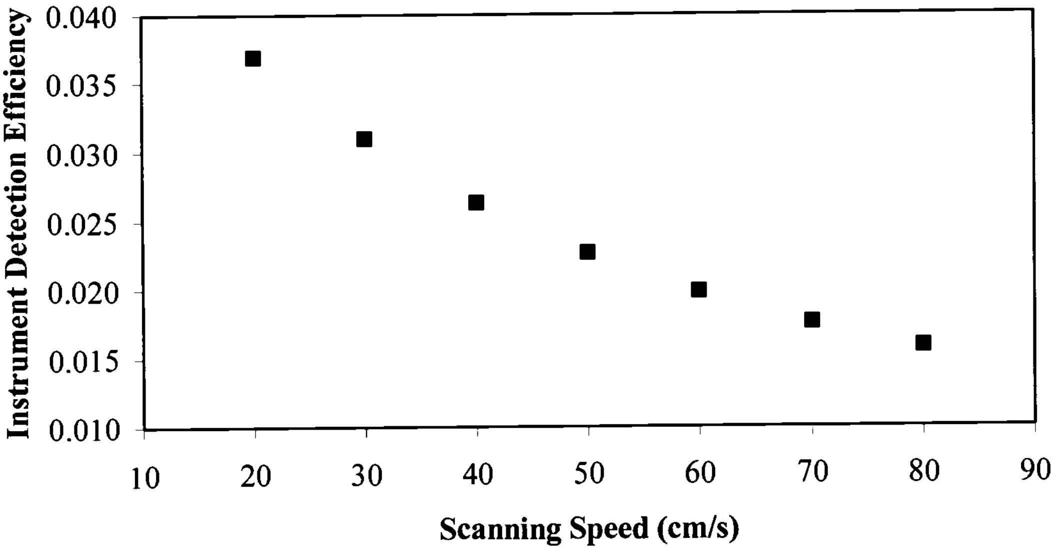


Figure 5. MCNP4b simulated 12.5 cm x 7.62 cm NaI(Tl) scintillator theoretical peak scanning instrument detection efficiency for 661.67 keV photons as a function of scanning speed.

Speed (cm/s)	Predicted Peak Instrument Scanning Detection Efficiency (%)	Observed Peak Instrument Scanning Detection Efficiency (%)	Percent Difference
20	3.53 ± 0.02	3.69 ± 0.02	4.50 ± 0.02
30	2.97 ± 0.01	3.09 ± 0.02	4.34 ± 0.02
40	2.53 ± 0.01	2.63 ± 0.01	4.15 ± 0.02
50	2.19 ± 0.01	2.27 ± 0.01	3.89 ± 0.02
60	1.92 ± 0.01	1.98 ± 0.01	3.28 ± 0.02
70	1.71 ± 0.01	1.76 ± 0.01	2.75 ± 0.02
80	1.54 ± 0.01	1.58 ± 0.01	2.47 ± 0.02

Table 1. Comparison of predicted and observed values of MCNP4b simulated 12.5 cm x 7.62 cm NaI(Tl) scintillator of peak scanning detection efficiency for 661.67 keV photons as a function of scanning speed. Uncertainties represent the 95% confidence interval, based on propagating the errors in Monte Carlo statistical analysis performed by MCNP4b.

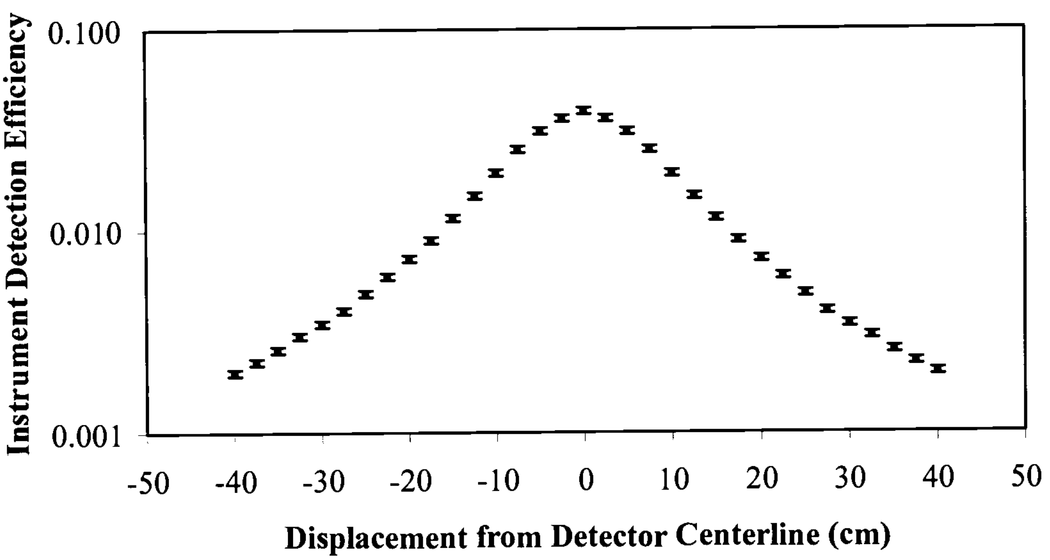


Figure 6. Experimentally determined 12.5 cm x 7.62 cm NaI(Tl) scintillator static detection efficiency of 661.67 keV photons as a function of position from the central axis of the detector. Error bars represent the 95% confidence interval, based on propagating the errors in counting statistics and in the measured source emission rate.

interval during a scanning application with the same detector. As a detector approaches the point source, instrument detection efficiency increases to a maximum value as the source is directly beneath the detector and decreases correspondingly as the detector travels away from the source. Predicted values of peak scanning instrument detection efficiency as a function of scanning speed were calculated as described and are displayed in Table 2.

Experimentally measured values of peak scanning detection efficiency and associated 95% confidence intervals are plotted in Figure 7. Once again, as the scanning speed is increased there is an observed decline in the value of detection efficiency. The results of these trials were compared to the values predicted with the measured static instrument detection efficiency values and are displayed in Table 2.

Data presented in Table 2 reconfirms the ability of the outlined procedure to accurately predict scanning detection instrument efficiency for a range of speeds from a series of static instrument detection efficiency measurements. In each case examined in this study the difference between the predicted value and measured value and associated 95% confidence interval for the difference includes the value of zero. The inclusion of the value zero within the confidence interval about the difference provides evidence of no statistical difference between the predicted and measured values of peak scanning instrument detection efficiency (Ramsey and Schafer, 1997).

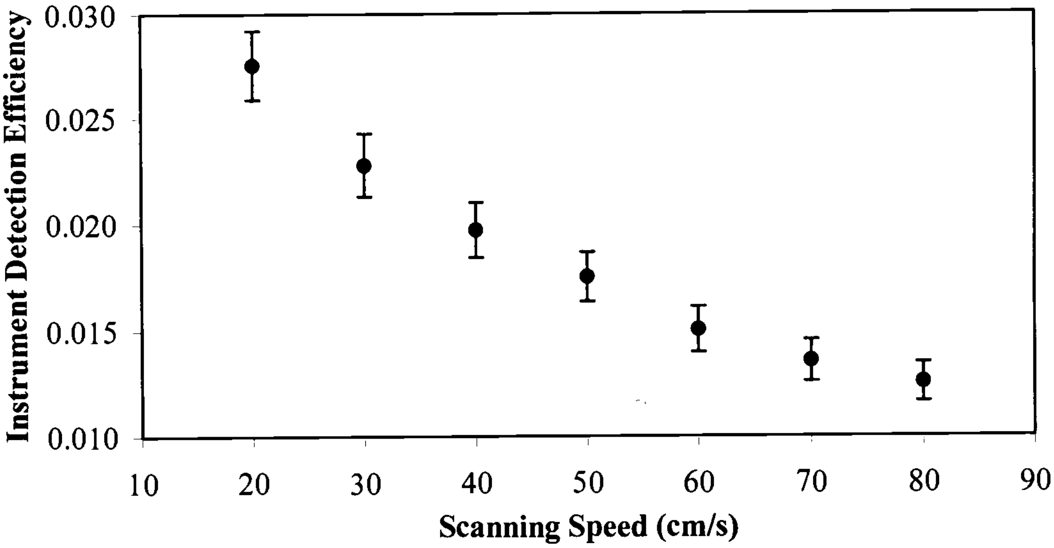


Figure 7. Experimentally determined values of 12.5 cm x 7.62 cm NaI(Tl) scintillator peak scanning instrument detection efficiency of 661.67 keV photons as a function of scanning speed. Error bars represent the 95% confidence interval, based on propagating the errors in counting statistics and in the measured source emission rate.

Speed (cm/s)	Predicted Peak Instrument Scanning Detection Efficiency (%)	Observed Peak Instrument Scanning Detection Efficiency (%)	Absolute Difference (%)
20	2.91 ± 0.11	2.76 ± 0.15	0.15 ± 0.19
30	2.42 ± 0.10	2.28 ± 0.13	0.14 ± 0.16
40	2.04 ± 0.09	1.97 ± 0.12	0.07 ± 0.15
50	1.75 ± 0.08	1.75 ± 0.11	0.00 ± 0.13
60	1.53 ± 0.07	1.50 ± 0.10	0.03 ± 0.12
70	1.36 ± 0.07	1.36 ± 0.09	0.00 ± 0.11
80	1.22 ± 0.06	1.26 ± 0.09	-0.04 ± 0.11

Table 2. Comparison of predicted and observed values of experimentally determined 12.5 cm x 7.62 cm NaI(Tl) scintillator peak scanning detection efficiency of 661.67 keV photons as a function of scanning speed. Uncertainties represent the 95% confidence interval, based on propagating the errors in counting statistics and in the measured source emission rate.

QUANTIFICATION TEST FOR ^{137}Cs SOURCE OF UNKNOWN ACTIVITY

Experimentally measured activity values and associated 95% confidence intervals of the ^{137}Cs source are compared to the HPGe detector determined value and associated 95% confidence interval in Table 5. These results further validate the efficacy of the outlined instrument peak scanning detection efficiency prediction procedure. Using the values of predicted peak scanning detection efficiency calculated in this procedure, the researchers were able to accurately quantify the activity of a discrete location or "hot particle" of radioactive contamination traveling along the centerline of the detector. In each case examined, the measured values of source activity were within ten percent of the HPGe determined value. More importantly, the percent difference between the measured activity and HPGE determined value and associated 95% confidence interval for the percent difference includes zero. This provides no statistical evidence of a difference between the experimentally measured and HPGe determined values of source activity.

Speed (cm/s)	Scanning Detection Determined Source Activity (Bq)	HPGe Counting Determined Source Activity (Bq)	Absolute Difference (Bq)
20	4.40E+04 ± 4.21E+03	4.08 E+04 ± 1.49E+03	-3.12E+03 ± 4.46E+03
30	3.85E+04 ± 4.05E+03	4.08 E+04 ± 1.49E+03	2.36E+03 ± 4.31E+03
40	3.99E+04 ± 4.46E+03	4.08 E+04 ± 1.49E+03	8.93E+02 ± 4.70E+03
50	4.10E+04 ± 4.84E+03	4.08 E+04 ± 1.49E+03	-1.43E+02 ± 5.07E+03
60	3.85E+04 ± 4.89E+03	4.08 E+04 ± 1.49E+03	2.36E+03 ± 5.11E+03
70	3.80E+04 ± 5.14E+03	4.08 E+04 ± 1.49E+03	2.79E+03 ± 5.35E+03
80	4.11E+04 ± 5.73E+03	4.08 E+04 ± 1.49E+03	-2.42E+02 ± 5.92E+03

Table 3. Comparison of scanning detection and HPGe counting determined values of unknown ^{137}Cs source activity. Uncertainties represent the 95% confidence interval, based on propagating the errors in counting statistics.

CONCLUSION

This study was designed to investigate the effects of scanning speed upon the scanning detection efficiency of a cylindrical NaI(Tl) detector subject to no signal processing effects, and to develop a field applicable method of predicting scanning detection efficiency as a function of scanning speed. It was found that peak instrument scanning detection efficiency is a function of the speed at which a scan is conducted. A decrease in detection efficiency was observed for the examined 12.7 cm x 7.62 cm NaI(Tl) scintillator as scanning speed was increased over speeds ranging from 20 cm s^{-1} to 80 cm s^{-1}. This behavior agrees well with the radiation detection systems examined in all of the previous works mentioned.

The ability to calculate an instrument's detection efficiency at various scanning speeds is essential to D&D activities. The procedure developed in this study was proven to accurately predict instrument peak scanning detection efficiency of discrete locations of radioactive contamination as a function of scanning speed from a series of static instrument detection efficiency measurements. These static detection efficiency measurements can be performed quickly and accurately in the field, thereby allowing for the accomplishment of the task of scanning detection efficiency determination. The validity of the peak instrument scanning detection efficiency values that are a result of the prediction method presented was verified. It is concluded that use of the predicted values of scanning detection efficiency allow for the quantification of discrete locations or "hot particles" of radioactive material with a scan performed directly above the source of radiation.

The use of the peak instrument scanning detection efficiency prediction procedure presented in this research may allow for savings in the number of man-hours expended to perform scan surveys by extending the purpose of scoping and characterization surveys to include the quantification of "hot particle" contamination. Moreover, it could ultimately prove to eliminate the need for follow-up surveys and sampling to verify the results of a characterization survey, providing additional resource savings to complete D&D activities. To achieve this resource benefit, however, further research must be conducted to develop a method for predicting scanning instrument detection efficiency for other source geometries. Additionally, further research must be conducted to verify the effectiveness of the suggested prediction method for NaI(Tl) detectors of other sizes, other commercially available field portable radiation detection systems, and those used in conjunction with GPS and data logging equipment.

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