A Case Study Correlating Innovative Gamma Ray Scanning Detection Systems Data to Surface Soil Gamma Spectrometry Results – 13580

Shannon Thompson, PhD[1], Rene Rodriguez, PE[1], Paul Billock, MS[1], and Peter Lit[2]
Affiliation: 1) HydroGeoLogic, Inc.
11107 Sunset Hills Road, Suite 400,
Reston, VA 20190
2) Address: Nomad Science Group
7738 Nautilus Shell Street,
Las Vegas, NV 89139

ABSTRACT

HydroGeoLogic (HGL), Inc. completed a United States Environmental Protection Agency (USEPA) study to characterize radiological contamination at a site near Canoga Park, California. The characterized area contained 470 acres including the site of a prototype commercial nuclear reactor and other nuclear design, testing, and support operations from the 1950s until 1988 [1]. The site history included radiological releases during operation followed by D&D activities. The characterization was conducted under an accelerated schedule and the results will support the project remediation. The project has a rigorous cleanup to background agenda and does not allow for comparison to risk-based guidelines. To target soil sample locations, multiple lines of evidence were evaluated including a gamma radiation survey, geophysical surveys, historical site assessment, aerial photographs, and former worker interviews. Due to the time since production and decay, the primary gamma emitting radionuclide remaining is cesium-137 (Cs-137). The gamma ray survey covered diverse, rugged terrain using custom designed sodium iodide thallium-activated (NaI(Tl)) scintillation detection systems. The survey goals included attaining 100% ground surface coverage and detecting gamma radiation as sensitively as possible. The effectiveness of innovative gamma ray detection systems was tested by correlating field Cs-137 static count ratios to Cs-137 laboratory gamma spectrometry results. As a case study, the area encompassing the former location of the first nuclear power station in the U. S. was scanned, and second by second global positioning system (GPS)-linked gamma spectral data were evaluated by examining total count rate and nuclide-specific regions of interest. To compensate for Compton scattering from higher energy naturally occurring radionuclides (U-238, Th-232 and their progeny, and K-40), count rate ratios of anthropogenic nuclide-specific regions of interest to the total count rate were calculated. From the scanning data, locations with observed Cs-137 ratios exceeding six standard deviations above the mean ratio were mapped in high resolution [2]. Field teams returned to those locations to collect static count measurements using the same detection systems. Soil surface samples were collected at 30 locations and analyzed for Cs-137. An exponential correlation was identified between Cs-137 concentrations in surface soil and field-scanned Cs-137 ratios. The data indicate field minimum detectable concentration (MDC) of Cs-137 at 0.02 Bq/g (0.5 pCi/g) or lower depending on contaminant distribution in soil.

INTRODUCTION

Gamma ray spectrometry has been used for decades to delineate the environmental distribution of gamma emitting radionuclides [3]. Detection systems designed for field applications continue

to be developed [4, 5]. Application examples include detectors mounted to vehicles to locate orphan sources, to respond to a radiological event or accident, and to survey large tracts of land [6]. Recently, mobile radiation detection capabilities have advanced because of increased efficiency through use of large detector arrays, increased resolution due to digital signal processing, improved GPS spatial resolution, and increased computing power. Together, these significantly improve detection sensitivity and location accuracy.

Gamma rays emanate from soil and rocks from natural background radionuclides and may be present from anthropogenic radionuclides. Field gamma ray spectrometry is based on two classes of detectors: scintillation detectors constructed of materials such as NaI(Tl), Cesium Iodide (CsI), or specialty plastics, and solid state intrinsic Germanium (Ge) detectors. Scintillation detectors operate at ambient temperatures and Ge detectors operate at very low temperatures which require cooling mechanisms. Detection efficiency depends on detector size. Scintillation detectors are available in larger volumes than Ge detectors. Scintillation detectors are most often selected for scanning systems designed to survey large, rugged ground surfaces.

Field survey methods include stationary or mobile measurements depending on the purpose of the survey [7, 8]. For remedial investigations, D&D, and environmental restoration operations, ground surveys may be pre-determined survey areas with incomplete coverage or "walkover" surveys providing complete coverage of relatively small areas. Survey results are then evaluated for decisions about soil sample locations [9].

Full surface coverage gamma ray surveys are becoming more common. Surveys employing high-resolution mobile detection systems result in very high density data (data quantities per area). Static measurements with incomplete surface coverage such as point locations on a grid are compiled, integrated, and interpolated. Incomplete surveys provide low density data [10]. A low data density survey requires manual data compilation, relies heavily on interpolation of areas outside the detector Field Of View (FOV) and either assumes that areas most distant from a measurement of interest are mathematically consistent with adjacent measured areas or will be further delineated using future survey or sampling events. Alternatively, complete surface coverage by scanning within a mobile detection system's FOV eliminates measurement compilation and spatial coordination, and increases the robustness of the survey.

The correlation of field survey measurements to soil analysis results provides a means to estimate the accuracy of scanning and high-resolution mapping of gamma radiation data and to approximate Cs-137 field detection limits. Gamma ray survey results have rarely been compared to analytical results, and, as field data, have been relegated to supporting analytical data. In this study, we directly compare in-situ data from gamma detection systems to ex-situ gamma spectrometry results from a radiochemistry laboratory.

Mobile detection systems linked to GPS provide excellent high-resolution information about surface and near-surface contamination rapidly and effectively. By understanding the desired sensitivity and coverage requirements, mobile detection systems can be configured to optimize the characterization of large areas. An obvious benefit to this "precision scanning survey" approach is it allows improved resource allocation for sampling and analysis. This type of survey approach empowers improved decision making during the investigation, removal, or

confirmation project phases by focusing expensive sampling and analysis on areas that indicate elevated gamma radiation levels and conversely reducing or eliminating unnecessary analyses.

MATERIALS AND METHODS

Detection Systems and Instrumentation Hardware

Each gamma ray scanning detection system consisted of NaI(Tl) scintillation detectors with shielding, a transportation mechanism, Global Positioning System (GPS), data acquisition module and advanced digital spectrometer, and a field computer with wireless capability. Detection systems displayed real time radiological data with current position as well as previously scanned areas. To maximize sensitivity toward the ground, shields surrounded the sides and top of the detectors with an unshielded "window" facing the ground. Rugged casings, shock-resistant foam, and a 6.25mm polycarbonate sheet at the bottom of protected the detectors.

The study area contained widely varying terrain with flat, rocky, sloped, and steep areas. Figure 1 presents four ground scanning system configurations featuring large detectors mounted beneath mobile platforms. Each was custom designed to operate in specific types of terrain. The size of the detection system volume is directly proportional to the gamma detection efficiency due to an increased likelihood of interaction between a gamma ray and the detector. Therefore, at a particular operating height, larger systems have greater sensitivity.

Figure 1. Photographs of detection systems.

At the upper left of Figure 1, an all-terrain vehicle mounted detection system called the Enhanced Radiation Ground Scanner (ERGS II) contains eight detectors and a 1.22m by 0.40m

active detection surface. At the upper right, the Mule Mounted Gamma Scanner (MMGS) has one detector on each side of a pack mule and is guided by a mule handler. At the bottom left, the Track Mounted Gamma Scanner (TMGS) has two parallel detectors mounted on a flexible platform propelled by a gasoline powered engine. At bottom right, the human-propelled Wheel Mounted Gamma Scanner (WMGS) has a field computer, GPS, and single downward-facing detector.   Single detector unit dimensions are 0.10m by 0.10m by 0.41m. Data acquisition modules and the GPS antennae are on top of the systems.

GPS signal merging

The GPS position is linked with gamma spectral data (1024 channels per second of counting). The data acquisition module had an on board GPS receiver for collecting positions as well as using the pulse of the GPS to time data collection. The GPS used to capture more accurate location data were not compatible with the onboard GPS receiver. To overcome this limitation GPSMerge software was developed by HGL which combined high accuracy GPS data recorded with ArcPad® with the binary output format of RadAssist® software creating a file consumable by Oasis Montaj software.

Radioactive Sources

Sources were discrete point sources containing NIST-traceable quantities of ^{137}Cs.

Detection System Sensitivity Testing

Results are based on count rate responses (counts per second (cps)) to sources under all test conditions. Tests established the operating parameters height, Field Of View (FOV), and maximum velocity [11]. The data from FOV, height, and velocity tests were combined with the gamma energy transmission through soil to estimate scanning MDCs of ^{137}Cs and ^{60}Co for each detection system.

Maneuverability in the field factored into selection of operating height. To establish the optimum height the detection system was suspended while the source was places at discrete distances below the detector centerline. Height was the distance between the detector center and the source. The ERGS II height tests ranged from 0 to 76.2cm, the MMGS height tests ranged from 12.7 to 88.9cm, and height was not tested for the TMGS or the WMGS because the detectors are mounted at fixed-heights of 38.1 cm and 30.5 cm, respectively.

The FOV was determined through integration of a series of detector-point source measurements. Sources were positioned on a radial grid under the detector center at the operating height. The maximum efficiency is the point directly under the center of the detector. Relative efficiency is the efficiency at a particular point relative to the maximum efficiency. FOV is defined as the length and width at which the relative efficiencies of integrated FOV data was 50% or greater than the integrated relative efficiency (IRE) of measurements within the detector footprint (the active detection surface). The perimeter of the footprint was expanded on all sides isometrically to the point where the IRE of the FOV was 50% or greater than the IRE of the detector footprint.
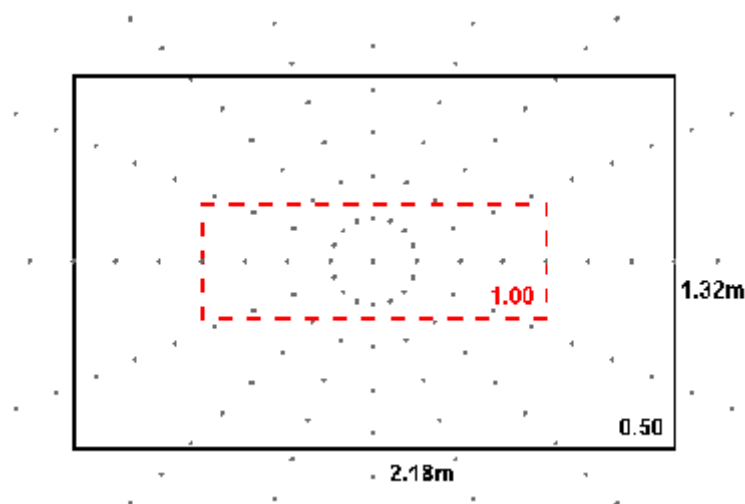
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Figure 2. ERGS II field of view dimensions relative to the active detector surface area (the detection system footprint)

Velocity tests quantified the decrease in count rate (compared to static count measurements) with increasing velocity to balance signal loss with surface coverage. Tests were conducted by moving sources at a constant speed relative to the detection system at the operational height. Tests began with the source positioned at centerline outside the detector forward FOV and ended with the source at the rear of the detector FOV. Three tests each were recorded for speeds of 30.5, 45.7, 61.0, and 91.4 cm per second (cm/s) and one second data 'snapshots' were integrated. The average of three tests was used to quantify the Cs-137 mobile source count rate compared to static count rate. The maximum acceptable velocity was equal to or greater than 80% of the static count rate. Together, the FOV and velocity were designed so scanning data was contiguous (i.e. surface coverage was complete in the direction of travel).

Estimation of Field Scanning MDCs

Using the FOV of each system and calculated masses of a 15.2 cm deep contamination volume, field scanning MDCs were computed using Equation 1 [11, 12], modified to reflect two considerations pertinent to scanning surveys of soil. The overall detector efficiency is the calculated efficiency in the field combining the FOV efficiency with the loss of efficiency at the maximum velocity. For *scanning MDC*, background count time is the same as sampling count time. During scanning, data from one-second intervals potentially contain both ambient background and radionuclides of interest. The MDC calculation accounts for the gamma energy transmission through soil.

Equation 1 $\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad , (\quad) = \dfrac{.\quad . \times\sqrt{\quad\times\quad}}{\times\ \times\ \times\times\ \ \times}$

Where DS, γ refers to a specific detection system and gamma emitting radionuclide

CR   -   Count Rate (cps) in the region of interest (ROI) of the radionuclide
t   -   time (scan rate of 1 s)

ε   -   overall detector efficiency in the field (counts per disintegration)
Iγ   -   branching ratio of a radionuclide
M   -   contaminated soil mass (grams)
CF   -   conversion factor (0.037 Bq/picocurie [pCi])
GTS -   gamma energy transmission through a specific soil depth

Table 1 lists the ^{137}Cs and ^{60}Co scanning MDC values for each detection system. The MDCs are based on for a homogenous volumetric contaminant distribution equal to the FOV of each system at a 15.2 cm soil depth. For example, the 1 s scanning MDC for Cs-137 of the ERGS II is 0.02 Bq/g which is equivalent to a 15 minute static count MDC for an in-situ gamma spectrometer and 20 times greater than the optimal MDC of a 7.6 cm by 7.6 cm hand-held detector.

Table I. Scanning Minimum Detectable Concentrations of ^{137}Cs and [60]Co

Radionuclide	Detection System	Count Rate (cps)	MDC FOV x 15.2 cm (Bq g^{-1})
[137]Cs	ERGS II	600	0.02
	MMGS	200	0.11
	TMGS	170	0.05
	WMGS	100	0.13
[60]Co	ERGS II	450	0.01
	MMGS	150	0.06
	TMGS	130	0.03
	WMGS	80	0.08

Initial Survey Approach

The study area was divided into subareas for work efficiency. The data discussed in this case study originate from the subarea encompassing the former location of a prototype nuclear reactor. Vegetation was removed and the detection system capable of achieving the greatest sensitivity was employed in the appropriate terrain. Scan transects were overlapped to ensure complete coverage by setting the transects at 85 percent or less of the FOV width. A marking system maintained transects. The survey goal was 100 % coverage, but final coverage was influenced by field conditions, i.e. certain areas contained very steep and rocky terrain such as cliffs so not all areas were accessible [13].

Data processing

Scanning data was collected, uploaded onto a server, processed, and analyzed to quantify and map locations that contained elevated gamma radiation of two types. The first was derived from nuclide-specific regions of the gamma spectrum for radionuclides, such as Cs-137, Co-60, Am-241, Eu-154, etc. The second type was the total counts per second of the entire spectrum which ranged from approximately 30 to 3,000 KeV.

Data from different detection systems was not comparable due to the number and arrangement of detectors. So, representative data from each system was analyzed to normalize and merge into a unified dataset such that gamma radiation maps clearly and simply illustrate areas containing elevated gamma radiation data [14].

An accurate background was determined after all scanning data within a subarea were collected. Mean and standard deviation of the nuclide specific region and total count rate data were calculated from the subarea dataset less excluded data. Excluded data contained turn-around transects, poor quality spatial location data, non-native surfaces (such as asphalt roads) and overlaps of different systems (in these cases, the most sensitive data were used). Excluded data were a small portion of the data collected. This form of background assessment permits comparison of the second by second spectra to a much larger representative population (up to 400,000 seconds of data) versus not performing background subtraction or using a much smaller dataset, e.g., a 300 second background dataset [13].

An advantage of using this survey approach is the total amount of information available; however a disadvantage is many thousands of seconds of spectral data occupies terabytes which requires large dataset handling and processing capabilities. Oasis Montaj® is a software product for processing and illustrating large datasets. Montaj was used to collect, store, normalize, and manage the large datasets.

Data analysis and high-resolution gamma radiation mapping

After normalization and determination of background parameters, data gradations were applied. For total cps, the mean and two standard deviation increments above the mean were applied to data which were binned as mean and below, mean to two (standard deviations above the mean), two to four, four to six, and greater than six standard deviations above the mean total cps. For nuclide specific regions of interest, the ratio of the nuclide ROI to total cps was computed for each second. For example, if the Cs-137 ROI (600 to 735 KeV) contained 600 cps and the total count rate (30 to 3,000 KeV) was 12,000 cps, then the ratio for that second was 0.050. The ROI to spectrum ratios were subject to larger statistical variability than the total count rate because the ROI has much fewer counts than the total spectrum. Therefore, the mean and 6 standard deviations above the mean nuclide ratios were computed for each detection system.

Gamma radiation maps were produced through Montaj or GIS. Applying the data gradations, the subarea dataset produce a colored map to differentiate gamma data. Maps provided gamma spectral information and high accuracy GPS coordinates to discretely identify areas of interest. Four total cps map layers were produced; each representing increasing total cps data, and one nuclide-specific layer was produced, indicating locations containing elevated ratios of Cs-137.

Verification of gamma radiation anomalies

Gamma radiation gradations of scanning data were mapped in high-resolution and superimposed on an aerial site photograph. Areas of interest contained Cs-137 ratios greater than six standard deviations above the mean Cs-137 ratio or total cps data greater than four standard deviations

above the mean total cps. Field teams returned to these areas with GPS locations to collect static measurements to obtain more accurate spectral data.

Static counts increased measurement accuracy as compared to scanning for two reasons. First, data were collected for a brief time (a few seconds) as the detection system traveled over a radiologically contaminated position. Collecting static measurements from five to 20 minutes (depending on the system) greatly improved the volume of information and counting statistics. Therefore, the static count results were evaluated to determine whether a location contained anthropogenic gamma radiation. If it did, then a soil sample was collected at the static count location. When scanning data indicated a large area of Cs-137 contamination, additional soil samples were collected to characterize the vicinity of the anomaly and the extent of contamination. Additional samples were sited based on the mapped scanning results.

Soil sampling and gamma spectrometry analysis

For the project, targeted sampling locations were identified through findings of historical site assessment, aerial photograph interpretation, gamma radiation survey, geophysical survey, and direct field observations. For this case study, the correlation is focused on those surface soil results which were collected at the static count location with positive indications of Cs-137. All of these were collected from the subarea containing the former reactor.

Sample locations were marked using a SPS 852 handheld Trimble GPS and magnetic survey spikes. Surface soil samples were collected by clearing vegetation and a stainless steel trowel or shovel was used to collect the sample from the top 15.2 cm of soil. The soil sample was packaged and shipped to a qualified commercial radiochemistry laboratory for analysis.

Laboratory gamma spectrometry analyses were conducted with approximately 1,000 g of dried, sieved and homogenized soil counted for 240 minutes on a high purity germanium detector following a DOE HASL 300 equivalent method. Results were validated per EPA level 4 QC criteria.

Correlation of Cs-137 in-situ ratio with ex-situ gamma spectrometry soil concentration

The correlation compares ratios of 30 Cs-137 static count field measurements to Cs-137 gamma spectrometry concentrations.   Cesium-137 observed through scanning was verified at a single static count location for each anomaly, which was measured at the soil sample location. Static count field measurements are presented as the Cs-137 ratio (unitless).   The Cs-137 gamma spectrometry analysis data are presented as Bq/g of soil.

DISCUSSION OF RESULTS

Figure 3 is a high-resolution gamma radiation data map indicating the two types of data (shown in the legend). Areas where the scanning Cs-137 ratio was six standard deviations above the mean ratio are shown in blue and the other colored gradations depict total cps data. There was considerable variation in the size and distribution of Cs-137 areas; therefore areas of interest were clustered by applying an operational boundary around the area. The Cs-137 surface

8

distributions varied by location. One static count and one or more soil samples were collected from each area of interest depicted by the perimeter boundary.

Inspecting figure 3, the positions of elevated Cs-137 ratio data and elevated total count rate and are generally independent. This demonstrates an advantage of evaluating spectral data in terms of nuclide specific energies. (At certain locations with larger Cs-137 concentrations, both the Cs-137 ROI and the total count rate increase significantly).
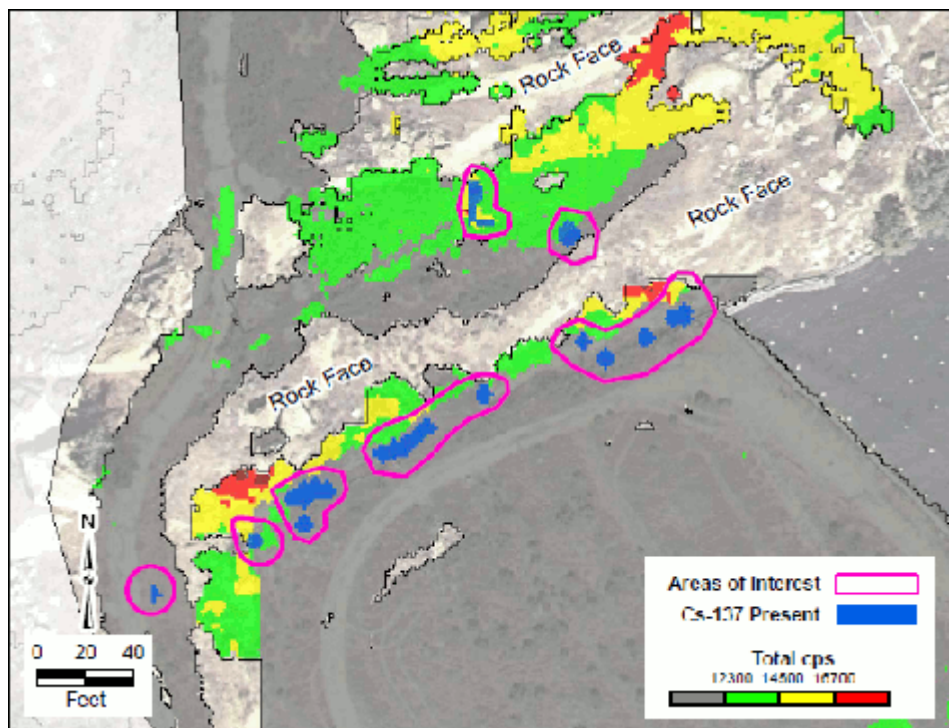
Figure 3. High-resolution gamma data map showing several gamma anomalies near the former site of the prototype nuclear reactor

Energy resolution and use of nuclide-specific ratios

Field surveys using NaI(Tl) scintillation detectors traditionally suffered from significant energy drift because of temperature changes in the field. These NaI(Tl) detectors perform an automated energy calibration at two minute intervals to compensate for this. Combined with the high-capacity digital processing, the resultant resolution is excellent with a 7 to 8 percent full-width at half maximum peak energy. This resolution enables differentiating Cs-137 from the near energy peaks of naturally occurring radionuclides (called NORM).

Table 2 lists specific peak energies of Tl-208, Bi-214, and Cs-137 and differences in the peak energies of Tl-208 and Bi-214 and of Bi-214 and Cs-137. Because of the separation between peak energies, the detection systems could not resolve the peaks of Tl-208 and Bi-214, but did so for Bi-214 and Cs-137.

9

Table II. Examples of Detection System Resolution

Peak Energy Range (KeV)	Source Nuclide	Energy (KeV)	Separation (KeV)
595 - 605	Tl-208	584	25
	Bi-214	609	
657 - 667	Cs-137	662	53

Figure 4 is composed of three spectra consisting of the detected gamma radiation peak signals described in Table II. Inset A is spectral data showing the NORM peak without Cs-137, inset B shows NORM with a slight Cs-137 peak present, and inset C shows a Cs-137 peak that is slightly larger than the NORM peak. Clearly, Cs-137 is distinct from Bi-214 and Tl-208.
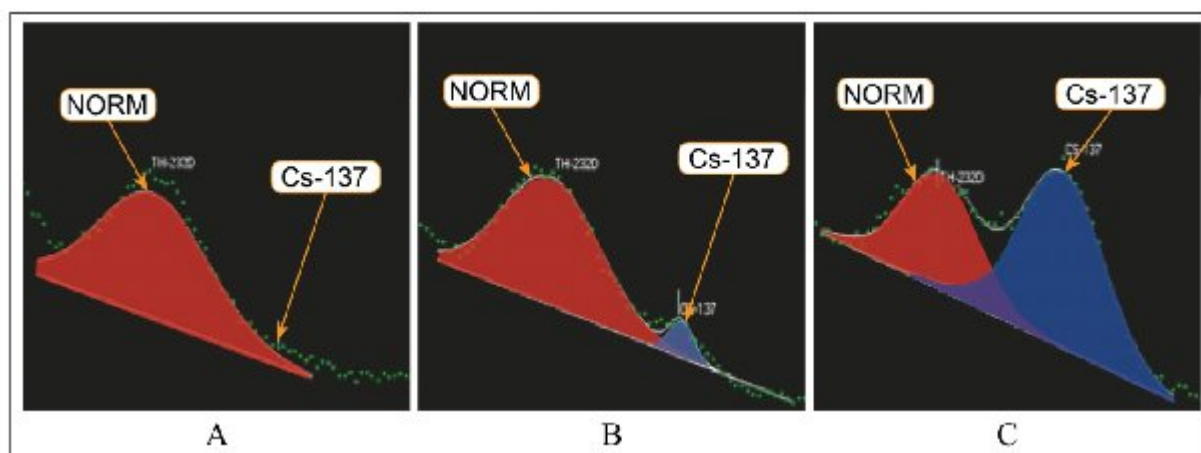
Figure 4. Spectra views focused on approximately 500 – 800 KeV demonstrating capability to resolve NORM peak from Tl-208 and Bi-214 (red) and Cs-137 peak (blue).

The nuclide-specific ratio enhances sensitivity in detection of anthropogenic radiation. The gamma spectrum of soil or rock is composed of Th-232 and U-238 (plus their progeny) and K-40 with peak energies ranging from approximately 50 to 2620 KeV. The predominant gamma radiation signal measured in a ground-based survey is normally from soil or rock, excluding widespread contamination or a strong signal from relatively high activity sources. Anthropogenic radionuclides typically emit gamma peaks at energies susceptible to Compton scattering from higher energy NORM peaks.

The Cs-137 ROI spans from 600 to 735 KeV. Examining Figure 4 inset A, some counts in the Cs-137 ROI are from the NORM peak. If either the NORM peak or Compton scattering from higher energy radiation increases, then the counts in the Cs-137 ROI also increases. Summing counts in an ROI is a common approach to evaluating survey spectra that does not compensate for these types of count increases. In Figure 4 inset B, using the ratio, the increased Cs-137 counts due to the radionuclide of interest result in a positive signal inflection. Another approach to overcome this problem is the use of stripping ratios to account for Compton scattering effects

of specific radionuclides. Stripping ratios can be accurate, but require complex site-specific calibrations of each detection system, matrix algebra, and intense data reduction. The calibrations are valid over a limited range of concentrations for each radionuclide.

The nuclide-specific ratio is a straightforward means to compensate for these effects and to enhance nuclide identification without site-specific detection system calibrations. It is worth noting that the nuclide-specific ratio is independent of the detection system, i.e. six standard deviations above the mean is appropriate for each (although sensitivity varies with the system).

Figure 5 shows the Cs-137 ratio as a function of scanning time. Mapping merges signal inflections over time with GPS for high accuracy position of potential contamination.
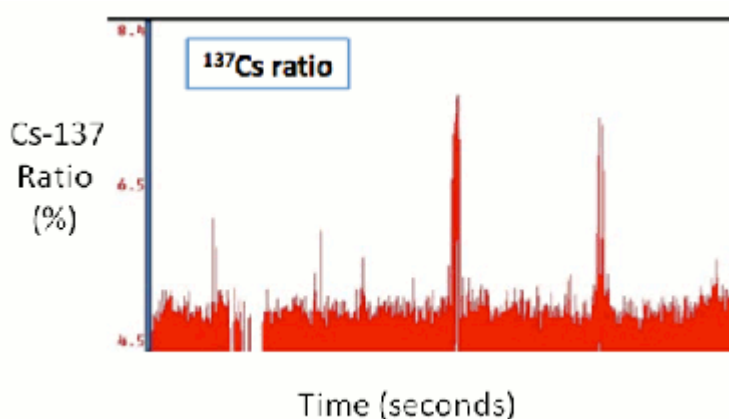

Figure 5. Plot of Cs-137 Ratio signal record with time

Correlation of field gamma radiation data to laboratory results

Clearly, field surveys inform decisions about potential radionuclide contamination, however traditional thinking has relegated gamma scanning as solely a sensing tool. The detection capabilities of large NaI precision-scanning systems enhance environmental characterizations throughout the investigation, remediation, and confirmation phases. Current methods require costly and time-intensive sampling and analysis; whereas, these NaI systems can be deployed to collect data quickly, efficiently, and at a lower cost with excellent sensitivities. Applications of the precision-scanning method are dependent upon the radionuclides of interest, the size and layout of the area, survey objectives, and time constraints. This study is focused on Cs-137 however this process can be applied to other gamma emitting radionuclides as well.

A critical step to validating the precision-scanning approach is to compare survey data with laboratory reported soil concentrations. The purpose for this study is to examine this field detection technology in direct comparison with analytical results to determine if field scanning can sufficiently characterize radionuclide content in soil without sampling and analysis, or greatly reducing reliance on invasive sampling.

Figure 6 is a plot of Cs-137 ratios from several detection systems versus concentration data from ~ 1 kg soil samples. Concentration data are plotted on a logarithmic axis whereas ratios are on a linear axis. This log-linear relationship is best fit using an exponential curve. Thirty results from the former reactor area are shown in Figure 6.
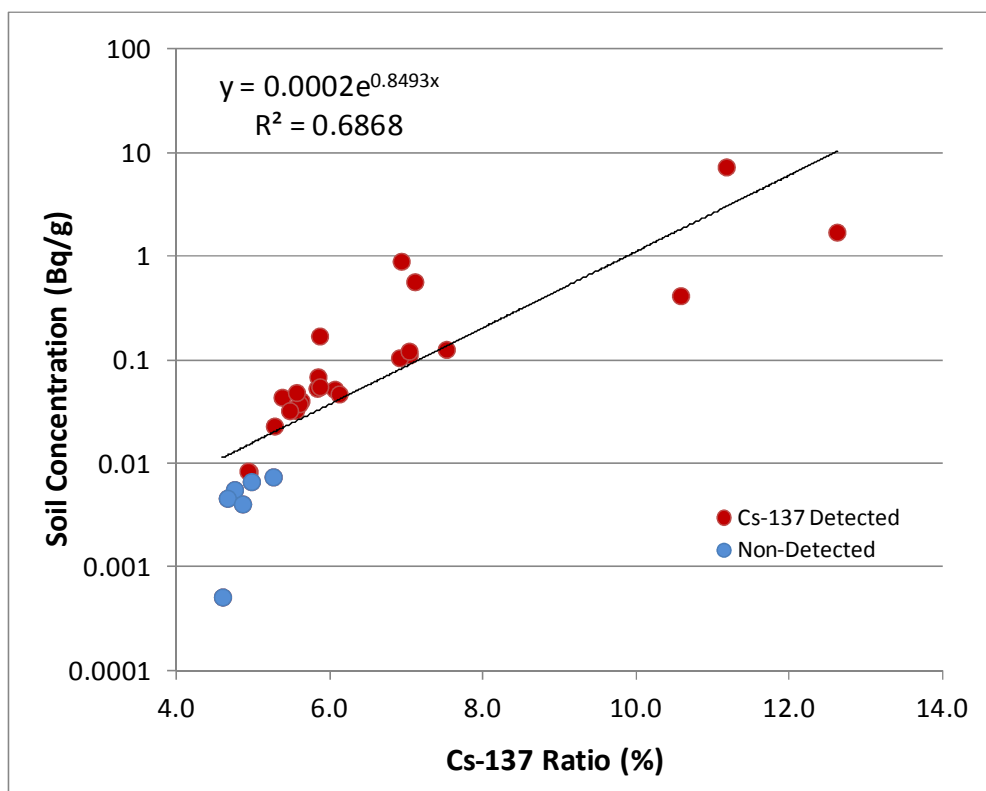

The plot shows:

$$y = 0.0002e^{0.8493x}$$
$$R^2 = 0.6868$$

Figure 6. Cs-137 Ratio vs. Surface Soil Concentration (n=30)

Key findings are evident in Figure 6. First, the trend correlating the Cs ratio used to determine soil sample locations is robust and has a reasonable coefficient of variation, especially if one considers the variables taken into account in a comparison between in-situ and ex-situ data, such as contaminant distribution, size differences between the survey FOV and a soil sample, etc. Next, as expected, the gamma survey Cs-137 ratio generally increases with increasing concentration in the surface soil. Lastly, the data include both detected and non-detected results (defined by the analytical results of surface soil samples). Of 30 areas of interest from the gamma radiation survey, 24 (80%) contain detectable Cs-137 concentrations.

It is logical that non-detected soil results are consistently below a certain concentration value. The Cs ratio data are also consistent with that trend because most non-detected results have low Cs ratios. The plot and trend line affirms that the gamma survey approach detected and located Cs-137 in the field at concentrations approximately 0.01 to 0.02 Bq/g with an accuracy of 80%. In other words, the fact that this correlation has a 20% (6 out of 30) false positive field detection rate is not severe, particularly when most of the false positives are observed at the lowest Cs-137 ratios. The use of a higher level of discrimination could improve the overall error rate.

12

Factors affecting accuracy and sources of error

Errors and uncertainties associated with the survey and correlation fall into three categories:
1. detection system parameters such as measurement uncertainty (over which there is an element of control)
2. spatial accuracy and operational processes
3. contaminant source type, activity, distribution, etc. (which are not controlled).

Measurement uncertainty was addressed through system testing, calibration and QC processes. Spatial accuracy is critical for operations to locate precisely defined positions in this case for verification counts and sampling. If this approach was applied to a remedial effort, then position accuracy directly impacts cost, i.e., to optimize removal, one needs to know precisely the extent of contamination. The FOV of the detection systems may have been larger than the area of contamination thus a possibility exists that in a few cases the survey detected Cs-137, but the corresponding sample was not collected at the exact location. The site was very rugged and contained a number of locations in which the GPS signal could have been compromised. The native GPS resolution was improved through the GPS signal merging process. Finally, the distributions of contamination at specific locations are uncontrollable. However, it is possible to deal with the distribution of contamination by other means. Geophysical surveys and historic site assessments provide useful insight into locations where the ground may have been disturbed.

Subsurface samples were not included in this correlation because gamma transmission through soil is influenced both by gamma ray energy and soil depth. For volumetrically contaminated soil, this is not an issue as contamination at the surface soil would provide a relatively strong (unattenuated) signal. However, for subsurface contamination with an uncontaminated overburden, this is significant because approximately 20% of Cs-137 gamma emissions penetrate 15 cm of soil and less than 10% penetrates 30 cm of soil.

CONCLUSIONS

HydroGeoLogic, Inc. (HGL) and The Palladino Company, under contract to USEPA, completed an accelerated characterization of a radiological study site near Canoga Park, CA using gamma scanning detections systems described here. A strong correlation was found between detection and location of Cs-137 via a precision-scanning survey approach and surface soil Cs-137 concentrations determined from gamma spectrometry. The survey approach provides an efficient and accurate method to pinpoint gamma radiation in surface and near surface soil suitable for making decisions about contamination.

Using GPS-linked detection systems with a goal of 100% coverage is an excellent approach to greatly reduce reporting cycle time due to rapid delivery of survey results as compared to the time required for sampling, analysis, validation, interpolation, and interpretation of lab results. This approach is applicable to scenarios in which the predominant radionuclides are gamma emitters or are co-located with gamma emitters. It is well suited to investigate a recent contaminant release in which the contamination is primarily located on the surface.

The use of gamma scanning detection systems as a leading sensing technology can provide significant cost savings during the investigation, remediation, or confirmation project phases by reducing reliance on random soil sampling (i.e., reducing the number of random samples) and by guiding the location of targeted samples. In this manner, efforts are focused on areas of concern and the costs of sampling and analysis can be optimized. Assuming collection of 100 surface soil samples per hectare (approximately 40 per acre), the average distance between each location is 10 m on a simple square grid. Due to the sub-meter position accuracy and spectral resolution offered by these detection systems, this approach merits examination to locate elevated gamma radiation with confidence and reduce the level of effort necessary to conduct multiple rounds of sampling. The data density obtained through full coverage scanning informs the nature and extent of contamination and is easily presentable as an accurate gamma data map.

A logical next step in increasing reliance on field sensing technologies and reducing sampling efforts is a comparison of costs. Due to the variables inherent in the exploration and removal of radiological contaminants, formal cost-comparison is challenging. However, it is possible to approximate. Survey costs using the precision-scanning approach are roughly $20,000 to $40,000 per hectare ($8,000 to $15,000 per acre), at the sensitivity levels described herein. Sampling and analyses costs can range from $50,000 to $500,000 per hectare and more ($20,000 to $200,000 per acre), depending on sampling density and the number and types of analyses.

For this study, detecting radiological contaminants as sensitively as possible was a primary goal, so the detection systems scanned near the ground surface and slowly, often over challenging terrain. In future efforts, the detection system height, FOV and velocity would be optimized to the project specifications and the survey costs should decrease dramatically.

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